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Nineteenth meeting
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Item 5 (c) (iv) of the provisional agenda*

Technical work: review of notifications of final regulatory action: chlorpyrifos

Chlorpyrifos: supporting documentation provided by Malaysia

Note by the Secretariat

As is mentioned in the note by the Secretariat on chlorpyrifos: notifications of final regulatory action (UNEP/FAO/RC/CRC.19/8), the annex to the present note sets out documentation provided by Malaysia to support its notification of final regulatory action for chlorpyrifos in the pesticide category. The present note, including its annex, has not been formally edited.

* UNEP/FAO/RC/CRC.19/1/Rev.1.

Annex

Chlorpyrifos: supporting documentation provided by Malaysia

List of documents:

1. Circular letter from the Pesticides Board, dated April 28, 2021.
2. Minutes from the 88th Pesticides Board Meeting, dated April 9, 2021.
3. National Poison Centre. Assessment of carbofuran and chlorpyrifos. (Unpublished report). Retrieved from internal document database, (2021).
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(Date)

[ENGLISH TRANSLATION]

TO WHOM IT MAY CONCERN

PESTICIDE BOARD CIRCULAR NUMBER 4 OF 2021
Pesticides Act 1974
CHLORPYRIPHOS PESTICIDE REGISTRATION STATUS

PURPOSE

This Circular letter is intended to inform pesticide registration companies about the registration status of chlorpyrifos pesticides in Malaysia.

DECISION AND JUSTIFICATION

1. The 88th Pesticides Board meeting convened on 9 April 2021 and decided that registration for the pesticide chlorpyrifos is no longer allowed for agricultural use in Malaysia and only allowed for public health and 'urban pest' use
only effective on May 1, 2023.

2. This decision was taken based on a risk assessment carried out against the active ingredient chlorpyrifos which found that chlorpyrifos risks causing adverse effects to human health, ecology and the environment through agricultural activities, as well as food safety risks due to the high content of pesticide residues in the produce

of agriculture. However, there are still various alternative pesticides to replace the use of chlorpyrifos for agricultural use.

3. Accordingly, effective 1 May 2021, all new registration applications involving agricultural use will be stopped and no new applications will be accepted. Therefore, re-registration is also not allowed or accepted starting from that date.

4. All registrant companies that still have chlorpyrifos pesticide registration for agricultural use are currently given a period until April 30, 2022 to exhaust all stock released from the market.

"PRIHATIN RAKYAT: DARURAT MEMERANGI COVID-19"

"BERKHIDMAT UNTUK NEGARA"

Saya yang menjalankan amanah,

(MAT ISAK BIN NGATHINE)
Setiausaha
Lembaga Racun Makhluk Perosak

s.k:

1) Ketua Pengarah Pertanian
2) Timbalan Ketua Pengarah Pertanian (Pembangunan Industri dan Pengembangan)
3) Timbalan Ketua Pengarah Pertanian (Pengurusan dan Regulatori)
4) Ahli-ahli Lembaga Racun Makhluk Perosak
5) Pengarah Sahagian / Pengarah Pertanian Negeri
6) Pengarah Eksekutif, Malaysian Crop Life & Public Health Association (MCPA)

Translation:

Meeting of the Pesticides Board. 01/2021 (No. 88)

09/04/2021, Bunga Raya Room, Department of Agriculture, Putrajaya.

3.3 Review of the Status and Direction of Registration and Use of Chlorpyrifos in Malaysia - (Paper 919)

It is hereby notified that:

a) The purpose of this paper is to request the Board members to consider and make decisions regarding the registration status of the active ingredient chlorpyrifos in Malaysia. Chlorpyrifos is an organophosphorus insecticide used to control pests in various types of crops and in the public health sector.

b) There are 139 registered products with the Board containing chlorpyrifos, divided into categories as follows:

CATEGORY	NUMBER OF PRODUCTS
Agriculture	75
PCO and Public Health	36
Household	7
For Manufacturing Purposes (TGAI)	21
TOTAL	**139**

c) The justifications for the review of the status of registration and use of chlorpyrifos in Malaysia are as follows:

i. Chlorpyrifos tends to have potential adverse effects on humans and the environment.

ii. Cases of chlorpyrifos MRL violations often occur in agricultural commodities for domestic and export use. The reports are a result of residue monitoring in agricultural products, Singapore's Enhanced Enforcement Programme (EEP), and notifications of violations exceeding the maximum residue limit (MRL) for export commodities to the EU and Japan.

iii. Regulatory actions by foreign countries that have banned and restricted the use of chlorpyrifos, such as the EU, California, USA, South Africa, and Australia.

iv. There are less risky alternatives to chlorpyrifos for use in Malaysia.

d) This paper is presented to this meeting with improvements and additions as necessary for the Board's reconsideration.

It was agreed that:

a) The Board members agreed to restrict the use of chlorpyrifos. Starting May 1, 2023, chlorpyrifos registration will no longer be allowed for agricultural use in Malaysia. It is only permitted for public health or urban pest control use.

Action: Secretary

(English Translation)

ASSESSMENT OF CARBOFURAN AND CHLORPYRIFOS BY THE NATIONAL POISON CENTRE OF MALAYSIA

Based on the findings presented below, the National Poison Centre concludes that:

1. Based on 10 years of data (2006-2015), 40% of reported cases of insecticide poisoning involved pesticides from the Organophosphate group, with Chlorpyrifos having the highest number of cases followed by Malathion.
2. Recent data on poisoning cases received by the National Poison Centre from 2016 to 2019 showed that Carbofuran accounted for 5% and Chlorpyrifos accounted for 24% of all reported cases of insecticide poisoning (N=1374).
3. Chlorpyrifos contributed more to intentional poisoning cases than unintentional cases.
4. Acute poisoning caused by Chlorpyrifos can have severe effects and can lead to long-term neurological disorders.
5. Scientific evidence shows that exposure to Chlorpyrifos in pregnant women and children can cause neurotoxic effects that can affect children's growth and development. In fact, one of the main issues leading to the ban of Chlorpyrifos by the European Union is due to studies showing these neurotoxic effects.
6. Carbofuran's ability to be absorbed by plants allows it to easily enter the human body and cause long-term effects.
7. Carbofuran is classified as a "highly hazardous" substance due to the acute effects of poisoning, which can lead to death. Poisoning cases involving pregnant women have resulted in fetal death and miscarriage.
8. Carbofuran's persistence in plants can lead to its accumulation in the human body, which poses a risk of long-term health effects.
9. Therefore, the National Poison Centre agrees with the proposal to completely stop the use of Chlorpyrifos and Carbofuran, including their use as insecticides for public health.
10. The replacement with DIMETHOATE should also be studied as it belongs to the "highly hazardous" group and has the potential to cause effects similar to Chlorpyrifos. In addition, there are various alternative insecticides that can be used.

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NATIONAL POISON CENTRE

MALAYSIA

For Immediate Release:

May 8, 2019

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California Acts to Prohibit Chlorpyrifos Pesticide

(en español)

Move to ban follows scientific findings that chlorpyrifos poses serious public health and environmental risks to vulnerable communities

Governor's May Revision proposes $5.7 million in new funding to support the transition to safer, more sustainable alternatives

CDFA and DPR will convene a new working group to identify, evaluate and recommend alternative pest management solutions

SACRAMENTO – In a move to protect workers, public health and the environment, the California Environmental Protection Agency (CalEPA) announced today that the Department of Pesticide Regulation (DPR) is acting to ban the use of the pesticide and toxic air contaminant chlorpyrifos in California by initiating cancellation of the pesticide.

CalEPA and the California Department of Food and Agriculture (CDFA) also announced that the Governor will propose $5.7 million in new funding in the May Revision budget proposal to support the transition to safer, more sustainable alternatives, and plans to convene a working group to identify, evaluate and recommend alternative pest management solutions.

"California's action to cancel the registration of chlorpyrifos is needed to prevent the significant harm this pesticide causes children, farm workers and vulnerable communities," said CalEPA Secretary Jared Blumenfeld. "This action also represents a historic opportunity for California to develop a new framework for alternative pest management practices."

The decision to ban chlorpyrifos follows mounting evidence, including recent findings by the state's independent Scientific Review Panel on Toxic Air Contaminants, that the pesticide causes serious health effects in children and other sensitive populations at lower levels of exposure than previously understood. These effects include impaired brain and neurological development.

In April, chlorpyrifos was formally listed as a "toxic air contaminant", which California law defines as "an air pollutant which may cause or contribute to an increase in mortality or an increase in serious illness, or which may pose a present or potential hazard to human health." The listing requires DPR to develop control measures to protect the health of farm workers and others living and working near where the pesticide is used.

DPR has determined, in consultation with CDFA, the Office of Environmental Health Hazard Assessment (OEHHA), and the California Air Resources Board (CARB), that sufficient additional control measures are not feasible.

As a result, DPR intends to move forward in a responsible manner by beginning the process of canceling the registrations for products containing chlorpyrifos, and at the same time, convening a cross-sector working group to identify safer alternatives to avoid replacing chlorpyrifos with an equally harmful pesticide.

DPR also will consult with county agricultural commissioners and local air pollution control districts before filing for cancellation. The cancellation process could take up to two years.

During the cancellation process, DPR's recommendations to county agricultural commissioners for tighter permit restrictions on the use of chlorpyrifos will remain in place. These include a ban on aerial spraying, quarter-mile buffer zones and limiting use to crop-pest combinations that lack alternatives. DPR will support aggressive enforcement of these restrictions.

DPR and CDFA will convene a cross-sector working group to identify and develop safer and more practical and sustainable alternatives to chlorpyrifos, including the use of biological controls and other integrated pest management practices. They will also partner with growers as they transition from using chlorpyrifos to implement safer alternatives.

In addition, the Governor's May Revision budget proposal includes $5.7 million in funding for additional research and technical assistance to support this effort. In combination, the working group and funding for alternatives will produce short-term solutions and prioritize the development of long-term solutions to support healthy communities and a thriving agricultural sector.

"We look forward to working with the Legislature through the budget process on the Governor's proposal to support growers in the transition to alternative pest management," said CDFA Secretary Karen Ross.

In 2015, DPR designated chlorpyrifos as a "restricted material" that requires a permit from the county agricultural commissioner for its application. In addition, application of chlorpyrifos must be recommended by a licensed pest control advisor and supervised by a licensed certified applicator.

The proposed cancellation would apply to dozens of agricultural products containing the pesticide. The pesticide has been prohibited by the U.S. Environmental Protection Agency for residential uses since 2001.

Chlorpyrifos is used to control pests on a variety of crops, including alfalfa, almonds, citrus, cotton, grapes and walnuts.

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CalEPA, 1001 I Street, Sacramento, CA 95814 • P.O. Box 2815, Sacramento, CA 95812 • (916) 323-2514 www.calepa.ca.gov

Chlorpyrifos Cancellation

Overview

The California Department of Pesticide Regulation (DPR) announced on October 9, 2019 that virtually all agricultural use of the pesticide chlorpyrifos in California will end by December 31, 2020. The move comes as Dow AgroSciences LLC and several other registrants have reached an agreement with DPR to withdraw their products from California. Recent research, cited in findings by the state's independent Scientific Review Panel on Toxic Air Contaminants, has shown that chlorpyrifos is also a developmental neurotoxin in children and sensitive populations.

Chlorpyrifos is an organophosphate pesticide that is used to control pests on a variety of crops, including alfalfa, almonds, citrus, cotton, grapes and walnuts. Although use of chlorpyrifos in California has declined by about 50 percent in the last decade, some growers who still use this pesticide to tackle pests will be impacted by the cancellation

Work Group

In order to support the transition to safer, more sustainable alternatives, DPR and the California Department of Food and Agriculture (CDFA) created a Chlorpyrifos Alternatives Work Group to identify, evaluate, and recommend alternative pest management solutions. Three workshops (Fresno, Sacramento, Oxnard) were held in January to gather public input.

The work group includes representatives from California universities, environmental justice groups, UC Cooperative Extension and IPM scientists, pesticide registrants, farmworker health and safety organizations, agricultural commissioners, commodity organizations, pest control advisors, product manufacturers, and state agencies. Their report, Towards Safer and More Sustainable Alternatives to Chlorpyrifos: An Action Plan for California (En Español), was issued in July 2020.

Addressing the Work Group’s Recommendations

The Chlorpyrifos Alternatives Work Group’ outlined five key recommendations in their report. These recommendations align with DPR’s mission to protect human health and the environment by regulating pesticide sales and use, and by fostering reduced-risk pest management. The Department’s past, current and planned activities related to the Work Group’s recommendations are described in a February 22, 2021 memo.

More Information

For continuous updates about the work group and other actions related to chlorpyrifos cancellation, please sign up for the Alternatives list serve.

Useful Links

For content questions, contact:
E-mail: Alternatives@cdpr.ca.gov

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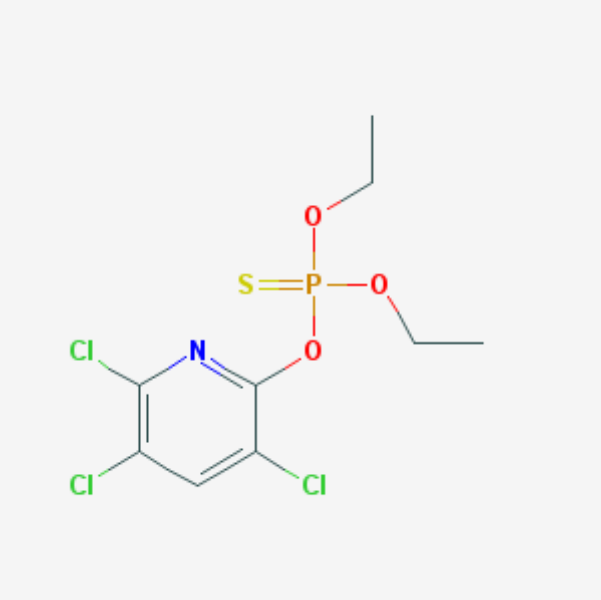
Final Toxic Air Contaminant Evaluation of Chlorpyrifos

Risk Characterization of Spray Drift, Dietary, and Aggregate Exposures to Residential Bystanders



Human Health Assessment Branch
Department of Pesticide Regulation
California Environmental Protection Agency
July 2018

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LIST OF ABBREVIATIONS

AADD	Annual average daily dose
AC	Adenylcyclase
AC_{50}	Active concentration resulting in activity of 50% of group
ACh	Acetylcholine
AChE	Acetylcholinesterase
ADD	Absorbed daily dose
AI	Active ingredient
BMD	Benchmark dose
BMDL	Benchmark dose lower limit (95^{th} percentile)
BuChE	Butyryl/plasma/pseudo-ChE or B-esterase
CalEPA	California Environmental Protection Agency
CCCEH	Columbia Center for Children's Environmental Health
CPF	Chlorpyrifos
CPF-oxon	Chlorpyrifos oxon
DAP	Dialkylphosphate
DPR	California Department of Pesticide Regulation
FIFRA	Federal Insecticide, Fungicide & Rodenticide Act
FQPA	Food Quality Protection Act
GABA	ɣ-aminobutyric acid
GD	Gestation day
GnRH	Gonadotrophin releasing hormone
HHA	Human Health Assessment Branch
HDT	Highest dose tested
IARC	International Agency for Research on Cancer
i.p.	Intraperitoneal
IRED	Interim Reregistration Eligibility Decision
IVIVE	In vitro to in vivo extrapolation
LADD	Lifetime average daily dose
LD	Lactation day
LDT	Lowest dose tested
LOAEL	Lowest observed adverse effect level
LOEL	Lowest observed effect level
LOD/LOQ	Limit of detection/limit of quantitation
MCL	Maximum contaminant level
MDL	Minimal detection limit
MOA	Mode of action
MOE	Margin of exposure
MTD	Maximum tolerated dose
NOAEL	No observed adverse effect level
NOEL	No observed effect level
OP	Organophosphate

P450/CYP	Cytochrome P450s
PAD	Population adjusted dose
PBPK-PD	Physiologically-based pharmacokinetic-pharmacodynamic
PDP	Pesticide Data Program
PISP	Pesticide Illness Surveillance Program
PND	Postnatal day
PoD	Point of departure
PON1	Paraoxonase 1 or A-esterase
PPE	Personal protection equipment
ppm, ppb	Parts per million; parts per billion
PUR	Pesticide use report
RAS	Risk Assessment Section
RBC	Red blood cell
RED	Reregistration Eligibility Decision
RfC	Reference concentration
RfD	Reference dose
SADD	Seasonal absorbed daily dose
STADD	Short term absorbed daily dose
SAP	Scientific Advisory Panel
SRP	Scientific Review Panel
s.c.	Subcutaneous
SF	Safety factor
TAC	Toxic air contaminant
TCPy	3,5,6-trichloro-2-pyridinol
UF	Uncertainty factor
US EPA	US Environmental Protection Agency

EXECUTIVE SUMMARY

Chlorpyrifos is a chlorinated organophosphorus (OP) ester used as an insecticide, acaricide, and miticide. Chlorpyrifos has major uses in California as an insecticide for nut trees, fruit, vegetable, and grain crops as well as non-food crop uses (e.g., golf course turf, industrial sites, greenhouse and nursery production, sod farms, and wood products). Major use areas include the Central Valley, Central Coast region, and Imperial County. Use occurs year-round, with peak use during the summer. There are several dozen chlorpyrifos products registered by approximately 20 different companies. Methods of application allowed by labels include aerial, airblast, ground boom, chemigation, and others.

Chlorpyrifos first entered the comprehensive risk assessment process after being given a "High" priority status by the California Department of Pesticide Regulation (DPR) in 2011. Concerns originally focused on potential neurodevelopmental and neurobehavioral effects, genotoxicity and reproductive toxicity in rats, probable human exposure due to spray drift, possible hand-to-mouth exposure by children, and exposure through food and drinking water. The first draft risk assessment was published in December 2015. It was in that risk assessment that potential human exposure to spray drift (via inhalation or deposition) became a concern. As such, chlorpyrifos entered the formal evaluation process to determine the scientific evidence for listing it as a pesticide Toxic Air Contaminant (TAC) (CA Food & Agricultural Code §14021-14027).

Chlorpyrifos entered the formal TAC evaluation process and the first draft evaluation was published by DPR in August 2017. A subsequent revision was published in December 2017, which was reviewed by the Scientific Review Panel on Toxic Air Contaminants (SRP)[1]. This 2018 final TAC evaluation reflects the SRP's recommendation that DPR evaluate and identify the developmental neurotoxicity effects as the critical endpoint for the chlorpyrifos risk assessment.

This final TAC evaluation of chlorpyrifos reflects DPR's thorough evaluation of the developmental neurotoxicity effects as the critical endpoint for the chlorpyrifos risk assessment. Recent in vivo animal studies provide evidence of neurotoxicity to developing organisms at chlorpyrifos doses below those causing cholinesterase inhibition. Effects noted include altered cognition, motor control, and behavior in rats and mice. These studies, along with epidemiological studies, are the impetus for DPR considering developmental neurotoxicity as the

[1] With the enactment of California's Toxic Air Contaminant Act, the Legislature created the statutory framework for the evaluation and control of chemicals, including pesticides, as toxic air contaminants (TACs) (Food & Agricultural Code §14021-14027). The statute defines TACs as air pollutants that may cause or contribute to increases in serious illness or death, or that may pose a present or potential hazard to human health. DPR is responsible for evaluating pesticides as TACs. The law defines specific steps DPR must follow for the identification, evaluation, and control of pollutants in ambient air in communities across California. One of those responsibilities is to extensively evaluate the potential adverse health effects of candidate pesticide TACs and estimate levels of exposure associated with their use. The SRP must review the risk assessment to determine if it is seriously deficient based upon a review of the scientific data, the procedures and methods used to support the data, and conclusions.

critical endpoint for chlorpyrifos. As such, DPR's Human Health Assessment (HHA) Branch conducted a chlorpyrifos risk assessment using developmental neurotoxicity as the endpoint based on in vivo animal findings. A target MOE of 100 was selected to be protective of human health. The target is comprised of 10x for interspecies sensitivity, 10x for intraspecies variability, and 1x for potential neurodevelopmental effects. The resulting points of departure (PoDs), reference doses (RfDs), and reference concentrations (RfCs) are also shown in Executive Summary Table 1.

Protecting against Developmental Neurotoxicity

Identification of a rigorous neurodevelopmental point of departure for chlorpyrifos would be strengthened by elucidation of a potential mechanism. Mammalian neurodevelopment is multifactorial and there are likely multiple pathways involved, some of which may be mediated via the classical cholinesterase toxicity pathway of binding and inhibiting acetylcholinesterase (AChE). Other potential mechanisms maybe covariates of this pathway, or may involve other key events at the molecular, cellular, and tissue level. While an adverse outcome pathway has not been elucidated at this time, it is important to note that developmental changes have been documented in experimental animal studies at chlorpyrifos levels below those that inhibit AChE. There is also evidence of potential associations between in utero exposure to chlorpyrifos and altered human growth and behavior later in life in the epidemiological studies. There are acknowledged uncertainties in the human evidence, including a lack of exposure-effect relationships, inconsistencies in reported outcomes across studies, and quantitative measures of chlorpyrifos exposure that vary from study to study.

As such, DPR considered protecting vulnerable subpopulations from chlorpyrifos exposure and the potential neurodevelopmental effects through the use of developmental neurotoxicity and AChE inhibition endpoints, the latter which can be considered a surrogate for developmental neurotoxicity when adjusted by an additional uncertainty factor (UF) of 10, as described below.

1) **Point of departure based on neurodevelopmental effects.** Recent in vivo animal studies and human epidemiological studies have continued the investigations into the potential effects or associations of chlorpyrifos on neurodevelopment, growth, and behavior. HHA conducted a comprehensive review of recently available animal studies published from 2015 – 2018, especially focused on the potential for evidence of neurodevelopmental toxicity at low dose levels. Critical PoDs were established from animal studies reporting developmental neurotoxicity at dose levels that are generally considered lower than those necessary for AChE inhibition in red blood cells (RBC). As mentioned earlier, a target MOE of 100 was selected to be protective of human health. The target is comprised of 10x for interspecies sensitivity and 10x for intraspecies variability. There is no need for an additional UF for neurodevelopmental effects. The risk of exposures to inhalation and spray drift is exacerbated by consumption of food and drinking water in this approach.

2) **Uncertainty factor of 10x applied to an AChE inhibition endpoint to account for the developmental neurotoxicity.** In its December 2017 Draft TAC Evaluation, DPR added an additional UF of 10x to account for more sensitive neurodevelopmental effects than AChE inhibition, the critical endpoint used to characterize the risk from chlorpyrifos exposure in that draft evaluation. Effects on cognition, motor control and behavior have been reported in

the human epidemiology and in vivo animal toxicology studies, the latter occurring at doses 10-fold lower than the threshold established for RBC AChE inhibition. However, neither the human epidemiological studies nor the in vivo animal studies available for our review at the time of the December 2017 draft were sufficient to derive critical PoDs for neurodevelopmental effects. Adding an additional 10x UF (resulting in a total UF of 100 when combined with the UF of 10 for variation in human sensitivity) would account for the possibility of neurodevelopmental effects, thus increasing the protection factor of the estimated RfCs and RfDs for chlorpyrifos. By increasing the total UF to 300 (see Appendix 3), DPR has further increased the protection factor and the conservativeness inherent in the chlorpyrifos proposed target RfCs and RfDs. Based on the AChE inhibition endpoint, inhalation resulting from spray drift is the exposure risk of concern.

The description of the uncertainties associated with each of these endpoints and a discussion of the weight of evidence is found in the Risk Appraisal Section.

The developmental neurotoxicity database for chlorpyrifos is evolving and currently contains five in vivo animal studies that permit the establishment of a critical oral no observed effect level (NOEL). As will be demonstrated below, the dose at which the neurodevelopmental effects occurred in these studies were similar regardless of the exposure window or the duration of the exposure. The most important implication of the five studies is that the threshold for chlorpyrifos-induced neurodevelopmental effects following exposure in early life may be 10-fold lower than the reported threshold of 1 mg/kg/day established for RBC AChE inhibition.

This final evaluation, as with the previous drafts, is intended to evaluate chlorpyrifos as a pesticide TAC as defined in the California Code of Regulations, Title 3, Section 6864. The determination of a pesticide TAC is based on the air concentration, either measured or modeled, that exceeds the RfC divided by 10. As explained in the Risk Appraisal section and Table 29 later in this document, chlorpyrifos meets the criteria of TAC designation by using either the developmental neurotoxicity endpoint or the AChE inhibition endpoint, even without the additional 10x uncertainty factor necessary to account for the fact that the developmental neurotoxicity effects occur at a lower level than AChE inhibition (see the August 2017 draft TAC evaluation of chlorpyrifos, available at https://www.cdpr.ca.gov/docs/risk/rcd/chlorpyrifos_draft_evaluation_2017.pdf).

Executive Summary Table 1. Points of Departure and Reference Dose or Concentrations used to evaluate the Risk from Exposure to Chlorpyrifos in Selected Population Subgroups for Developmental Neurotoxicity

Route	PoD[a]	RfD[b] or RfC
Uncertainty Factors (UF)		**10 inter 10 intra 1 DNT**
Acute Oral [mg/kg/day] Infants Children 1-2 Children 6-12 Females 13-49	0.01	0.0001
Acute Dermal [mg/kg/day][c] Infants Children 1-2 Children 6-12 Females 13-49	0.104	0.001
Acute Inhalation [mg/m^3][c] Infants Children 1-2 Children 6-12 Females 13-49	 0.405 0.459 0.624 0.862	 0.004 0.005 0.006 0.009

[a] Point of Departure (PoD): The critical acute oral PoD for chlorpyrifos is a no-observed effect level (NOEL) for developmental neurotoxicity in animals based on changes in cognition, motor control and behavior in rats and mice (Lee et al, 2015, Silva et al, 2017, Carr et al, 2017, Gómez-Giménez, 2017, 2018).

[b] Reference Dose (RfD) or Reference Concentration (RfC): RfDs and RfCs are derived by dividing the appropriate PoD by the product of all uncertainty factors (UF).

[c] Route to route extrapolation:

Dermal: Route specific dermal PoD: oral PoD in animals (mg/kg/day) / dermal absorption in human (9.6% ; Thongsinthusak, 1991).

Inhalation: Route specific inhalation PoD: oral dose mg/kg/day / [Breathing Rate (BR) m^3/hr/Body Weight (BW) kg]; Oral PoD=0.01 mg/kg/day; Infants BR=0.188 m^3/h BW= 7.6 kg; Children 1-2 yrs BR=0.283 m^3/h BW=13 kg; Children 6-12 yrs BR= 0.417 m^3/h, BW=26 kg; Females 13-49 yrs BR=0.833 m^3/h, BW 71.8 kg (derived from Andrews and Patterson (2000) assuming 24-hr breathing rates of 0.59, 0.52, 0.38 and 0.28 m^3/kg/24 hr for infants, children 1-2 yr, children 6-12 yr and females 13-49 yr, respectively.) [See Appendix 4.]

I. INTRODUCTION

Chlorpyrifos is a chlorinated organophosphorus (OP) pesticide with a primary and well established toxicity pathway that involves the binding and inhibition of the enzyme acetylcholinesterase (AChE) by the oxon metabolite of chlorpyrifos. AChE hydrolyzes acetylcholine at synaptic clefts in the central and peripheral nervous systems and in some non-neuronal targets such as plasma and red blood cells. Exposure to high levels of chlorpyrifos may result in a cholinergic syndrome typified by respiratory distress, miosis, muscular twitches, tremors, ataxia, diarrhea, and vomiting.

Recent research has revealed that chlorpyrifos toxicity may extend beyond the classical cholinesterase-dependent pathway into more complex and often nuanced effects. Chlorpyrifos likely causes developmental neurotoxicity at exposure levels that do not induce overt toxicity in adult animals or inhibit cholinesterase activity. In contrast to the cholinesterase-based studies in animals and humans that were previously used to establish risk assessment endpoints, the five most recent studies show evidence of developmental neurotoxicity occurring at non-cholinesterase-inhibiting doses. Likewise, epidemiological findings provide likely evidence of an association between exposure to chlorpyrifos and impacts on growth and development. However, the measurement of specific biomarkers of exposure has been problematic in human studies, including major differences in analytical sensitivities and the common reliance on non-specific markers of exposure on which to base exposure-response relationships. Even with these challenges, there is a degree of concordance in the qualitative and quantitative effects seen in humans and recent animal studies, including changes in cognition, motor control, and behavior at low dose levels. Even so, deficiencies in quantified exposure analysis in epidemiological studies make it difficult to strictly compare those studies with the rodent DNT studies reviewed for this assessment.

History of Chlorpyrifos Risk Assessment in California

In its December 2015 draft risk assessment, DPR's Human Health Assessment (HHA) Branch initially adopted the points of departure (PoDs) from the 2014 US EPA Revised Human Health Risk Assessment for Chlorpyrifos (US EPA, 2014) which utilized an AChE inhibition endpoint. The PoDs were human estimates derived from physiologically based pharmacokinetic-pharmacodynamic (PBPK-PD) modeling of 10% AChE inhibition in red blood cells. It was in the December 2015 draft that the potential human exposure to spray drift (via inhalation or deposition) first became a concern. As such, chlorpyrifos entered the formal process to evaluate the scientific evidence for listing as a pesticide Toxic Air Contaminant (TAC) (CA Food & Agricultural Code §14021-14027).

The first draft TAC evaluation was published by DPR in August 2017. A subsequent revision was published in December 2017 which has been reviewed by the SRP. In the December 2017 Draft TAC Evaluation (see Appendix 6), the critical no-observed-effect level (NOEL) for evaluating oral, dermal, and inhalation exposure to chlorpyrifos was a PBPK-PD derived PoD based on 10% inhibition AChE after an acute (single day, 24 hr) or steady-state (21-day) exposure. The PBPK-PD model includes parameters that account for human-specific physiology and metabolism and can be used to derive age, exposure duration, and route specific PoDs.

Risks were calculated as a margin of exposure (MOE) for infants, children, youths, and non-pregnant adults. The MOE equals the critical PoD divided by the estimated human exposure level. DPR considered a MOE of 100 to be protective of human health for all exposure scenarios. The target of 100 included uncertainty factors (UF) of 1x for interspecies sensitivity, 10x for intraspecies variability, and 10x for potential neurodevelopmental effects. Exposures resulting in MOEs lower than the target of 100 are considered to be of potential health risk to humans.

Using the 10% AChE inhibition endpoint and exposures estimated from spray drift following aerial applications of chlorpyrifos, human health risks were identified from hand-to-mouth exposure to children, from inhalation exposure to children and women of childbearing age, and from various aggregate exposures. The air component of the exposure contributed up to 95% of the total aggregate exposure risk. Consequently, exposure to aerosols in the air near chlorpyrifos application sites was the main driver of the risk estimates of cholinesterase inhibition, especially for children 1-2 year olds, and thus substantiated the evaluation of chlorpyrifos as a TAC.

HHA revised its PBPK-PD modeling outputs for AChE inhibition as well as the resulting exposure estimates and MOEs (see Appendix 3). After further review of the PBPK-PD modeling parameters, and in consultation with the SRP, HHA subsequently increased the interspecies UF for model insufficiencies, thus adjusting the target MOE from 100 to 300.The revised PoDs, RfCs, and RfDs are found in Table 28 later in this document.

Also as part of their review of the December 2017 draft, the SRP recommended additional and detailed review of developmental neurotoxicity studies, in particular recent in vivo animal studies as well as a more in depth analysis of human effects of chlorpyrifos. In addition, the SRP recommended that DPR reevaluate the critical endpoints, the associated UFs, and the resulting RfCs and RfDs for each endpoint.

This final TAC evaluation of chlorpyrifos provides an update to the December 2017 draft and incorporates these changes.

II. TOXICOLOGY PROFILE

Recent in vivo animal studies and human epidemiological studies have continued the investigations into the potential effects or associations of chlorpyrifos on neurodevelopment, growth, and behavior. In finalizing this TAC evaluation, HHA conducted a comprehensive review of animal studies published from 2015 – 2018, especially focused on the potential for neuro-disruptive behavior at dose levels below those that cause overt cholinesterase inhibition. Care was taken to consider the timing of chlorpyrifos dosing, as well. Therefore in vivo studies are summarized by timing of exposure, e.g., gestation-only, postnatal-only, or combined dosing to provide comparison of results. The epidemiological studies reviewed herein are also new since the December 2017 Draft TAC Evaluation (Appendix 6). This section now also includes a review of new cohort and descriptive epidemiological studies as well as a comprehensive examination of the analytical methods used to quantify human exposure, which is important when considering the applicability of the epidemiological data to quantitative human health risk assessment. Also included in this revised Toxicology Profile is a review of a primate study and

discussion of potential mechanisms for DNT effects. This Toxicology Profile has been enhanced with a section on delayed neuropathy and neurodegenerative effects of organophosphate pesticides in animal, human, and mechanistic studies. Additional effects of chlorpyrifos have also been examined, including respiratory effects, glucose metabolism and obesity, and recent advances in PBPK modeling.

II.I. Developmental Neurotoxicity

The ability of chlorpyrifos to disrupt development is evaluated in this section. To this end, a series of studies was examined with the intent of establishing both a neurodevelopmental PoD and a plausible mode of action. A FIFRA-compliant developmental neurotoxicity (DNT) study submitted to fulfill registration data requirements under the California Birth Defect Prevention Act of 1984 (SB 950) was reviewed. This study evaluated the effects on neurological development following gavage exposure to chlorpyrifos in rats between gestation day 6 (GD 6) and postnatal day 11 (PND 11) (Hoberman, 1998). The study was originally summarized in the December 2017 Draft TAC Evaluation, however focusing on AChE inhibition. The updated review below provides a comprehensive review of all neurodevelopmental endpoints established in the Hoberman study. Furthermore, reviews of several in vivo animal studies published in the open literature from 2015 – 2018 have also been reviewed to provide as clear a picture as currently possible of the sensitivity of the developing nervous system to low doses of chlorpyrifos. Study findings and summaries are grouped according to the developmental periods in which the exposures occurred.

II.I.1. Gestational and Post-Natal Exposure to Chlorpyrifos

II.I.1.a. Hoberman (1998)

This registrant-submitted study examined the neurodevelopmental consequences of daily oral gavage exposure to chlorpyrifos in Crl:CD7(SD)BR VAF/Plus® pregnant rats (25/dose) during gestation and the perinatal period, GD 6 - PND 11 inclusive. Doses were 0 (corn oil), 0.3, 1, and 5 mg/kg/d. On GD 20, 5 dams/dose were sacrificed for measurement of plasma, RBC and brain ChE activities, in addition to examination of clinical, necropsy and reproductive parameters. On PND 5, 20 litters/dose were continued on treatment, from which four subsets consisting of 20 pups/sex/subset (1/sex/litter) were selected for evaluation of neurodevelopmental parameters as follows:

Subset 1: morphometric and histopathologic evaluations of brains after PND 12 sacrifice in 6/sex/dose;

Subset 2: Learning and memory evaluations by spatial delayed alternation (SDA) studies, including maze acclimation, acquisition training and delay training at PND 23-25 and 62-91in 8/sex/dose;

Subset 3: motor activity testing on postpartum days 14, 18, 22, and 61 (20/sex/dose) and acoustic startle response on PND 23 and 60 (20/sex/dose);

Subset 4: developmental landmarks (pinna unfolding, eye opening, preputial separation or vaginal opening) in 20/sex/dose; brain weight determination in 10/sex/dose sacrificed during PND 66-71, and neurohistopathology following *in situ* perfusion of 6/sex/dose.

Body weights were measured in all pups on PNDs 1 and 5 (pre-and postcull) and at several additional predetermined times (the latter for Subset 4 pups only). Positive non-concurrent controls were analyzed for neurohistopathology, spatial delayed alteration and motor activity, morphometry (PND 12 and PND 66-71) but not for acoustic startle response (Hoberman, 1999). Historical control brain morphometry data from the same laboratory but conducted after this study were available for 4-5 additional DNT studies (Hoberman, 1998). Finally, a satellite group consisting of 5 pregnant dams/dose was run to determine the effects of chlorpyrifos on maternal blood and brain cholinesterase on GD 20 (*i.e.*, after 2 weeks of exposure).

Maternal observations. Clinical signs in dams during the initial days of lactation included hyperpnea (1 mg/kg/d) and fasciculations, hyperactivity and hyperpnea (5 mg/kg/day). Neither maternal body weights nor food consumption was affected at any dose. Maternal plasma ChE was inhibited at the low dose on GD 20 (57% of controls; $p<0.0001$), with even greater levels of inhibition occurring at the mid and high doses. RBC ChE was also inhibited at the low dose (59% of controls, not statistically significant), with statistically significant inhibition occurring at the mid and high doses. Brain ChE was statistically inhibited at 1 mg/kg/day (18%; $p<0.0001$) and at 5 mg/kg/day (90%; $p<0.0001$) on GD 20. Benchmark dose analysis conducted by US EPA of the RBC ChE data generated BMD_{10} / $BMDL_{10}$ values of 0.06 / 0.03 mg/kg/day. US EPA analysis of the brain ChE data generated BMD_{10} / $BMDL_{10}$ values of 0.65 / 0.54 mg/kg/day (US EPA, 2011; p. 158). AChE inhibition by repeated doses of OPs, including chlorpyrifos, achieves a steady state degree of inhibition after 2 weeks of treatment. Similar levels of inhibition are observed after exposures of longer duration (subchronic or chronic scenarios). Thus the $BMDL_{10}$ for RBC and brain AChE inhibition from the current study were viewed by HHA as evidence of toxicity occurring after repeated exposures. In 2011, US EPA used the $BMDL_{10}$ of 0.03 mg/kg/day based on RBC AChE inhibition to characterize the risk from chronic exposure to chlorpyrifos (US EPA, 2011).

Pup observations. Neonatal pup losses, decreased pup growth, decreased pup body weight gains and developmental delays (represented by delayed pinna unfolding) were observed at 5 mg/kg/day. In addition, indicators of sexual maturation (preputial separation in males, vaginal patency in females) were delayed at that dose. The SDA maze studies conducted in PND 23-25 and 62-91 offspring did not yield convincing evidence for a chlorpyrifos-mediated effect. On the other hand, motor activity, gauged as the number of movements per 60-minute period, was reduced at 5 mg/kg/day in PND 14 pups compared to concurrent controls. No consistent pattern was present after that time (PNDs 18, 22 and 61). Measurements of peak acoustic startle response revealed possible reductions at 5 mg/kg/day in PND 23 and 60 animals. Similarly, the latency to peak response was greater in high dose animals on both days. Finally, two measures of sexual maturation, preputial separation in males and vaginal patency in females, showed delays at 5 mg/kg/day. All results are summarized in Tables 1 and 2.

Morphometric measurements for nine brain regions in PND 12 pups revealed statistically reduced cerebellar dimensions in high dose males (anterior-posterior decrease: 24.5%; height decrease: 14.2%; $p<0.05$) compared to concurrent controls (Table 3). As high dose male brain weights were 11.5% lower than concurrent controls, a chlorpyrifos -mediated impact on cerebellar growth in these males was considered to be possible. Other regions also exhibited

dimensional declines, but they were quantitatively less than, or similar to, the 11.5% brain weight decline, they couldn't necessarily be viewed as direct responses to chlorpyrifos.

Similar morphometric measurements were conducted in PND 66-71 adults, though the 0.3 and 1 mg/kg/day doses were omitted in males, as was the 0.3 mg/kg/day dose in females. The PND 66-71 measurements revealed statistically reduced parietal cortex dimensions in 1 and 5 mg/kg females (4% and 5%, respectively; $p<0.05$) (Table 4). Because control and 1 mg/kg/day female brain weights were unaffected, these changes were consistent with the possibility of a chlorpyrifos-mediated effect. In addition, non-statistically significant reductions in hippocampal gyrus dimensions in 1 and 5 mg/kg/day females (4% and 7%, respectively; $p>0.05$) may have resulted from chlorpyrifos exposure.

NOEL determinations in pups. A developmental lowest observed effect level (LOEL) of 1 mg/kg/day was established based on reduced parietal cortex and hippocampal dimensions in PND 66-71 female adults at 1 and 5 mg/kg/day. Morphometric observations were not made at 0.3 mg/kg/day; consequently, a discrete no-observed effect level (NOEL) could not be determined. In addition, cerebellar dimensions in PND 12 pups and hippocampal gyrus dimensions in PND 66-71 adults at 5 mg/kg/day were reduced. These observations were likely secondary to decreased pup growth over the course of gestation and perinatal development. Many other observations in pups, including body and brain weight decrements, neonatal pup losses, decreased pup growth, decreased pup body weight gains, decreased motor activity and developmental and sexual maturation delays, were observed at the high dose of 5 mg/kg/day.

NOEL determinations in pregnant dams. Because statistically significant inhibition of RBC cholinesterase was observed after 2 weeks of treatment in the pregnant dams at the low dose of 0.3 mg/kg/day, US EPA resorted to BMD analysis, generating a **maternal BMD_{10} / $BMDL_{10}$ of 0.06 / 0.03 mg/kg/day,** respectively. Brain cholinesterase underwent statistically significant inhibition at 1 mg/kg/day, generating BMD_{10} /$BMDL_{10}$ values of 0.65 and 0.54 mg/kg/day, respectively. These inhibitory effects were viewed as a result of repeated rather than acute toxicity. Clinical signs were noted at as low as 1 mg/kg/day.

Table 1. Effect of Daily Gavage with Chlorpyrifos in Pregnant Rats on Litter and Pup Parameters

	Dose (mg/kg/day) [c]			
	0	**0.3**	**1**	**5**
Surviving pups per litter				
Day 1	12.3	13.3	13.0	12.7
Day 5, pre-cull	12.2	13.1	12.7	8.9 [a]
Day 5, post-cull	10.0	10.0	10.0	8.7 [a]
Found dead (total pups / total litters)	1/25	2/24	2/24	50/23 [a]
Mean pup weight (g)				
Males: Day 1	6.6	6.7	6.4	6.1
Day 5, post-cull	9.8	10.2	10.1	8.8 [a]
Females: Day 1	6.3	6.2	6.1	5.6
Day 5, post-cull	9.4	9.6	9.5	8.2 [a]
Pinna unfolding				
% pups reached as of day: 2	7	3	1	0
3	48	47	47	17 [b]
4	94	99	91	71
5	100	100	100	99
Sexual maturation (day)				
Preputial separation, males	44.2±1.9	43.4±1.9	45.2±3.2	47±5.9
Vaginal patency, females	32.4±1.0	31.5±1.5	32.1±2.3	33.4±2.2*
No. of movements / 60 min				
PND 14				
Males	246±200	182±205	168±147	109±109
Females	228±197	238±208	183±207	145±126
PND 18				
Males	373±277	328±209	390±300	319±187
Females	343±268	402±234	357±226	520±239
PND 22				
Males	314±179	249±125	299±187	302±207
Females	229±88	258±174	253±153	347±207
PND 61				
Males	585±191	612±187	616±142	681±140
Females	635±164	693±97	701±144	743±102
Auditory startle habituation (g)				
PND 23				
Males	56.6±23.3	63.7±30.1	56.9±21.2	40.5±10.0
Females	59.9±18.1	57.6±16.0	55.7±17.4	48.7±20.5
PND 60				
Males	219.7±100.2	156.3±69.5	171.3±92.4	168.3±80.5
Females	146.6±81.2	145.5±89.2	97.0±47.6	133.7±82.3
Latency to peak auditory response (msec)				
PND 23				
Males	39.3±7.1	38.5±8.4	39.2±9.4	49.1±16.0
Females	37.1±8.8	36.8±7.0	38.2±7.0	43.0±7.5
PND 60				
Males	36.5±6.5	39.0±9.2	37.5±5.6	40.8±11.6
Females	39.3±9.2	43.4±9.4	45.6±11.3	43.1±8.8

* $p<0.01$

[a] Noted by the investigators as statistically significant.

[b] Noted by the investigators as not statistically significant. However, the apparent delay was consistent with body weight decrements and was thus considered to be treatment related.

[c] Values are expressed as arithmetic means ± standard deviations.

Table 2. Effect of Two Weeks of Daily Chlorpyrifos Gavage on Cholinesterase Activities in Pregnant Rats

Compartment	Dose (mg/kg/day) [a] 0	0.3	1	5
plasma (nmol/min/ml) (% of controls)	861.31±63.42 (100.00±7.36)	488.33±23.18*** (56.70±2.69)	268.15±35.04*** (31.13±4.07)	72.64±10.22*** (8.48±1.19)
RBC (nmol/min/ml) (% of controls)	652.50±235.34 (100.00±36.07)	363.31±105.03 (58.74±16.10)	101.72±44.35* (15.59±6.80	-0.88±0.98** (-0.13±0.15)
brain (nmol/min/g) (% of controls)	11296.28±315.01 (100.00±2.79)	11264.23±167.01 (99.72±1.48)	9274.83±316.47*** (82.11±2.80)	1149.97±104.14*** (10.18±0.92)

[a] Values are expressed as arithmetic means ± standard deviations.
*,**,***: p<0.05, 0.01, 0.0001, respectively, using one-way ANOVA

Table 3. Morphometric Observations in Postnatal Day (PND) 12 Pups after Daily Chlorpyrifos Gavage During and After Pregnancy

	Dose (mg/kg/d) 0	0.3	1	5	Historical controls (range)
Parameter [a]	**PND 12 males**				
Body weight (g) [b]	23.5±1.6	27.6±2.4 117%	25.9±2.4 110%	19.4±4.3* 83%	NA
Brain weight (g) [b]	1.28 ±0.04	1.41±0.07 110%	1.36±0.06 106%	1.17±0.16* 91%	1.24 (1.132-1.32) n=5
Brain / Bwt [b]	5.5±0.36	5.16±0.25 94%	5.3±0.36 96%	6.2±0.87 113%	NA
Cerebrum, ant.-post. (mm)	12.5±0.03	13.4±0.5 107%	13.1±0.49 105%	11.8±0.95 94%	12.2 (10.5-12.9) n=5
Cerebellum, ant.-post. (mm)	3.27±0.31	3.45±0.35 106%	3.33±0.19 102%	2.47±0.55* 76%	5.2 (3.2-6) n=5
Cerebellum, height (µm)	3504±129	3456±172 99%	3416±200 97%	3008±504* 86%	3410 (3005-3606) n=5
Frontal cortex (µm)	1348±53.5	1360±100.3 101%	1352±47.2 100%	1272±153 94%	1461 (1356-1551) n=5
Parietal cortex (µm)	1336±56	1448±58 108%	1448±32.8 108%	1256±138 94%	1483 (1409-1584) n=4
Caudate-putamen (µm)	2240±84	2240±108 100%	2312±93.2 103%	2224±148 99%	2400 (2304-2488) n=4
Corpus callosum (µm)	293±25.4	302±24.3 103%	290±35.7 99%	293±55.6 100%	285.7 (272-302) n=4
Hippocampal gyrus (µm)	904±93.2	1004±114 111%	972±54.2 108%	824±65.6 91%	1054 (948-1136) n=5
External germinal layer, cerebellar cortex (µm)	37.2±2	38.3±4 103%	40±7 108%	37.7±3 101%	35.9 (30.3-38.8) n=5
Parameter	**PND 12 females**				
Body weight (g) [b]	23.1±2.3	23.2±1.8 100%	23.1±2.8 100%	18.8±3.6* 81%	NA
Brain weight (g) [b]	1.28±0.08	1.28±0.04 100%	1.27±0.13 99%	1.17±0.13 91%	1.27 (1.08-1.34) n=5
Brain / Bwt [b]	5.59±0.37	5.53±0.36 99%	5.54±0.35 100%	6.36±0.87* 114%	NA
Cerebrum, ant.-post. (mm)	12.4±0.26	12.7±0.28 102%	12.8±0.63 103%	12.2±0.58 98%	12.2 (10.8-12.98) n=5

Cerebellum, ant.-post. (mm)	3.18±0.22	3.03±0.32 95%	3.3±0.17 104%	3±0.31 94%	5.09 (3.1-6) n=5
Cerebellum, height (µm)	3512±200	3176±130 90%	3120±328 89%	3208±226 91%	3404 (2856-3756) n=5
Frontal cortex (µm)	1376±92	1388±79.5 101%	1356±54.2 99%	1368±85.9 99%	1512 (1356-1616) n=4
Parietal cortex (µm)	1380±54.2	1376±19.6 100%	1368±80.3 99%	1304±72.3 94%	1513 (1423-1616) n=4
Caudate-putamen (µm)	2384±131	2224±116 93%	2288±108 96%	2152±134 90%	2398 (2328-2530) n=4
Corpus callosum (µm)	307±38.4	286±26.8 93%	304±35.7 99%	274±39.6 89%	281 (261-320) n=5
Hippocampal gyrus (µm)	936±81.7	912±50.3 97%	932±96.5 100%	828±78.5 88%	1014 (919-1060) n=4
External germinal layer, cerebellar ctx (µm)	38.7±3	36.3±6 94%	41.2±6 106%	40.8±6 105%	39.5 (36-44.8) n=4

[a] Values are expressed as arithmetic means ± standard deviations. Percentages refer to the percent of control values. Greyed boxes indicate brain regions for which morphometry was plausibly impacted by chlorpyrifos exposure.
[b] Body weights and brain body weight ratios were from Subset 1, PND 12 pups. Brain weight/body weight ratios were multiplied by 100.
* $p<0.05$; analysis conducted by the study investigators
NA = data not available

Table 4. Morphometric Observations in Postnatal Day (PND) 66-71 Adults after Daily Gavage with Chlorpyrifos in Pregnant & Postnatal Rats

	Dose (mg/kg/d)				**Historical controls (range)**
	0	**0.3**	**1**	**5**	
Parameter [a]	PND 66-71 males				
Body weight (g) [b]	388.9±24.9	385.4±35.6 99%	389.8±31.8 100%	348.0±31.8 89%	NA
Brain weight (g) [b]	2.30±0.069			2.30±0.021 100%	2.23 (2.127-2.4) n=5
Brain / Bwt [b]	0.59			0.66 112%	NA
Cerebrum, ant.-post. (mm)	15.9±0.400			16.18±0.264 102%	15.88 (14-16.7) n=5
Cerebellum, ant.-post. (mm)	5.7±0.232			5.67±0.216 99%	7.09 (6.27-7.6) n=5
Cerebellum, height (µm)	5152±218			5104±351.0 99%	5078 (4648-5419) n=5
Frontal cortex (µm)	1792±105			1768±75.4 99%	1791 (1660-1838) n=5
Parietal cortex (µm)	1756±79			1792±58.1 102%	1861 (1776-1956) n=4
Caudate-putamen (µm)	2800±176			2744±98.0 98%	3300 (2920-3624) n=4
Corpus callosum (µm)	266±29			247±17.9 93%	265.6 (243.2-285) n=4
Hippocampal gyrus (µm)	1640±92			1612±95.3 98%	1668 (1552-1819) n=5

Parameter [a]	PND 66-71 females				
Body weight (g) [b]	228.7±15.4	238.1±27.9 104%	228.8±20.6 100%	220.3±14 96%	NA
Brain weight (g) [b]	2.103±0.071		2.13±0.079 101%	2.05±0.05 97%	2.08 (1.93-2.15) n=5
Brain / Bwt [b]	0.92		0.93 101%	0.93 101%	NA
Cerebrum, ant.-post. (mm)	15.617±0.306		15.63±0.344 100%	15.52±0.248 99%	15.27(13.83-15.88) n=5
Cerebellum, ant.-post. (mm)	5.5±0.232		5.50±0.261 100%	5.38±0.098 98%	6.89 (5.77-7.38) n=5
Cerebellum, height (µm)	5016±120		4888±150 97%	4968±207.57 99%	4863.8(4592-5028) n=5
Frontal cortex (µm)	1744±56		1748±75 100%	1724±79.48 99%	1708 (1628-1818) n=4
Parietal cortex (µm)	1792±36		1716±36** 96%	1700±55.60** 95%	1738 (1656-1824) n=4
Caudate-putamen (µm)	2576±131		2552±178 99%	2704±112.23 105%	3142.8(2904-3379) n=4
Corpus callosum (µm)	244.8±25		258±18 105%	234±18.89 96%	264 (246-275) n=5
Hippocampal gyrus (µm)	1708±58		1644±149 96%	1592±86.76* 93%	1547 (1420-1602) n=5

[a] Values are expressed as arithmetic means ± standard deviations. Percentages refer to the percent of control values. Greyed boxes indicate brain regions for which morphometry was plausibly impacted by chlorpyrifos exposure.
[b] Body weights and brain body weight ratios were from Subset 4, postnatal day (PND) 66 pups. Brain weight to body weight ratios were multiplied by 100. The ratios in this table were calculated by DPR.
*,** $p<0.05$ & 0.01, respectively; analysis conducted by study investigators
NA = data not available; examination of external germinal layer of cerebellar cortex not completed in this group of animals

II.I.1.b. Gómez-Giménez et al. (2017)

Chlorpyrifos was dissolved in corn oil, mixed in a sweet jelly and fed to pregnant Wistar rats (6/dose). The females were treated from GD 7 to GD 20, then continued through lactation day (PND) 21 at doses 0, 0.1, 0.3 and 1.0 mg/kg/day. The purpose of the study was to determine (1) if spatial learning was affected in either sex after developmental exposure and (2) if hippocampal inflammation was associated with effects on spatial learning. There were no treatment-related effects on growth, number of offspring, survival, or bodyweights of the pups at any dose.

Cognitive Impairment Study: Pups were weaned on PND 21 and tested at age 2-3 months in the Morris water maze for effects on spatial learning.

1. Escape latency (Day 3) – pups were trained to learn the fixed location of a platform under water for escape (6-11 males/dose; 9 females/dose).
2. Reference errors (Day 4) – an 8-arm radial maze was used to record the number of first entries into an arm without pellets. In this test pups learn which 4 of the 8 arms have a food reward (3-10 males/dose; 9-10 females/dose).
3. Working memory (Day 5) – working errors were the number of entries into the 8-arm maze which the rat had entered previously (4-10 males; 9-10 females). A learning index was

calculated as the number of correct choices per number of errors for first entry into each arm of the radial maze.

Males were tested at all doses in all behavior tests, whereas female pups were only tested at 0.3 and 1.0 mg/kg/day. Escape latency in males increased at 0.1 mg/kg/day and above. Time spent in right quadrant on day 3 of testing was decreased in males at 1.0 mg/kg/day and unaffected in females. Spatial reference errors (first visits to unbaited arms) on testing day 4 were increased in males at ≥0.3 mg/kg/day. Working errors (visits to arms already visited in the same trial when seeking the baited arm) over the 5 days of testing increased in males at 0.3 mg/kg/day; females were not statistically significantly affected. Learning index (#correct choices ÷ #errors for first entry into each arm when seeking the baited arm) at day 4 decreased in males at ≥0.3 mg/kg. There was no apparent dose response in any of the effects. The authors conclude that chlorpyrifos impaired learning in males but not in females. **The LOEL for decreased spatial learning in males was 0.1 mg/kg/day.**

Inflammation Study: At 5-7 days after the behavioral tests were performed, rats (7-12 males/dose; 5-10 females/dose) were sacrificed and the hippocampus, a focal area for learning and memory, was dissected out to examine proteins that are markers of neuroinflammation (Iba-1, IL-4 and IL-10, IL-1b and TNF-α, GABA- α 1, GABA α 5 and GABA γ2, GluR1, GluR2, NR1, NR2A and NR2B). Protein assays were performed in males at all doses and at 0.3 and 1.0 mg/kg/d in females. Males exhibited decreased IL10 levels at 1.0 mg/kg/day in a dose-responsive manner that became significant at 1.0 mg/kg/day, while females showed decreases at 0.3 mg/kg/d and greater. IL-1b was increased at 0.1 mg/kg/day and greater in males but not in females. In contrast, Iba-1 was decreased in females at 1.0 mg/kg/d, while males were unaffected. The authors concluded that increased IL-1b in the hippocampus may correlate with the decreased spatial learning observed in males.

II.I.1.c. Gómez-Giménez et al., 2018

This study tested for potential gender-related effects of chlorpyrifos on spontaneous motor activity and motor coordination. Extracellular γ-aminobutyric acid (GABA) levels in the cerebellum and N-methyl-D-aspartate receptor (NMDR) subunit expression in the hippocampus were tested for possible associations. Extracellular cerebellar GABA modulates motor coordination (Chiu *et al.*, 2005; Hanchar *et al.*, 2005; Boix *et al.*, 2010); increased extracellular GABA has been associated with a decrease in motor coordination on the rotarod test (Boix *et al.*, 2010). NMDR subunit expression also affects motor activity and coordination. As in the previous study by this research group, pregnant Wistar rats were fed chlorpyrifos mixed in sweet jelly at 0 (n=10), 0.1 (n=4), 0.3 (n=4) and 1.0 (n=7) mg/kg/day, GD 7 through PND 21. The number of pups/dose (mg/kg/day) was 0 (22 males, 25 females), 0.1 (9 males, 5 females), 0.3 (18 males, 22 females), and 1.0 (21males, 20 females). The pups, weaned on PND 21, were tested at age 2-3 months for impacts on motor activity. Reproductive parameters were not affected in either sex.

Behavioral Effects: Spontaneous motor activity was measured in an open-field activity chamber (novel environment) using an actimeter (infrared motion detection). Motor coordination was measured by rotarod (constant minimum speed 2 min; increased from 4-40 rpm over 300 seconds). Females at 0.3 mg/kg/day exhibited decreased motor coordination on the rotarod.

There was a statistically significant increase in spontaneous motor activity in males and females at 0.1 mg/kg/day, but not at 0.3 or 1 mg/kg/day. **The LOEL was established at 0.1 mg/kg/d based on increased spontaneous motor activity in both sexes at that dose**.

Extracellular GABA and NMDR Levels: Assays for extracellular GABA in the cerebellum and NMDR subunit expression in the hippocampus were performed when the animals were 2-3 months of age. Microdialysis cannuli were implanted in the rat skull in half of the rats to allow access to the cerebellum in freely moving rats. Five samples of cerebrospinal fluid were collected for extracellular GABA analysis 3-7 days after performing motor activity tests. Brain tissue, dissected out and the hippocampus, was analyzed by Western Blot for NMDR subunit expression. Males exhibited no effects on motor coordination but showed increased extracellular GABA at 0.3 mg/kg/d (0.1 mg/kg/d not tested; dose responsiveness not apparent). There was no association in either sex between extracellular GABA subunits and motor coordination on the rotarod. However, males at 0.1 mg/kg/day who showed an increase in spontaneous motor activity also showed increased NMDA receptor subunits. On the other hand, females with increased spontaneous activity at 0.1 mg/kg/d showed decreased levels of NMDA receptor subunits. The NMDR pathway in the hippocampus is activated by glutamine and causes dopamine release in the nucleus accumbens, thus affecting voluntary motor activity (Peleg-Raibstein and Feldon, 2006; Barr *et al.*, 2014). However, a clear association in this study between spontaneous motor activity and NMDA receptor subunits was not detected in this study.

II.I.2. Gestational Only Exposure to Chlorpyrifos

II.I.2.a. Silva et al., 2017

Silva and colleagues investigated the effects on complex behaviors (particularly anxiety and depression) in Wistar rats exposed to chlorpyrifos in utero. Pregnant dams (11- 14/dose) received 7 consecutive daily doses of chlorpyrifos (0.01, 0.1, 1 and 10 mg/kg/day) by oral gavage on gestation days 14–20. Controls received the vehicle only (Tween 20 in 9% saline = 0.1 ml/ml). The last third of the gestation period was chosen because it is a critical period for fetal brain development and neurogenesis. Behavioral parameters in male pups were evaluated twice, during the infant-juvenile period (PND 21) and in adulthood (PND 70). Reproductive parameters (maternal body weight and weight gain, clinical signs of toxicity, gestation length, number of implants, post-implantation loss, mean pup weight, pup/dam ratios, number of live births and stillbirths, and male/female ratios at birth) were also examined. Male pups were separated into 4 groups (8-10 pups/group) comprised of those tested on PND 21 or PND 70. The elevated plus-maze test was used to assess anxiety levels. The open field test was used to evaluate locomotor activity. The modified forced swimming test was used to assess depressive behavior. Neither RBC nor brain AChE levels were measured, either in dams or in pups. Gestational exposures to 10 mg/kg/day chlorpyrifos resulted in reduced body weight gains in mothers during the treatment period. Maternal toxicity was not observed at lower doses. There were neither clinical signs nor effects on pregnancy that could be attributed to treatment.

Two tests conducted in PND 21 pups evidenced anxiety-like behaviors at maternal doses of 0.1

mg/kg/day and above. In the first test, time spent in the open arm of the elevated plus-maze was reduced by 45-50% at 0.1, 1 and 10 mg/kg/day ($p<0.05$).[2] And in the second, increased locomotor activity was detected in the open field test (30.3±3.43, 26.1±3.23, 40.6±3.28*, 52.1±5.26* and 42.3±5.66* intersections per 5-minute period at 0, 0.01, 0.1, 1 and 10 mg/kg/day; *$p<0.05$). The absence of a dose-related exacerbation of this response above 0.1 mg/kg/day was unexplained, but plausibly due to saturation of one or more of the many neural pathways involved in regulation of complex behaviors. There was no effect of chlorpyrifos on depressive-like behavior as evaluated in the modified forced swimming test. PND70 animals displayed neither anxiogenic (elevated plus-maze and open field locomotor activity test) nor depressive (modified forced swimming test) behaviors.

The authors concluded that chlorpyrifos treatment during pregnancy induced anxiogenic behavior in pups at the end of lactation (PND 21). As a result, they set the **LOEL for neurodevelopmental effects at 0.1 mg/kg/day. The lowest tested dose 0.01 mg/kg/day was the NOEL**.

II.I.3. Post-Natal Only Exposure to Chlorpyrifos

II.I.3.a. Mohammed et al. (2015); Buntyn et al. (2017); Carr et al. (2017)

Initial studies showed that male and female rat pups treated by oral gavage at 0 (corn oil) and 0.5 mg/kg/day during PND 10-16 exhibited behavioral anomalies when tested on PND 25. AChE was not measured. Decreased anxiety was evident through increases in number and percent of open arm entries, time and percent time spent in open arm of a plus maze, occurrences of crawling over/under, motor activity, play-fighting and time spent playing (Mohammed *et al*., 2015). In a subsequent study, pups were treated by gavage on PND 10-15 with 0, 0.5, 0.75 or 1 mg/kg/day chlorpyrifos (6-8/sex/dose) (Carr *et al.*, 2017). Forebrain AChE inhibition was noted at the high dose. Behavioral testing showed decreased times to emergence from a dark container into a novel environment at 0.5 mg/kg/day in both sexes. This behavior was associated with decreased anxiety. The data confirm earlier findings from this group showing that chlorpyrifos treatment generated behavioral effects at doses lower than those inhibiting brain AChE. The **LOEL for decreased anxiety in PND 25 pups was 0.5 mg/kg/day**.

II.I.3.b. Lee et al. (2015)

Male NMRI mice were treated by gavage with chlorpyrifos during rapid brain growth and maturation to investigate whether an acute perinatal exposure could be associated with behavioral effects in adulthood. Mammals undergo well-defined stages of neural development prior to full maturation, regulated by proteins (calcium/calmodulin-dependent kinases II (CaMKII), growth associated protein-43 (GAP-43), glutamate receptor 1 (GluR1), postsynaptic density protein-95 (PSD95), synaptophysin and tau control. These proteins are active during much of the brain growth spurt (BGS) stage (Wiedenmann and Franke, 1985; Navone *et al.*,

[2] Precise values are not provided for the elevated plus-maze test because the results were expressed in the form of histograms by the investigators.

1986; Benowitz and Routtenberg, 1997; Rongo and Kaplan, 1999; Ehrlich and Malinow, 2004; Wang and Liu, 2008; Traynelis *et al.*, 2010). The timing of the BGS in humans occurs from the 3rd trimester through age 2-3 years. In rodents the BGS occurs from birth through PND 21-28 (Semple *et al.*, 2013). The vehicle (20% fat emulsion/kg b.w. [1:10 egg lecithin + peanut oil]) used in this study was designed to simulate the fat content of mouse milk (~14%) in order to facilitate physiologically relevant absorption and distribution.

Treatment groups were as follows*:*

1. Brain AChE inhibition analysis: PND 10 pups received chlorpyrifos by gavage at 0 and 5.0 mg/kg (n=4/dose) as a single treatment. Assays were performed at 1, 3, 6, 12, 24 or 36 hours post-dose;
2. Neuroprotein analysis: PND 10 pups received a single gavage dose of chlorpyrifos at 0 and 5.0 mg/kg. These mice were sacrificed at 24 hours or 4 months after exposure and the hippocampus and cerebral cortex were frozen (n=5-8/dose)
3. Motor activity assessment: PND 10 pups were treated with chlorpyrifos by gavage at 0, 0.1, 1.0 and 5 mg/kg in a single dose followed by assessment at 2 or 4 months of age (n= 12/dose/time point). Locomotion, rearing and total activity were measured when mice were put in a novel cage and allowed to explore.

Results indicated 8-12% brain AChE was inhibition at 5.0 mg/kg (only dose tested: inhibition peaked at 3 h post-dose) which was reversed by 6 hours post-dose. CaMKII and synaptophysin were statistically significantly decreased by 42-50% at 5.0 mg/kg (only dose tested) 24 hours post-dose when brain AChE was no longer inhibited. The spontaneous motor behavior tests at 2 or 4 months after exposure showed statistically significant decreases in locomotion, rearing and total activity at 5.0 mg/kg. Total activity was statistically significantly increased at 0.1 and 1 mg/kg/day at 2 months and remained increased for the rats at 1 mg/kg/day at 4 months. The **LOEL for increased total activity was 0.1 mg/kg/day**, which is below doses causing brain or RBC AChE inhibition. The authors suggested that homeostatic disturbances during BGS of CaMKII may lead to irreversible behavioral effects lasting into adulthood.

II.I.4. Additional in vivo Animal Studies of Chlorpyrifos Reviewed

Reviews of two additional studies with chlorpyrifos in animals are included in this section: a long–term oral study with in non-human primates and a study with adult rats that were treated subcutaneously 7-day study (Coulston *et al.*, 1971; Muller *et al.*, 2014). Both studies showed that plasma ChE is more sensitive than plasma or RBC AChE. In addition, the rat study indicated that in adult neurotoxicity can occur in the absence of AChE inhibition. Neither of the studies established critical endpoints for repeated exposure to chlorpyrifos.

II.I.4.a. (Coulston et al., 1971)

Fourteen rhesus macaque monkeys (8 males and 6 females) were treated with chlorpyrifos by gavage for 6 months. The doses were 0, 0.08, 0.40, or 2.00 mg/kg/day (3-4 animals/group). Four males (1/group) were sacrificed at 3 months. Nine of the remaining 10 monkeys survived to sacrifice at 6 months. There were no effects on body weight, clinical signs, hematology, or clinical chemistry. Plasma ChE inhibition was observed at all dose levels starting from the first

measurement at 1 week, where 38%, 63% and 81% inhibition compared to pretreatment activities were noted at 0.08, 0.40, or 2.00 mg/kg/day (sexes combined), respectively, and continuing through week 24, where 34%, 70% and 62% inhibition were observed. RBC AChE was inhibited at the mid and high doses throughout the study. At 1 week, 0%, 11% and 67% inhibition were observed at increasing doses. At 24 weeks, 1%, 28% and 32% inhibition were observed. Two monkeys, a male and a female were evaluated for midbrain cholinesterase at 2.00 mg/kg/day. The male was sacrificed at 3 months and showed no difference from the control. The female was sacrificed at 6 months and had15% brain AChE inhibition. Midbrain AChE was not inhibited at the mid and low dose. The level of inhibition of brain AChE activity in the female after 6 months was comparable to values obtained for repeat-dose studies in the rat and dog. The NOEL was 0.08 mg/kg/day based on RBC AChE inhibition at 0.40 and 2 mg/kg/day after repeated treatment. The HHA Data Review Section classified this study as supplementary because it was not conducted according to FIFRA guidelines.

II.I.4.b. (Muller et al., 2014)

Investigators treated adult males rats (4-10/group) subcutaneously with chlorpyrifos at 0, 0.1, 1, or 10 mg/kg/day daily for 7 days. In Sprague-Dawley rats, the activities of plasma esterases, AChE, butylcholinesterase (BuChE), and carboxylesterase (CES) were measured, and comet assays and auditory startle tests were performed to assessed DNA damage and neurotoxic effects. Wistar rats received the same treatments prior to assessments of EEG's and somatosensory evoked potentials as measures of neurotoxicity. Inhibition of CES inhibition was significant at 10 mg/kg/day AChE $\geq$ 1 mg/kg/day and BuChE $\geq$ 0.1 mg/kg/day. The comet assay showed a significant damage index at 10 mg/kg/day. An assessment of startle response by a preceding sub-threshold sound pulse found significant attenuation at all dose levels, with nearly equal values for 0.1 and 1 mg/kg/day, and a marked reduction at 10 mg/kg/day. EEG recorded frequencies that were divided into 6 ranges and fractional power was calculated for each range. The 10 mg/kg/day group had more fractional power in the higher frequency ranges, which is consistent with an excitatory effect. For the somatosensory evoked potentials, rats were fitted with electrodes on the brain and the left paw. The paw was then stimulated and the evoked response was measured at the brain electrode. The response was recorded as positive peaks, negative peaks and latency. Negative peaks were significantly greater in magnitude than controls in all treated groups. The lack of apparent dose-response could be due to a saturable response at 0.1 mg/kg/day. Overall, a variety of parameters appeared to be affected at 10 mg/kg/day. Neurotoxicity in the absence of AChE inhibition was evident at 0.1 mg/kg/day in two strains of rats, however, the atypical dosing route limited the utility of this study for establishing a critical NOEL.

II.I.5. Neurodevelopmental Mechanistic Studies

Identification of a rigorous neurodevelopmental point of departure for chlorpyrifos would be strengthened by elucidation of the potential mechanism(s). Mammalian neurodevelopment is multifactorial and there are likely multiple pathways involved, some of which may be mediated via the classical cholinesterase toxicity pathway of binding and inhibiting AChE or others that are covariates of this mechanism. While an adverse outcome pathway for chlorpyrifos-mediated DNT has not yet been elucidated, several recent studies have examined key events at the

molecular, cellular, and tissue level (reviewed (Burke *et al.*, 2017). These key events may involve other serine hydrolases such as monoacylglycerol lipase (MAGL) or fatty acid amide hydrolase (FAAH), oxidative stress, disruption of G protein-coupled receptors, changes in receptor tyrosine kinase (RTK) activity, disruption in ligand-gated ion channels, or chlorpyrifos-oxon mediated changes in neuronal growth (the latter reviewed in Eaton *et al.*, 2008). A full treatment of potential mechanisms for chlorpyrifos-mediated DNT and the proposal of an adverse outcome pathway are outside of the scope of this risk assessment. However, a review of current literature of chlorpyrifos related serine hydrolase disruption and disruption of adenylyl cyclase and serotonergic pathways can be found in Appendix 5 of this document.

II.K. Epidemiological Studies Related to Neurodevelopmental Effects

HHA completed a comprehensive search of human epidemiological studies that have investigated the correlation between exposure to pesticides and human development to more completely assess the available data beyond those published the December 2017 Draft TAC Evaluation. In addition, and at the suggestion of the SRP, HHA more closely reviewed the chlorpyrifos exposure analysis in these and other studies that were cited in previous drafts. Below is a summary of those findings and potential applicability of these results for quantitative risk assessment of chlorpyrifos.

II.K.8. Additional Epidemiological Studies

Several additional epidemiological studies have been reviewed. The cohorts or descriptive studies are generally focused on potential exposure to pesticide during pregnancy and consider study populations that reside in Bulacan, Philippines (Bielawski *et al.*, 2005; Corrion *et al.*, 2005; Ostrea *et al.*, 2006; Posecion *et al.*, 2006; Ostrea *et al.*, 2012), Central Ohio (Fluegge *et al.*, 2016), the Zhejiang Province, China (Wickerham *et al.*, 2012; Silver *et al.*, 2015; Silver *et al.*, 2017), and Mexico City, Mexico (Fortenberry *et al.*, 2014).

Bulacan, Philippines

A cohort study was initiated by Wayne State University and the University of the Philippines to consider fetal exposure to environmental toxicants. Pregnant women who resided in a rural area in the province of Bulacan, Philippines were enrolled at midgestation at the Provincial Hospital in Malolos. Over 598 mother/infant dyads and 638 individual infants were eventually recruited into the study. A preliminary survey of pesticides in home or farm use showed that 37% of study enrollees used chlorpyrifos (Ostrea et al., 2012). Maternal blood and hair samples were collected at midgestation and at birth, cord blood was collected at birth, and infant hair and meconium were collected within a few days after birth. Samples were analyzed for both parent pesticide and metabolites (Bielawski et al., 2005; Corrion et al., 2005; Ostrea et al., 2006; Posecion et al., 2006; Ostrea et al., 2012). Analysis of the meconium resulted in no detection of either chlorpyrifos or 3,5,6-trichloro-2-pyridinol (TCPy) (Bielawski et al., 2005). No maternal hair samples were positive for chlorpyrifos at midgestation and only 0.4% of the study population (n=2 of 449 subject) had detectable concentration of chlorpyrifos in hair at birth (median = 4.48 µg/g), which is slightly higher than the LOD of 4.15 µg/g. No maternal blood samples collected at midgestation or at birth were positive for chlorpyrifos (Ostrea et al., 2006) and no cord blood samples tested positive for chlorpyrifos (Ostrea et al., 2009). Additional samples were tested, and

only 1 of 282 mothers (0.35%) tested positive for chlorpyrifos in hair, with a concentration of 4.58 µg/g (Posecion et al., 2006). The investigators then analyzed the correlation between fetal exposure to pesticides and neurodevelopment as measured by the Griffiths Mental Development Scale at 2 years of age (95.1% follow up rate). Meconium was the most sensitive biomarker of fetal exposure to pesticides of all those analyzed (Ostrea et al., 2012). The Griffiths test evaluates 5 developmental parameters including motor skills, social acuity, hearing/language, eye and hand coordination, and visuospatial skills and reaction time. Because of the very minimal detection of chlorpyrifos or TCPy in any of the study samples, chlorpyrifos was excluded from further analysis (Ostrea et al., 2012). The only other birth cohort that analyzed meconium was the Columbia Center for Children's Environmental Health (CCCEH) study conducted at Columbia University, New York (Whyatt *et al.*, 2009). CCCEH researchers analyzed meconium for TCPy and not the parent chlorpyrifos, so it is difficult to compare results to the Bulacan cohort. It is interesting to note that in CCCEH meconium samples which had detectable TCPy above the LOD (0.2 ng; 28%), the highest concentration detected was 0.77 ng TCPy/g meconium (0.77 ppb) (Whyatt *et al.*, 2009).

Central Ohio

Fluegge et al. (2016) describe the effect of prenatal exposure to OPs as measured by maternal urinary metabolites and infant neurodevelopment ascertained at 3 months of age (Fluegge *et al.*, 2016). A cohort of 174 pregnant women were recruited from central Ohio from 2002 – 2005. Maternal urine was collected in the 2nd and 3rd trimesters, infant urine was collected at 2 months of age, and the neurodevelopment was assessed at 3 months using the Bayley Scales of Infant Development for 140 maternal-infant dyads. The arithmetic mean for maternal urinary TCPy (adjusted for body weight) was 26.69 (± 1.77) ng/kg/day, with a maximum measured of 334.72 ng/kg/day while the arithmetic mean for infant levels was 14.67 ng/kg/d (± 3.42) with a maximum measured of 399 ng/kg/d (Fluegge *et al.*, 2016). Third trimester maternal urinary TCPy was associated with impaired motor development ($p<0.05$) and infant urinary TCPy was associated with impaired mental development ($p<0.01$) both in the 3 month old infants (Fluegge *et al.*, 2016). Because TCPy is a metabolite of chlorpyrifos but also exists in the environment, it is difficult to ascertain how or if the mothers were exposed to chlorpyrifos parent compound, especially since measurements of the pesticide were not included in the study.

Zhejiang Province, China

Investigators considered the link between development and pesticide exposure in China, one of the world's leaders in pesticide use and production. Investigators conducted a pilot study (Wickerham *et al.*, 2012) and a full-scale cohort of pregnant women who were enrolled during the 36th week of gestation from Fuyang Maternal and Children's Hospital in the Zhejiang Province of China (Silver *et al.*, 2015; Silver *et al.*, 2017). In the pilot study, pesticides were analyzed in umbilical cord blood at delivery. Chlorpyrifos was measured in 27 of 116 samples above the LOD (>0.05 ng/ml), with the maximum concentration measure at 0.26 ng/ml (Wickerham *et al.*, 2012). No mean measurement was reported, although the 90th and 95th percentiles were reported as 0.17 ng/ml. These values were not associated with measured birth outcomes such as low birth weight (Wickerham *et al.*, 2012). In the full cohort study conducted from 2008 - 2011, investigators performed cord blood pesticide analysis on 336 infants samples. Chlorpyrifos was detected in 136 samples, with a maximum measured concentration of 11.40 ng/ml and the 75th percentile reported at 0.76 ng/ml (LOD = 0.675 ng/ml) (Silver *et al.*, 2015).

When the same infants were assessed for development using the Peabody Development Motor Scales-2nd Edition (PDMS-2), no significant associations were found between measured OP concentrations and PDMS outcomes at 6 weeks of age (Silver *et al.*, 2017). However, chlorpyrifos concentrations were associated with lower scores in all PDMS measurements of fine and gross motor skills at 9 months of age. When compared to unexposed infants, chlorpyrifos-exposed infants measured significant deficits in reflexes ($p = 0.04$), locomotion ($p = 0.02$), grasping ($p = 0.05$), and visual-motor integration ($p < 0.001$), respectively (Silver *et al.*, 2017). In the most recent study examined, the same cord blood measurements of chlorpyrifos were also significantly inversely associated with decreased head circumference in the infants (0.44 cm reduction; 95th CI 0.88, 0.1cm; $p = 0.02$) (Silver *et al.*, 2018).

Mexico City, Mexico

Fortenberry et al. (2014) investigated the relationship between in utero chlorpyrifos, chlorpyrifos-methyl, or TCPy exposure and attention-deficit hyperactivity disorder (ADHD) in school aged children in Mexico City using urinary TCPy as a biomarker of exposure. Women were enrolled in the prospective birth cohort called the Early Life Exposure in Mexico to Environmental Toxicants (ELEMENT) study during 1999 – 2005. Mother and child pairs were re-invited to examine childhood and adolescent neurodevelopmental characteristics when the children reached 6 – 11 years of age (Fortenberry *et al.*, 2014). Three psychometric assessments were used to assess ADHD related symptoms; the authors note the assessment tools used are for screening only, not diagnosis of ADHA. A total of 230 samples were analyzed for TCPy, 90% of which were above the LOD of 0.10 ng/ml. The geometric mean was 1.76 ng/ml (95th CI 1.55, 2.02) (Fortenberry *et al.*, 2014). When comparing the highest and lowest TCPy concentration tertiles, the authors noted suggestive (non-significant) associations between increased ADHD index in the highest TCPy tertile in boys ($p = 0.06$) as well as increased attention problems for the middle but not the highest TCPy concentration tertile in girls ($p = 0.08$). There were no statistically significant associations between any tertile of material TCPy concentration and ADHD observations in children (Fortenberry *et al.*, 2014).

II.K.9. Quantitative Analysis of Exposure

Human environmental epidemiology studies are being considered more in more in quantitative risk assessment, so much so that the US EPA Office of Pesticide Programs published the *Framework for Incorporating Human Epidemiologic & Incident Data in Risk Assessments for Pesticides* in December 2016. In that guidance, US EPA states that quantitative biomonitoring is more advantageous than other exposure assessment methods, however there are several limitations including: 1) biological samples are generally only taken from a single point in time and may not accurately reflect longitudinal patterns, particularly if exposures are highly variable; 2) there can be degradation and metabolism of chemicals in both the environment and human body; 3) biomarkers of exposure may differ between individuals for reasons other than exposure level (differences in metabolism, presence of co-morbidities, etc.); and, 4) uncertainties inherent in the measurements, such as whether the biomarker is measuring exposure to the parent compound or environmental degradates (US EPA 2016). Both Burns and colleagues (2013) and LaKind and colleagues (2014) have noted challenges in accurately assessing quantitative exposure analysis in epidemiological studies. Burns notes that there must be careful attention to the type and specificity of exposure metrics and the validity of outcome measurement when evaluating the likelihood of establishing causality (Burns *et al.*, 2013). LaKind has noted that the

quality of exposure assessment is a major determinant of the overall quality of any environmental epidemiology study and has designed a tool to evaluate the quality of epidemiology studies that include biomonitoring. That tool outlines the important components for biomarker selection and measurement including the biological relevance (i.e., the biomarker in a specific matrix has accurate and precise quantitative relationship with external exposure, internal does, or target dose) as well as method sensitivity, biomarker stability, sample contamination, method requirements, and matrix adjustment (LaKind *et al.*, 2014).

As detailed in the December 2017 Draft TAC Evaluation (DPR, 2017), chlorpyrifos has several specific and non-specific markers of exposure. Most of the recent studies examined herein are finding value in quantifying the most specific biomarkers for chlorpyrifos, such as measured parent compound in blood, hair, and meconium and TCPy in blood and urine. Doing so adds weight to any possible association, more so than measuring nonspecific urinary biomarkers.

Even when these specific biomarkers have been measured in studies, there have been noticeable variations in the analytical methods, making comparison of results across studies difficult. The only way to unequivocally identify chlorpyrifos exposure is by measuring the intact pesticide in biological samples. Chlorpyrifos quantitation in blood can provide an estimation of the target site dose. Umbilical cord blood can provide some idea of recent in utero exposure, although large quantities (> 30 ml) are generally needed to perform the analysis using ultrasensitive analytical techniques (Barr and Angerer, 2006). Analysis is further complicated by the inherently low concentrations of chlorpyrifos present in the blood (~ng/L, ppt range) compared to levels of urinary metabolites (Barr *et al.*, 1999; Barr *et al.*, 2002). TCPy is a product of both the activation and detoxification pathways for chlorpyrifos, and therefore cannot be directly associated with toxicity. Urinary TCPy can also indicate exposures to CPF-oxon, CPF-methyl, and triclopyr (Barr and Angerer, 2006; Whyatt *et al.*, 2009). Environmental and dietary exposure to TCPy can also occur (Barr and Angerer, 2006; Whyatt *et al.*, 2009), complicating the use of TCPy as a biomarker of exposure. Fortenberry et al. (2014) also noted that while there was good trimester-to-trimester consistency of the urinary TCPy measurements in their study, there was significant within-woman variability across trimesters, which decreases the reliability of TCPy as a biomarker of exposure. In addition, when comparing chlorpyrifos levels in maternal or cord blood samples and TCPy levels in urine from the same subject, there was no association found (Whyatt *et al.*, 2009). Below is a description of the varying analytical techniques and sensitivities reported when chlorpyrifos as a parent compound was measured in biological samples in epidemiological studies, also summarized in Table 5.

II.K.9.a. Columbia Center for Children's Environmental Health (CCCEH)

The CCCEH study is described in the December 2017 Draft TAC Evaluation. Briefly, the cohort enrolled pregnant nonsmoking women residing in Washington Heights, Central Harlem, and the South Bronx, New York originally to investigate the effects of ambient and indoor pollutants on birth outcomes and development (Whyatt *et al.*, 2003). Samples of cord blood (n=211) were collected near delivery and maternal blood (n=199) was collected within 2 days postpartum and analyzed at the CDC using solid phase extraction and gas chromatography – mass spectrometry (GC-MS) as described in Barr et al., 2002. Standards were originally prepared with donor sera obtained from the American Red Cross, however the samples contained detectable background pesticide residues, and could not be used (Barr *et al.*, 2002). The investigators instead used water for QC standards, which is a very different matrix then the study samples being analyzed. For

method validation, a standard curve was created from 0.25 – 400 pg/µl (ppb) and chlorpyrifos recovery was approximately 20% (Barr et al., 2002). Chlorpyrifos in maternal serum ranged from ND – 35 pg/g (mean = 4.8 ± 5.5 pg/g) and ND – 63 pg/g in cord plasma samples (mean = 4.7 ± 6.5 pg/g) with a method LOD of 0.5 – 1 pg/g (ppt) (Whyatt *et al.*, 2003). It is important to note several issues with the analytical results. First, the standard curve was developed in the low to mid pg/µl (ppb) range while the chlorpyrifos concentrations detected in the samples fell several orders of magnitude below the calibration curve, in the pg/g or ppt range. In addition, the method documented a minimal recovery of chlorpyrifos in samples of approximately 20% (Barr *et al.*, 2002). Therefore, the low detection frequency and imprecision likely underestimated the true chlorpyrifos concentrations in the samples. Barr and colleagues noted the imprecision can be attributed to such things as deterioration of pesticides in frozen serum, the instability of pesticides in the heated GC injection port, and/or instability due to the reactive nature of pesticides; the imprecision was approximately double that of studies that had higher detection limits (Barr *et al.*, 2002). During the April 2016 US EPA Scientific Advisory Panel, Dr. Barr noted that the method was developed primarily to optimize pyrethroids detection, not chlorpyrifos. While the method was not developed for chlorpyrifos, the CCCEH principal investigators used this methodology when samples were sent to CDC for analysis (US EPA/SAP 2016). As such, HHA has reduced confidence in the CCCEH analytical findings, which, if used, may result in correlating of adverse developmental effects to exposures that are underestimated.

II.K.9.b. Saint Peter's University Hospital, New Brunswick, NJ

The New Brunswick prospective cohort is described in the 2017 December Draft TAC Evaluation. Briefly, pregnant women scheduled for C-sections were recruited from Saint Peter's University Hospital from 2003 – 2004 in a study to investigate pesticide exposure in maternal and fetal biological matrices (Barr *et al.*, 2010). Maternal samples were taken pre-operatively and cord blood samples were collected within 15 minutes of delivery and analyzed for chlorpyrifos using a solid phased extraction GC-MS methodology detailed in Barr et al., 2002. Chlorpyrifos was detected in n=138 (98.6%) of maternal samples (mean = 0.09 ng/g ± 0.87) and n=148 (62.8%) of newborn samples (mean= 0.55 ng/g ± 0.73). Assuming that the same analytical method was used in the CCCEH study without improvement, the same weaknesses in sample analytical findings can be assumed.

II.K.9.c. Johns Hopkins Hospital, Baltimore MD

The Johns Hopkins Baltimore Tracking Health Related to Environmental Exposures (THREE) Study was a cross-sectional study of fetal exposure to pesticide mixtures in babies born between 2004 and 2005 (Neta *et al.*, 2010). A total of 341 cord blood serum samples were collected and nonpersistent pesticides were tested using the GC-MS method detailed in Barr et al., 2002. Of a total of 185 samples, only 5 samples (3%) tested above the LOD of 21pg/ml, with the range equaling <LOD – 14 pg/ml (Neta *et al.*, 2010). Because of the low number of samples in which chlorpyrifos was detected, those samples and chlorpyrifos were excluded from any further analysis. Note that while the authors state they are using the analytical method used published in Barr et al., 2002, the study LOD was higher than reported in the original methodology (21 pg/g).

II.K.9.d. Center for the Health Assessment of Mothers and Children of Salinas (CHAMACOS)

The CHAMACOS prospective cohort is described in the December 2017 Draft TAC Evaluation. Briefly, OPs were measured in maternal blood collected shortly before delivery and in cord

blood collected after delivery. Measurements were only made in those participants with sufficient blood volumes for the analysis at the CDC using the solid phase GC-MS method described in (Perez *et al.*, 2010). The LOQ reported herein was higher than that reported in CCCEH studies and the authors ascribe the difference to aging equipment and the inclusion of pyrethroids in the analysis which reduced the sensitivity to chlorpyrifos (Huen *et al.*, 2012). Even with the lower sensitivity (LOQ = 21 pg/ml), chlorpyrifos was detected in 70.5% of maternal samples and 87.5% of cord blood samples (Huen *et al.*, 2012). The detections ranged from ND – 1385 ng/ml for mothers and ND – 1726 ng/ml for newborns, however the two maximum values were considered outliers as they were more than 100-fold higher than the 95th percentile, and were removed from subsequent analysis (Huen *et al.*, 2012). The authors note that the median values detected in this study were below the LOQ for both maternal (0.006 pg/ml) and cord blood (0.004 pg/ml) samples (Huen *et al.*, 2012), thus decreasing their confidence in the values.

II.K.9.e. Bulacan, Philippines

As described above in Section II.K.8., pregnant women residing in the province of Bulacan, Philippines were enrolled at midgestation. Maternal blood was collected at midgestation and at birth and cord blood was collected at birth. Samples were analyzed using sold phase extraction techniques and GC-MS (Bielawski *et al.*, 2005; Corrion *et al.*, 2005). Calibration standards were prepared to encompass the entire calibration curve range, from 0.10 to 25 µg/ml. Internal QC standards were prepared using whole blood from subjects with no exposure from which 3 positive and 1 negative control were created for each of 3 concentrations. The mean chlorpyrifos recovery [[spiked control conc/expected conc]*100] was 137.5% with an LOD of < 0.10 µg/ml (ppm) (Bielawski *et al.*, 2005; Corrion *et al.*, 2005). The authors noted that the very high recovery for chlorpyrifos may have been due to errors in spiking volumes or evaporation that may have increased the concentration of the standards. No maternal blood samples collected at midgestation or at birth were positive for chlorpyrifos (Ostrea *et al.*, 2006) and no cord blood samples tested positive for chlorpyrifos (Ostrea *et al.*, 2009).

II.K.9.f. Zhejiang Province, China

As described above in Section II.K.8., investigators conducted a pilot study and a full-scale cohort of pregnant women who were enrolled during the 36th week of gestation from Fuyang Maternal and Children's Hospital in the Zhejiang Province of China. A 30 ml umbilical cord blood sample was collected which underwent solid phase extraction and isotope dilution GC-MS using fetal bovine serum as blanks and positive controls with a serial dilution of 0.01 – 50 µg/L. In the pilot study, chlorpyrifos was measured in 27 of 116 cord blood samples above the LOD (>0.05 ng/ml), with a maximum of 0.26 ng/ml (Wickerham *et al.*, 2012). In the full cohort, chlorpyrifos was detected in 136 samples cord blood samples, with a maximum of 11.40 ng/ml (LOD = 0.675 ng/ml) (Silver et al., 2015). Authors note that the 90th percentile chlorpyrifos concentration reported in the present study (3.85 ng/ml) was several orders of magnitude higher than the maximum concentrations reported in US studies (Silver *et al.*, 2015).

Table 5. Analytical Quantitation of Chlorpyrifos in Maternal or Cord Blood Samples

Study (reference)	No. samples	Samples > LOD or LOQ (%)	Median (Range)	LOD or LOQ	Notes on Methodology
CCCEH, New York (Whyatt et al., 2003)					
Maternal blood	199	148 (74%)	3.1 pg/ml (ND – 35 pg/ml)	0.5-1.1 g/ml	Method in Barr et al., 2002 CPF recovery 18-21% Standard curve = 21 – 400 pg/ul (ppb) Standards in water not plasma/serum
Cord blood	211	150 (71%)	2.6 pg/ml (ND – 63 pg/ml)		
Johns Hopkins THREE Study, Baltimore MD (Neta et al., 2010)					
Cord blood	185	3 (1.6%)	Median NR (< LOD – 14 pg/ml)	21 pg/ml	Method in Barr et al., 2002 The LOD reported is higher than originally validated in Barr et al., 2002
Saint Peter's University Hospital, New Brunswick, NJ (Barr et al., 2010)					
Maternal blood	140	138 (98.6%)	0.0007 ng/g (ND – 10.09 ng/g)	0.001 ng/g	Method in Barr et al., 2002
Cord blood	236	148 (62.8%)	0.0007 ng/g (ND – 1.84 ng/g)		
CHAMACOS Cohort, California (Huen et al., 2012)					
Maternal blood	234	42 (17.9%)	0.006 pg/ml (<LOQ – 400 pg/ml; 95th%-ile)	21 pg/ml	Method in Perez et al., 2010
Cord blood	256	29 (11.3%)	0.004 pg/ml (<LOQ – 1330 pg/ml; 95th%-ile)		
Zhejiang Province, China (Wickenham et al., 2012; Silver et al., 2015, 2017)					
Cord blood (pilot)	116	27 (23.3%)	NR (ND – 0.26 ng/ml)	0.05 ng/ml	Method modified from Perez et al., 2010
Cord blood (full cohort)	336	136 (40.5%)	NR (ND – 11.40 ng/ml)	0.675 ng/ml	
Bulacan, Philippines (Ostrea et al., 2006; 2009)					
Cord blood only	598	0 (0.0%)	0.0 µg/g	<0.10 µg/ml	Method in Corrion et al., 2005 and Bielawski et al., 2005

NR = not reported

II.M. Delayed Neuropathy and Neurodegenerative Effects of Chlorpyrifos

Delayed neuropathy and neurodegenerative effects were assessed further based on suggestions received during the January and March 2018 SRP hearings. The following new information outlines both specific human, in vivo animal and mechanistic studies that examined exposure to

OPs and associations with delayed neuropathy, Parkinson's Disease (PD), and Alzheimer's Disease (AD). Neurodegeneration in the form of organophosphate-induced delayed neuropathy (OPIDN), PD and AD have been reported after acute high-dose exposure to chlorpyrifos where significant brain AChE inhibition has occurred. In addition to AChE inhibition, high-dose chlorpyrifos appears to also result in misfolding of proteins, disruption of axonal transport, and mitochondrial dysfunction.

II.M.1. Human Studies of Delayed Neuropathy

II.M.1.a Human Case Reports of Delayed Neuropathy

Lotti et al. (1986b) evaluated a 42 yr old man who attempted suicide by ingesting approximately 300 mg/kg chlorpyrifos. After 3 weeks the cholinergic signs disappeared. On Day 30, RBC AChE, BuChE and lymphocyte neuropathy target esterase (NTE) were inhibited 50, 90 and 60%, respectively. On Day 40 he developed clinical signs consistent with organophosphate-induced delayed neuropathy (OPIDN). Other more recent cases of OPIDN have been reported in the open literature, all associated with acute high dose ingestion of chlorpyrifos from suicide attempts ((Nand *et al.*, 2007; Thivakaran *et al.*, 2012; Ostwal *et al.*, 2013; Mendes *et al.*, 2017; Yalbuzdag *et al.*, 2017).

II.M.1.b. Human Epidemiological Studies of Delayed Neuropathy

Ross and colleagues produced a fairly comprehensive meta-analysis of neurobehavioral problems in human adults following low level exposure in occupational settings (Ross *et al.*, 2013). In that systematic review, the authors pooled data from 14 studies and over 1600 participants and found significant associations between low level exposures to OPs and consistent (although at times, small in magnitude) changes in psychomotor speed, executive function, visual-spatial ability, and working memory (Ross *et al.*, 2013). The meta-analysis was not specific enough to detail if any of these effects were specifically related to chlorpyrifos exposure, although three of the base studies noted occupational exposure within their study populations to chlorpyrifos alone or in combination with other pesticides. Steenland et al., (2000) conducted a case-control study paring termite applicators who used chlorpyrifos with non-exposed maintenance workers and correctional officers. In comparison to the non-exposed controls, the chlorpyrifos-exposed cases did not differ significantly on the outcome of 40 subclinical tests, however, they did perform significantly worse on hand flexibility and body movements with closed eyes. The applicators also reported more qualitative symptoms including problems with memory, increased emotionality, increased fatigue, and loss of muscular strength. The outcomes were worse for those applicators who had reported an acute OP poisoning some time in their job history (Steenland *et al.*, 2000). In a more recent investigation of adolescent male pesticide applicators in the Menoufia Governorate, Egypt, researchers have assessed the potential for effects of low level cumulative chlorpyrifos exposure (Farahat *et al.*, 2011; Rohlman *et al.*, 2016; Callahan *et al.*, 2017; Ismail *et al.*, 2017a; Ismail *et al.*, 2017b). The investigators have considered the relationships between cholinesterase activity, neurobehavioral performance, and chlorpyrifos exposure across two application/growing seasons in groups of young male applicators and non-applicators and found that neurobehavioral deficits including motor function and speed were negatively impacted and cumulated over time and directly correlated with TCPy concentrations in urine as well as BuChE inhibition (Rohlman *et al.*, 2016;

Callahan *et al.*, 2017; Ismail *et al.*, 2017a; Ismail *et al.*, 2017b). While not a delayed neuropathic effect, it is important to note the potential for sustained effects after chlorpyrifos exposure has ceased.

II.M.2. Animal Studies of Delayed Neuropathy

Seven studies in hens were conducted to evaluate the risk for OPIDN (Table 6). Note that FIFRA guidelines require that the age of hens must be at least 8 months since younger hens are less sensitive. Hens are the animal model of choice since they are more sensitive. Positive controls usually tested at the same time using tri-ortho-cresyl phosphate (TOCP). Guidelines only require behavioral and histopathology examination of the brain, spinal cord and peripheral. Some of the non-guideline studies analyzed neuropathy target esterase (NTE) activity instead of performing histopathological examinations.

Lotti et al. (1986a) also measured in vitro the 50% inhibition concentration (I_{50}) values for chlorpyrifos oxon of AChE and NTE in hen brains, human brains, and human blood. The I_{50} values for AChE and NTE in hen brains were 0.006 and 0.15 µM, respectively. In human brains, the I_{50} values were 0.013 and 0.18 µM, for AChE and NTE, respectively. In human blood, the AChE and NTE I_{50} values were 0.007 and 0.11 µM, respectively. These I_{50} values indicate chlorpyrifos has less affinity for NTE than AChE, suggesting it is not neuropathic, but the observation of ataxia in the hens at 90 mg/kg indicate otherwise. Capodicasa et al. (1991) also calculated fixed time (20 min.) I_{50} values for CPF-oxon in hen and human brain homogenates at 6 and 13 nM for AChE, and at 150 and 180 nM for NTE, respectively. Richardson et al. (1993a) conducted kinetic experiments using two different approaches. The I_{50} for AChE and NTE calculated from their k_i were 2.24 and 239 nM, respectively. Using a fixed-time (20 min) pre-incubation method the I_{50}s were 2.16 and 206 nM, respectively. These I_{50} values were similar to those reported by Lotti et al. (1986b) and Capodicasa et al. (1991), with CPF-oxon being a more potent inhibitor of AChE than NTE suggesting that chlorpyrifos does not cause OPIDN. However, their study did not find any evidence of OPIDN. No evidence of OPIDN was seen in 2 subchronic studies in hens based on lack of ataxia and histopathological lesions in one study conducted by Barna-Loyd *et al.* (1986) and only transient staggering gait and low NTE inhibition (19%) in another study conducted by Richardson et al. (1993b).

Table 6. Hen Studies for Chlorpyrifos-Induced Delayed Neuropathy

No./dose age	Dosing Regimen	Antidotes	Findings	Ref.[a]
10/dose 17 months	Once, capsule 0, 50 or 100 mg/kg	Atropine prior to dosing	No evidence of OPIDN based on behavior and histopathology at 50 or 100 mg/kg, NTE not measured	1
No./dose NR age NR	Once, oral gavage 150 mg/kg	NR	Ataxia at Day 20, ↓NTE (>80%) on Days 4-5, no histopathology performed	2
5/dose age NR	Once, oral gavage 60, 90, 120 or 150 mg/kg (in glycerol)	Atropine and physostigmine before dosing, atropine & 2-PAM after	↓NTE (60%) at 60 mg/kg, ↓NTE (80%) and ataxia on Day 25 at 90 mg/kg, no histopathology performed	3
12/dose 18 months	Once, oral gavage 0, 75,150 or 300 mg/kg (in corn oil)	Atropine only as needed up to 54 hrs after	No evidence of OPIDN, ↓NTE (76%) on Day 4 at 300 mg/kg, no histopathology performed	4
5/dose 18 months	Once, oral gavage 150 mg/kg (in glycerol)	Atropine prior, atropine & 2-PAM after	Ataxia and gait disturbances by day 12; ↓AChE (88%) and ↓NTE (43%), ↓CI (69%) and ↓ATP (55%), no histopathology performed	5
10/dose 8-14 months	91 Days, oral gavage, corn oil, 0, 1, 5, or 10 mg/kg/day	None	No ataxia or histological evidence of OPIDN	6
15-18/dose, 18 months	20 days, oral gavage, corn oil, 0 or 10 mg/kg/day	None	Transient staggering gait, no histopathology performed, ↓brain AChE (58-70%); ↓NTE (~18%)	7

a. References: 1. Rowe et al. 1978; 2. Lotti et al. 1986a; 3. Capodicasa et al. 1991; 4. Richardson et al. 1993a; 5. Salama et al. 2014; 6. Barna-Lloyd et al. 1986;7. Richardson et al. 1993b.
Abbreviations: OPIDN = organophosphate-induced delayed neuropathy; NTE = neuropathy target esterase; 2-PAM = 2-pyridine aldoxime methyl chloride or pralidoxime; AChE = acetylcholinesterase; CI = Complex I; ATP = adenosine triphosphate.

Salama et al. (2014) suggested that the inhibition of Complex I rather than NTE was the cause of OPIDN based on their research. Complex I (also known as NADH dehydrogenase) is one of the enzymes in the respiratory chain in the mitochondria. In the brains of hens treated with chlorpyrifos at 150 mg/kg, NTE inhibition was only 45% while Complex I inhibition was approximately 70%. ATP levels around 55% below controls. Since the inhibition of Complex I was greater than the NTE inhibition, they proposed that the reduction in ATP levels was more likely due to Complex I inhibition than NTE inhibition. They pointed out that TOCP also caused a very strong inhibition of Complex I (~90%), although the NTE inhibition was greater (~95%).

II.M.3. Mechanistic Studies of Delayed Neuropathy

The first cases of OPIDN were with industrial OPs like TOCP that were not potent inhibitors of AChE, but were potent inhibitors of NTE. When Lotti et al. (1986b) reported a case of OPIDN in

man from ingestion of chlorpyrifos, OPIDN was thought to be related to inhibition of NTE whose function was not well understood. If an OP was a more potent inhibitor of NTE than AChE, it was considered potentially neuropathic. Even with these OPs, an NTE inhibition greater than 70% was thought to be necessary to produce OPIDN. At that time, the aging of the OP-inhibited NTE was considered essential for development of OPIDN. Aging involves the loss of the alkyl group of the phosphoryl residue attached to NTE leaving a negatively charged phosphorylated NTE. It was noted that neuropathic OPs reduced retrograde axonal transport and that NTE was located in the microsomes of neurons, so it was suggested that they may be important in axonal transport. Cytoskeleton proteins, such as microtubules, neurofilaments, and microfilaments, were also thought to be involved in the pathogenesis of OPIDN.

After several decades of research regarding the structure and function of NTE, it is now known that NTE is a serine hydrolase that is a member of the patatin-like phospholipase (PNPLA) subfamily and is sometimes referred to as PNPLA6 ((Richardson *et al.*, 2013). It resides in the membranes of the endoplasmic reticulum (ER) with the highest concentrations in neurons and lymphocytes. As a phospholipase, NTE is primarily responsible for hydrolyzing membrane-bound lysophospholipids, although it can also hydrolyze phospholipids. Lysophospholipids can disrupt membrane structure by acting as detergents (Wijeyesakere and Richardson, 2010). NTE is thought to maintain the lysophospholipids concentrations to 0.5-6% of the membrane by of weight. With NTE inhibition, there is a loss of homeostasis in the membrane resulting in lysophospholipid micelles which solubilize regions of the ER membrane. This can then lead to a loss of calcium homeostasis in the cell since the ER is the primary cellular store of calcium which can then lead to unregulated activation of calpains (calcium-dependent non-lysosomal cysteine proteases) resulting in the breakdown of the cytoskeleton and accumulation of calcium in the mitochondria. Increased calcium in the mitochondria can affect the permeability of mitochondria and eventually result in axonopathy through apoptosis. Another serine hydrolase referred to as phospholipase A2 (PLA2) is primarily responsible for hydrolyzing phospholipids to lysophospholipids. Since it is a serine hydrolase it can also be inhibited by OPs. Based on this new understanding of NTE's function it has been proposed that if the ratio of the I_{50}s for NTE to PLA2 is greater than one, it indicates that an OP is potentially neuropathic.

Some of the understanding of NTE's function was the result of research using *Nte*$^{-/-}$ and *Nte*$^{+/-}$ knockout mice (Winrow *et al.*, 2003). With these mice, these investigators determined that the *Nte* gene is highly expressed in the hippocampal neurons, the Purkinje cells of the cerebellum, the spinal cord, the Leydig cells of the testes and the developing lens. *Nte*$^{-/-}$ mice did not survive past embryonic day 8 indicating that NTE is critical for neurodevelopment. *Nte*$^{+/-}$ mice survived to birth with ~40% less NTE activity in their brain, but were hyperactive. The heterozygous knockout mice were also more sensitive to the potent NTE inhibitor, ethyl octylphosphono-fluoridate (EOPF), with higher mortality rates at 6 and 10 mg/kg. At 1 mg/kg of EOPF, wild type mice exhibited hyperactivity similar to that observed in the heterozygous knockout mice without EOPF. Based on this finding, the investigators concluded from this that aging of NTE was not critical in the development of OPIDN, but it is simply due to the sustained loss of NTE activity.

Additional research with conditional knockout mice (NTE-cKO) further elucidated the role of NTE in the nervous system (Akassoglou *et al.*, 2004). In NTE-cKO mice the NTE deletion does not occur until after embryonic day 11 so that these mice survive to birth. In these NTE-cKO mice, swelling of the neuronal cytoplasm, disruption and loss of the ER membranes, abnormal

reticular aggregates and vacuolation, were observed primarily in the large neurons of the hippocampus, thalamus and cerebellum. The lesions seen in the NTE-cKO mice were qualitatively similar to those seen in adult OP-dosed mice (Read *et al.*, 2009). In this study the investigators noted that the distal degeneration of the long spinal axons of the medulla oblongata preceded the swelling of neuronal bodies. They found that the phospholipid, phosphatidyl-choline (PtdCho), was elevated in the brains of both NTE-cKO mice and OP-dosed mice, although the increase in OP-dosed mice was transient. The axonal damage seen in the OP-dosed mice was limited to the longest spinal axons while the NTE-cKO mice had larger areas of axonal damage suggesting a linkage between the phospholipid homeostasis and axonal damage. The investigators concluded that the similar neuropathic lesions in the OP-dosed mice and the NTE-cKO mice suggest these lesions result from disruption of mature axons rather than abnormal neural development.

Other evidence supporting the role of NTE in the axonopathy associated with OPIDN comes from the identification of several NTE gene mutations associated with various forms of motor neuron disease (MND). Rainer et al. (2008) performed a DNA analysis on a consanguineous family of 10 subjects (3 affected) with Ashkenazi Jewish ancestry and a nonconsanguineous family of 5 subjects (2 affected) of northern European ancestry which exhibited progressive spastic paraplegia and distal muscle wasting which resembled OPIDN. Several mutations in the *Nte* gene were found. In the consanguineous family the affected individuals were homozygous for the NTE mutation c.3034A→G in NTE's catalytic domain. The two affected subjects in the nonconsanguineous family were heterozygotes for two mutations in NTE's catalytic region; one mutation (c.2669G→A) in NTE's catalytic domain and another involving an insertion (c.2946_2947insCAGC) causing frameshift and protein truncation (p.S982fs1019). Amyotrophic lateral sclerosis (ALS) is considered one form of MND. Ticozzi et al. (2010) sequenced the *PON* genes (*PON1, PON2 and PON3*) in subjects with either familial ALS (FALS) or sporadic ALS (SALS). From eight FALS and three SALS cases they found at least seven mutations in PON genes that were not in the controls. The incidence of *PON* gene mutations in the FALS subjects was about 2.5% after adjusting for cases with *SOD1*, *TARDBP* and *FUS* mutations. Based on the low incidence of these *PON* mutations among FALS cases, the authors concluded they were not the main cause of FALS, but they proposed that the loss of anti-oxidative capacity of the paraoxonases contributes to the development of ALS.

There are some investigators who think the mitochondrial dysfunction associated with OPIDN is independent of NTE inhibition. Masscotte et al. (2005) evaluated the activity of Complex I-IV in the human neuroblastoma cell line (SH-SY5Y) and in primary dorsal root ganglia (DRG) with exposure to phenyl saligenin phosphate (PSP) and mipafox (which are neuropathic OPs), paraoxon (which is a non-neuropathic OP) and phenylmethyl sulfonyl fluoride (PMSF) (which is a non-neuropathic NTE inhibitor). They did not test chlorpyrifos. They found that PSP and paraoxon were the most effective in inhibiting Complex I and IV in SH-SY5Y cells, although the inhibition was greater with PSP. PMSF only inhibited these enzymes at the highest concentration tested and mipafox didn't inhibit either even at the highest concentration. When rotenone (Complex I inhibitor) or sodium azide (Complex IV inhibitor) were added in addition to the OPs, no further inhibition was seen. Only PSP significantly inhibited Complex II and III activities. In DRG cells, only PSP and mipafox significantly reduced Complex I, III and IV. These investigators suggested that the ability of PSP to inhibit ATP production is unrelated to NTE

inhibition because PMSF at 1 μM should have caused greater than 90% inhibition of NTE (not measured) and yet was only a weak inhibitor of Complex 1 and IV. Masoud et al. (2009) reported reduction in mitochondrial respiratory enzyme activities, Complex I (20-55%), Complex II (30-45%) and Complex IV (15-40%) in rats after being administered the neuropathic OPs, monocrotophos (20 mg/kg oral) or dichlorvos (200 mg/kg s.c.). They also reported increased lipid peroxidation based on malondialdehyde (MDA) levels (10-20%) and decreased reduced glutathione levels (10-50%) in various brain regions. They proposed that oxidative stress lead to the inhibition of these mitochondrial respiratory enzymes.

II.M.4. Parkinson's Disease

Parkinsonism-like symptoms have been occasionally observed after acute OP poisoning. These symptoms occur at approximately the same time as the more common intermediate syndrome (IMS). The intermediate syndrome (IMS) was first reported following acute organophosphate (OP) poisoning in Sri Lanka (Karalliedde *et al.*, 2006). This syndrome occurs in only about 20% of acute OP poisonings. IMS differs from the cholinergic crisis in that muscarinic symptoms are not observed. IMS differs from OPIDN not only in terms of onset (earlier), but the paralysis associated with it is proximal while with OPIDN the paralysis is distal affecting the long axons, although there is some CNS involvement. The parkinsonism-like symptoms referred to as the extrapyramidal syndrome (EPS) has an onset about the same time as IMS are (Hsieh *et al.*, 2001; Detweiler, 2014; Panda *et al.*, 2014). The symptoms of IMS can be distinguished from EPS in that the symptoms from IMS are thought to be due to excess acetylcholine (ACh) at the nicotinic receptors and include paralysis of respiratory, neck, proximal limb muscle and cranial nerves. By contrast EPS is thought to be due to imbalance between cholinergic and dopaminergic neurons in basal ganglia and substantia nigra. The basal ganglia is more vulnerable to xenobiotics, metabolic abnormalities as well as to vascular insult because it is rich in mitochondria, vascular supply, neurotransmitters and chemical content compared with other areas of the brain. Hsieh *et al.* (2001) proposed there is a critical level of AChE in the basal ganglia that is necessary to regulate the dopaminergic system and this level may be lower than necessary for hydrolyzing acetylcholine. This may explain why some cases of EPS occurred in absence of cholinergic signs, although it is not clear if it occurred in absence of AChE inhibition. Both syndromes are considered transient syndromes, but there a couple reports of irreversible Parkinsonism after the acute OP poisoning (Goel *et al.*, 2006; Kwon and Kim, 2014).

There have been a couple reviews of the numerous epidemiology studies evaluating the association of Parkinson's disease (PD) with pesticide exposure. Brown et al. (2006) reviewed 38 case-controls epidemiological studies (13 in the United States, 11 in Europe, 5 in Asia, 2 in Australia, one in South America and another in Nigeria) and found 12 with significant positive associations in many studies with odds ratios (ORs) ranging from 1.6-7.0. They noted associations were strongest for exposure to herbicides and insecticides and with long durations of exposure to pesticides. They also noted that the toxicological evidence was strongest for rotenone and paraquat specifically. Freire and Koifman (2012) reviewed various types of epidemiological studies evaluating pesticide exposure and PD. This included one cross-sectional study, 8 prospective studies, and 38 case-control studies. The cross-section study found an OR of 3.7 (95% CI 1.6 – 8.6) among Italian men with pesticide use licenses compared to those without a license. Among the 8 prospective studies, most reported positive associations with occupational exposure to pesticides with risk estimates greater than 2, except one recent study with Swedish

male twins which found no association. Of the 38 case-control studies, 23 only examined overall exposure to pesticides and PD risk. Thirteen of these 23 studies found significant ORs between 1.1 and 2.4. They noted that when specific pesticides were examined, insecticides were the most widely studied. Among insecticide groups, positive associations were found with organophosphates, organochlorines, arsenic and rotenone. Among herbicides, positive associations were found primarily with paraquat.

Chuang et al. (2017) examined the association of PD with OP or carbamate (CM) poisoning in a retrospective study involving a cohort of 45,594 patients (9,128 patients with a history of OP or CM poisoning and 36,466 control patients) that were part of the Taiwan National Health Insurance Research Database. The incidence rate ratio (IRR) for PD in OP or CM poisoned patients was 1.36 (95% CI 1.26 – 1.47). The incidence of PD in patients over 75 years old was 77.4% in patients with OP or CM poisoning, but only 43.7% in control patients. The age-specific relative risk was highest in those less than 50 years old (adjusted IRR = 3.88, 95% CI 3.44 – 4.39). They did not look at PD risk with poisoning by specific OPs or CMs or even separate risk analysis for OPs and CMs.

II.M.4.a. Human Epidemiological Studies of Parkinson's Disease

The Parkinson's Environment and Gene (PEG) project conducted a number of population based case-control studies in three rural central California counties (Kern Tulare and Fresno) in which they estimated ambient residential and workplace pesticide exposure using the DPR California Pesticide Use Reporting (PUR) data from 1974 to 1999 and GIS-based modeling. Use of PUR data and home and work addresses to estimate pesticide exposure avoids some of problems other case-control studies have due with recall bias and exposure misclassification from broad ever/never exposure categories. However, it should be noted that the PUR database before 1990 is not very accurate since full use reporting was not required at that time (http://www.cdpr.ca.gov/docs/pur/purmain.htm).

In one PEG study conducted by Gatto et al. (2009), PUR data was used to estimate well water pesticide exposure assuming that if that pesticide was applied nearby and was a potential groundwater contaminant and well water was their primary source of drinking water, then there was exposure to these pesticides in well-water (Table 7). Six pesticides that were water soluble were considered separately, including chlorpyrifos, diazinon, propargite, paraquat, dimethoate and methomyl. They considered people who did not use well water as their primary source of drinking water had ambient only exposure. Consequently, all exposures were theoretical since there was no environmental monitoring of well-water or air. It also does not appear that they factored in possible occupational exposure or household use of pesticides. This study included 368 PD cases and 341 controls that were mostly male (cases = 56.2%, controls = 51.6%) and predominately white (cases = 85.3, controls = 85.6%). The adjusted odds ratio (OR) for chlorpyrifos was 1.87 in the high exposure group (95% CI 1.05 – 3.31). The authors also note that well water could also be contaminated with multiple agricultural and industrial chemicals as well as metals.

In another PEG study, the authors looked at the incidence of PD among different genotypes of PON1 (Manthripragada *et al.*, 2010). The PD cases (351) were mostly male (57.4%) and predominately white (80.4%) compared to controls (363) which had fewer males (46%) and

whites (69.9%).Among the PD cases the frequency of this *PON1*$_{55MM}$ genotype (slow metabolizers) was 14% while in controls it was only 10%. Without considering pesticide exposure, a higher OR was found among *PON1*$_{55MM}$ genotypes (adjusted OR = 1.45; 95% CI 0.87 – 2.40). When considering high chlorpyrifos residential exposure, the OR increased to 1.56 (95% CI 1.02 – 2.40) and when combining subjects with both high and low residential chlorpyrifos exposure, the resulting OR increased to 2.61 (95% CI 1.25 – 5.44).

As an extension of the previous PEG study, these investigators considered additional sources of ambient exposure and examined two additional variants, *PON1*$_{Q192R}$ and *PON1*$_{C\text{-}108T}$, which were also slow metabolizers (Lee *et al.*, 2013). Subjects included 287 PD cases and 440 controls. Subjects were all Caucasian and with a slightly greater portion being male among cases (56.1%) compared to controls (49.3%). The prevalence of the slow metabolizer variants (*PON1*$_{55MM}$, *PON1*$_{192QQ}$ or the *PON1*$_{108AA}$) was slightly higher in the cases at 14.6%, 51.3% and 26.4%, respectively, compared to controls at 11.1%, 45.3% and 24.8%. They focused specifically on 3 OPs, including chlorpyrifos. They did not find any association of PD risk between the *PON1*$_{C\text{-}108T}$ variants regardless of OP exposure; however, they did find a higher PD risk with the *PON1*$_{55MM}$ and *PON1*$_{192QQ}$ variants based on their OP exposure. The adjusted OR was clearly significant for chlorpyrifos exposure and *PON1*$_{55MM}$ (2.45, 95% CI 1.24 – 4.83). The adjusted OR for *PON1*$_{192QQ}$ and chlorpyrifos exposure was lower, but still significant (1.95, 95% CI 1.13 – 3.37).

In another PEG study conducted by Narayan et al. (2013), exposure to household pesticide and risk for PD was examined. As with previous PEG studies, PD cases (357) were more likely to be male and white (57.4% males and 80.5% white) with fewer white males among controls (807; 46.0% males and 69.9% white). Exposure was based on self-reported use of home and garden pesticide products along with DPR's product label database. Exposure was classified as either none or rare or frequent. Subjects were genotyped for *PON1*$_{L55M}$ and *PON1*$_{Q192R}$. The prevalence of the variants for these genotypes was not reported. The association between frequent pesticide use was significant (adjusted OR =1.47, 95% CI1.13 – 1.92), but even greater for frequent OP use (adjusted OR = 1.71, 95% IC = 1.21 – 2.41). When association with chlorpyrifos exposure was examined, the adjusted OR was 2.73 (95% CI 1.03 – 7.24), possibly due to the small number of cases and controls (9/9). When *PON1*$_{192QQ}$ genotype was considered, the adjusted OR for frequent use of OPs was 2.51 (95% CI 1.28 – 4.94) and for frequent organothiophosphate use the OR was 3.71 (95% CI 1.42 – 9.68). Since exposure for this study was assessed retrospectively, recall bias could have contributed to findings.

Table 7. Summary of Parkinson's Environment and Gene (PEG) Epidemiology Studies Examining Chlorpyrifos Exposure

Study	Pesticide/Exposure	Cases/ Controls	Adjusted Odds Ratio (95% CI)
(Gatto *et al.*, 2009) Residential cumulative ambient exposure	Chlorpyrifos Unexposed Ambient only Ambient + well water - all Low High	 186/210 115/90 67/41 25/21 42/20	 1.00 (reference) 1.42 (1.00-2.01) 1.63 (1.04-2.57) 1.05 (0.56-1.96) 1.87 (1.05-3.31)
(Manthripragada *et al.*, 2010) Residential average ambient exposure	*PON1-55* variants and PD LL LM MM	 159/180 144/148 48/35	 1.00 (reference) 1.04 (0.75-1.44) 1.45 (0.87-2.40)
	Chlorpyrifos – Residential ambient Low High	 93/74 88/74	 1.56 (1.06-2.31) 1.56 (1.02-2.40)
	Chlorpyrifos – Low/High Exposure *PON1-55* LL + LM *PON1-55* MM	 154/135 27/13	 1.48 (1.04-2.12) 2.61 (1.25-5.44)
(Lee *et al.*, 2013) Cumulative ambient residential and workplace exposure	Chlorpyrifos – Low/High Exposure *PON1-55* LL + LM *PON1-55* MM *PON1-192* RR+QR variants *PON1-192* QQ variants	 134/188 26/21 73/100 83/82	 139 (0.91-2.12) 2.45 (1.24-4.83) 1.48 (0.86-2.56) 1.95 (1.13-3.37)
(Narayan *et al.*, 2013) Self-reported household use for 4 age periods (16-24 yrs, 25-44 yrs, 45-64 yrs and ≥ 65 yrs)	Household Use of Pesticides Any – frequent OPs – frequent Chlorpyrifos – frequent	 161/303 83/121 9/9	 1.47 (1.13-1.92) 1.71 (1.21-2.41) 2.73 (1.03-7.24)
	Organophosphates – frequent PON1-192 QQ variants Organothiophosphates - frequent PON1-192 QQ variants	 28/19 16/7	 2.51 (1.28-4.94) 3.71 (1.42-9.68)
(Wang *et al.*, 2014) Ambient residential and workplace exposure	Chlorpyrifos Ambient residential Ambient workplace Ambient residential and workplace Mitochondrial disruptor OPs Ambient residential Ambient workplace Ambient residential and workplace	 46/88 31/57 39/64 69/138 53/84 110/168	 1.69 (1.06-2.69 1.94 (1.12-3.34) 1.92 (1.15-3.18) 1.7 (1.13-2.58) 2.22 (1.41-3.51) 2.23 (1.52-3.27)

Wang et al. (2014) evaluated in the associated of PD with ambient workplace and residential exposure in another population-based case-control PEG study which involved 357 cases and 752

controls. A positive association was found for PD and ambient residential exposure to chlorpyrifos (adjusted OR = 1.69; 95% CI 1.06 – 2.69). The association was stronger for PD and ambient workplace exposure to chlorpyrifos (1.94, 95% CI 1.12 – 34). They also grouped together OPs based on their mechanism of toxicity to see if there were any associations based on that. For OPs that caused mitochondrial disruption, which included chlorpyrifos, significant positive associations with PD were found with either residential or workplace exposure, but particularly with combined residential and workplace exposure (2.23, 95% CI 1.52 – 3.27). However, the strongest association with PD was with OPs that were carcinogenic (which did not include chlorpyrifos), especially with combined residential and workplace exposure (3.21, 95% CI 1.75 – 5.91).

There are a couple other case-control studies that were conducted outside California that examined the association of PD with exposure to chlorpyrifos along with other pesticides. In one case-control study involving pesticide applicators and their spouses from Iowa and North Carolina who participated in the Agricultural Health Study found positive associations with incident (i.e., sporadic) PD and personal application of pesticides, but none of the adjusted ORs were significant, except when cumulative days of use were greater than 397 days over a lifetime (Kamel *et al.*, 2006). When individual pesticides were examined, the adjusted OR for chlorpyrifos was clearly not significant (0.9, 95% CI 0.5 – 1.6). A case-control study in Texas found positive associations of PD with pesticide exposure, but only the exposure to rotenone was clearly significant (10.0, 95% CI 2.5 – 48.0) (Dhillon *et al.*, 2008). Exposure to chlorpyrifos was positively associated with PD (adjusted OR= 2.0; 95% CI 1.02 – 3.80). They also found positive associations of PD with industrial chemicals, but none of these were significant based on their 95% CI.

In a case-only study of pesticide handlers in Washington State (Nielson *et al.*, 2015), the levels of plasma α-synuclein were measured. α-Synuclein is a protein that aggregates in Lewy bodies which are considered a pathological hallmark of PD. They also measured blood ChEI and BuChE-CPF adducts as biomarkers of exposure and they found no association of BuChE-CPF adducts, blood ChEI or self-reported chlorpyrifos exposure with increased α-synuclein levels. They also looked at the association of plasma α-synuclein levels and the polymorphism of two PON1 genotypes, $PON1_{Q192R}$ and $PON1_{C\text{-}108T}$. They did find higher α-synuclein levels with the $PON1_{108T}$ allele and with more than 10 hrs exposure to a ChEI insecticide in the past 30 days, but neither had a clear dose response.

II.M.4.b. Animal Studies of Parkinson's Disease

As previously discussed in Section II.I, Behavior and Developmental Neurotoxicity in the December 2017 Draft TAC Evaluation, researchers observed significant reductions in the DA levels in the hippocampus, but not in the striatum of rat pups given chlorpyrifos in dimethyl sulfoxide (DMSO) during GD 17-20 at 1 and 5 mg/kg/day which are near the threshold for AChE inhibition (Aldridge *et al.*, 2005). The DA turnover was increased in the cerebral cortex, striatum and midbrain of the pups at 5 mg/kg, but not 1 mg/kg. The changes in DA levels and turnover were minor in pups exposed to these same doses on PND 1-4 (decreases in cerebral cortex, increases in striatum and midbrain) and no effects in DA levels were seen in pups exposed PND 11-14 at these doses, indicating a window of vulnerability closed in the second postnatal week. The investigators suggested that the differential sensitivity of the hippocampus

compared to the striatum indicate that oxidative stress was not a contributing factor in this dopaminergic developmental neurotoxicity since the striatum has a high concentration of DA which is considered an oxidative neurotransmitter. The studies are summarized in Table 8, below.

Table 8. Studies Evaluating Effects Related to Parkinson's Disease in Animals Exposed to Chlorpyrifos

Species, Sex, Age	Exposure Route & Duration	Effect	LOEL mg/kg/day	Ref.[a]
Rat, Pups GD 17-20	CPF s.c. daily in DMSO 1 or 5 mg/kg/day	↑ DA level in hippocampus	1	1
		↑ DA turnover	5	
PND 1-4	1 mg/kg/day	Minor ↑ DA level & turnover	1	
PND 11-14	5 mg/kg/day	No effect on DA level	--	
Rat, Pups PND1-21	CPF gavage in corn oil 0 or 1.5 mkd PND 1-7 → 3 mkd PND 8-14 → 6 mkd PND 15-21	PND 22: Change in ratio of nAChR subunits expression	1.5>6	2
		PND 50: ↑DOPAC and DA turnover, no effect on nAChR subunit expression		
Rat, pups PND 11-14	CPF s.c. daily in DMSO 0 or 5 mg/kg/day	↓ Dopaminergic neurons & ↑ neuroinflammation in substantia nigra	5	3
Mice, pups GD0–8 mos	CPF in diet, 0, 0.1, 1, or 10 mg/kg/day	↓ Brain AChE (30%), ↓ dopaminergic gene expression	10	4
		↑ gene expression of *UBC* and *Casp9*	0.1	
Rats, M Adults Age NR	CPF s.c. in olive oil 0 or 250 mg/kg	Day 2: ↑ DA turnover in striatum Day 7 & 15: ↓ 5-HT turnover in striatum Day 30: ↓ DA, 5-HT, NE & metabolites in nucleus accumbens	250	5
Mice, M 7-9 mos	CPF gavage in corn oil, 3X in 2 weeks, 75 mg/kg	No effect on gene expression of α-synuclein, DT or TH	75	6
Rats, M 11 wks	CPF s.c. in peanut oil, daily for 21 days, 3 or 10 mg/kg/day	↓Brain AChE (87%), ↑ expression of *Nptx2* in hippocampus	10	7
		↓ Brain AChE (42%), no effect on PD related gene expression	3	
Mice, M, 7-8 mos	CPF s.c in corn oil, 3X in 2 weeks 0, 25, 50 & 100 mg/kg	↓ activity in FOB, ↓ DA uptake, ↑ DOPAC, ↓ MTT activity	100	8
Mice, M 7-9 mos	CPF s.c. in corn oil, pretreated with MPTP 0 or 50 mg/kg	No additional ↓ TH or ↑ GFAP with CPF	--	9
Mice, M 10-12 wks	CPF s.c. in saline, 3X in 2 weeks, 0 or 80 mg/kg	Hind limb paralysis, neuro-degeneration & protein deposits in substantia nigra, ↑ biomarkers for oxidative stress in plasma & brain	80	10

a References: 1. (Aldridge *et al.*, 2005); 2. (Eells and Brown, 2009); 3. (Zhang *et al.*, 2015); 4. (Pallotta *et al.*, 2017); 5. (Moreno *et al.*, 2008); 6. (Kou *et al.*, 2006); 7. (Lee *et al.*, 2016); 8. (Karen *et al.*, 2001); 9.(Dodd and Klein, 2009); 10. (Devici and Karapehlivan, 2018).

Abbreviations: CPF = chlorpyrifos; s.c. = subcutaneous injection; DMSO = dimethyl sulfoxide; DA = dopamine; mkd = mg/kg/day; PND = postnatal day; DOPAC = 3,4 dihydroxyphenylacetic acid; nAChR = nicotine acetylcholine receptor; AChE = acetyl-cholinesterase; 5-HT = serotonin; NE = norepinephrine; DT = dopamine transporter; TH = tyrosine hydrolase; PD = Parkinson's disease; FOB = functional observational battery; MTT = 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide; GFAP = glial fibrillary acidic protein.

Eells and Brown (2009) also examined the effects of chlorpyrifos given s.c. in corn oil to newborn rat pups at increasing doses from 1.5 mg/kg/day on PND 1-7, 3 mg/kg/day on PND 8-15 and 6 mg/kg/day on PND 16-21. On PND 22, the levels of DA and it's metabolites, 3,4 dihydroxyphenylacetic acid (DOPAC) and homovanillic acid (HVA) in the striatum, were not significantly different from the vehicle controls nor was the DA turnover (DOPAC/DA or HVA/DA) affected. However, on Day 50 DOPAC levels were elevated as well as the DA turnover. The also examined the dopamine transcription factors, *Nurr1* and *Lamx1b,* and the expression of genes involved in dopamine neurotransmission, including tyrosine hydrolase (TH), GTP cyclohydrolase, dopamine transporter (DT), vesicular monoamine transporter 2, and the nicotine acetylcholine receptor (nAChR) subunits, α6 and α7. TH is involved in DA synthesis and DT is involved in the uptake of DA into neurons. On Day 22, only the ratio of the nAChR subunits was altered (↓α7/α6). On Day 50, there was no difference in the ratio of these nAChR subunits or any other gene expression related dopamine neurotransmission.

Others have reported changes in the dopaminergic system in developing rats and mice at low doses. There was a significant reduction in dopaminergic neurons in rat pups receiving chlorpyrifos in DMSO s.c. at 5 mg/kg/day from PND 11 to PND 14 when examined on PND 30 and PND 60 ((Zhang *et al.*, 2015). Furthermore, there was increased immunostaining for cluster of differentiation protein 11b (CD11b) and glial fibrillary acidic protein (GFAP) in the substantia nigra indicating activation of microglia cells and astrocytes, respectively, indicating there was neuroinflammation. Specifically, there was an upregulation of the nuclear factor kappa B (NF-κB) p65 and p38 mitogen-activated protein kinase (MAPK) inflammatory signaling pathways. Pallotta et al. (2017) also found that long-term exposure in mice pups to chlorpyrifos in the diet during gestation through 8 months of age affected the expression of genes related to the onset of PD. No significant brain cholinesterase inhibition was seen at 0.1 and 1.0 mg/kg/day. Brain AChE inhibition was 80% at 10 mg/kg/day at 3 months and 30% at 8 months. At 3 months, down regulation of 4, 48 and 66 genes were seen at 0.1, 1 and 10 mg/kg/day, respectively. Of the four genes down-regulated at all doses, two were related to dopaminergic signaling(*Park2* and *Nr4a2*), one related to GABAergic signaling (*Gabbr2*), and one related to transmembrane transport activity (*Sv2b*). At 8 months of age, 2, 14 and 16 genes still had altered expression at 0.1, 1.0 and 10 mg/kg/day, respectively. Among the genes that had altered expression, more were upregulated than down regulated. Some genes related to the dopaminergic system were still downregulated at 10 mg/kg/day at 8 months, including *Park2*, *Atxn2*, and *DRD2*. The two genes that were altered (upregulated) at all three dose levels were *UBC* which is involved in maintaining ubiquitin levels under stress conditions and *Casp9* which is involved in apoptosis. Upregulation of UBC transcripts has been found in cerebrospinal fluid of PD patients.

Changes in DA levels and DA turnover have also been observed in adult animals exposed to chlorpyrifos. Moreno et al. (2008) administered a single dose of chlorpyrifos s.c. in olive oil to adult male rats (age not reported) at 250 mg/kg and then analyzed brain AChE levels as well as the levels of various monoamines, including, DA, serotonin (5-HT), norepinephrine (NE) and their metabolites DOPAC, HVA and 5-hydroxy-3-indolacetic acid (5-HIAA) in the striatum and the nucleus accumbens on Days 2, 7, 15 and 30 after dosing. The nucleus accumbens is a brain region involved in motivational function. Brain AChE was inhibited from 68% (Day 2) to 82% (Day 15) in the striatum and from 53% (Day 2) to 82% (Day 15) in the nucleus accumbens. No difference in DA, DOPA and HVA were seen in the striatum at any time. However, the DA turnover (i.e., DOPAC/DA and HVA/DA ratios) in the striatum was significantly increased on

Day 2. The 5-HT levels were also not affected in the striatum, but the 5-HT turnover (i.e., 5-HIAA/5-HT) was significantly reduced on Days 7 and 15. All of monoamine levels were significantly reduced in the nucleus accumbens on Day 30 including their metabolites, but only the HVA/DA ratio was significantly different.

In addition, changes in gene expression related to the dopaminergic system have been reported in adult animals. Kou et al. (2006) reported that there was no effect on the gene expression for α-synuclein, DT, and TH in the striatum of adult mice given chlorpyrifos in corn oil at 75 mg/kg by oral gavage. Usually the expression of both TH and DAT are reduced with PD. However, Lee *et al.* (2016) reported an increase in the gene expression of *Nptx2* in the hippocampus of adult rats when injected s.c. with chlorpyrifos in peanut oil at 3 or 10 mg/kg/day for 21 days. *Nptx2* encodes the neuropeptide, NPTX2, which is involved in long-term plasticity and response to a novel environment. Changes in its expression have been associated with PD. The expression of this gene was not affected at 3 mg/kg/day. Brain AChE activity was reduced to 58% and13% of controls at 3 and 10 mg/kg/day, respectively. Five other genes involved with receptor-mediated cell survival signaling pathways that have been associated with neurocognitive disorders were also increased at 10 mg/kg/day. These included *Bdnf* (Alzheimer's disease, Huntington disease, epilepsy, addiction), *Cort* (sleep disorders, reduced locomotor activity), *Crhbp* (reduced anxiety and bipolar disorder), *Npy* (addiction, compulsion behavior, anxiety) and *Pnoc* (anxiety and increased pain sensitivity).

Karen et al. (2001) reported effects on striatal dopaminergic pathways in adult male mice injected s.c. three times with chlorpyrifos in corn oil at 0, 25, 50 or 100 mg/kg/day over two weeks. Significant reductions in open field movement and rearing activity were seen in the mice receiving chlorpyrifos that were significant at 100 mg/kg. Reductions in these behaviors were also seen at 50 mg/kg, but the differences were not significant. There was no apparent effect on neurobehavior at 25 mg/kg. Dopamine (DA) uptake was only affected in mice receiving chlorpyrifos at 100 mg/kg. The ability to reduce the dye, 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide (MTT), which is a measure of mitochondrial metabolic capability, was significantly reduced in the striatal only at 100 mg/kg. The dopamine metabolite, DOPAC, was only significantly increased in mice receiving chlorpyrifos at 100 mg/kg, but not at lower doses.

Dodd and Klein (2009) evaluated the effects of chlorpyrifos (50 mg/kg s.c in corn oil) in mice previously treated with, MPTP (1-methyl-4-phenyl-1,2,3,6-tetrahydropyridine, 30 mg/kg i.p.) to determine if it increased the nigrostriatal damage induced by MPTP. They measured TH activity and the glial fibrillary acidic protein (GFAP) levels which is a biomarker of nervous system damage due to reactive gliosis (O'Callaghan and Sriram, 2005). Mice given MPTP only had reduced TH activity and increased GFAP levels. Mice given chlorpyrifos after pre-treatment with MPTP had no additional changes in TH activity or GFAP levels.

Devici and Karapehlivan (2018) claimed to have created a chlorpyrifos-induced Parkinson's model in mice by injecting them with chlorpyrifos in saline s.c. 3 times in 2 weeks at 80 mg/kg. They reported movement difficulties in the 1st week, walking difficulties in the 2nd week and hind limb paralysis and difficulties reaching food and water in the 3rd week. Histopathological examination of the substantia nigra (no other neuronal tissue examined) revealed neurodegeneration and deposits they described as Lewy bodies. However, they did not perform

immunochemical staining of the slides for α-synuclein to confirm that these deposits were Lewy bodies. These investigators did evaluate oxidative stress based on the total oxidant capacity (TOC), total antioxidant capacity (TAC), PON1 activity, lipid profile and total sialic acid (TSA) in plasma and brain. In the chlorpyrifos treated mice, TOC, LDL and TSA levels were elevated while the TAC, PON1, HDL levels were reduced compared to controls.

II.M.4.c. Mechanistic Studies of Parkinson's Disease

Apoptosis: Caughlan et al. (2004) reported that they induced apoptosis in rat cortical neurons with both chlorpyrifos and CPF-oxon. The mitochondrial dysfunction (based on reduced MTT activity) occurred at lower chlorpyrifos doses than apoptosis occurred suggesting that mitochondrial dysfunction precedes the apoptosis. CPF-oxon was only slightly more potent than chlorpyrifos indicating the apoptosis is unrelated to AChE inhibition. They also found embryonic (E17) neurons were more susceptible to chlorpyrifos, than postnatal (P0) neurons, but not CPF-oxon. They also observed that chlorpyrifos activated ERK1/2 and p38 MAP kinases and a sub-pool of c-Jun NH_2-terminal protein kinase (JNK). Blocking of these activations by various inhibitors suggests the ERK1/2 and JNK are acting as pro-apoptotic pathways, while p38 MAP kinase is acting as a compensatory survival mechanism to counteract chlorpyrifos neurotoxicity.

Oxidative Stress: Qiao et al. (2005) evaluated the potential of chlorpyrifos to cause oxidative stress in PC12 and SH-SY5Y cells. PC12 cells are rat pheochromocytoma cells that are immature neuronal precursor cells that can be induced to differentiate with nerve growth factor (NGF), developing axonal projections, electrical excitability, and increase the number of nicotinic AChE receptors (nAChRs). SH-SY5Y cells are human neuroblastoma cells which are also neuronal precursors that can be induced to differentiate with NGF. Chlorpyrifos at 30 to 100 μM caused a significant increase in thiobarbituric acid reactive species (TBARS) in undifferentiated cells. Initiation of differentiation by NGF did not increase TBARS with chlorpyrifos. Chlorpyrifos at these concentrations also caused a dose-dependent antimitotic effect on cells that was similar between undifferentiated and differentiating cells. Nicotine inhibited these antimitotic effects of chlorpyrifos when given at the same time. AChE inhibition was not measured in these cells, but Middlemore-Risher *et al.* (2011) observed AChE inhibition in rat primary cortical neurons at chlorpyrifos concentrations greater than 5 μM. Bagchi et al. (1995) reported an increase in leakage of lactate dehydrogenase (LDH) from PC-12 cells exposed to chlorpyrifos at 50 nM and higher which they considered an indicator of cellular damage and cytotoxicity. They also reported an increase DNA-single strand breaks (SSBs) in these cells at 200 nM. In vivo, rats given two doses of chlorpyrifos at 41 mg/kg by oral gavage 21 hrs apart had increased TBARs and DNA-SSBs in liver and brain homogenates. Although AChE activity was not measured in these rats this dose level was high enough that it should have caused significant AChE inhibition.

Garcia et al. (2005) provided evidence that glial cells are a target for chlorpyrifos in the later stages of neurodevelopment, but the effect of chlorpyrifos on glial cells in mature animals is less clear. Glial cells play an important role in neuroinflammation, therefore, activation of them could lead to generation of radical oxygen species (ROS) which could theoretically lead to PD (EFSA, 2017). In their a review of the function of glial cells in the adult brain, Jakel and Dimou (2017) found that the effect of ablation of glial cells depends on the glial population and whether the animal is healthy at the time of ablation. Microglia cells are immunocompetent and act like

phagocytes in the nervous system. Ablation of microglia was neuroprotective in Alzheimer's mouse model. On the other hand, ablation of astrocytes generally had negative effects in both healthy animals and animals with neurodegenerative diseases. Astrocytes have numerous functions with the brain, including maintenance of water and ion homeostasis, participation in the tripartite synapse and maintenance of the blood brain barrier. Ablation of oligodendrocytes also had primarily negative effects in healthy animals. There were no published studies of its effect in animals with neuropathological conditions.

Dopaminergic Signaling: Torres-Altoro *et al.* (2011) evaluated the effect of CPF-oxon on downstream effectors in the dopaminergic signaling pathway in mouse striatal slices *ex vivo* and in mice and rats in vivo. They observed in mouse striatal slices that CPF-oxon at 100 μM for 60 min caused hyperphosphorylation of certain sites in downstream effectors, DARPP-32 (dopamine and cAMP-regulated phosphoprotein of M_r 32 kDa) and GluR1 (glutamate receptor 1) subunit of AMPA (α-amino-3-hydroxy-5-methyl-4-isoxazolepropionic acid) receptor. Hyperphosphorylation of these downstream effectors also occurs with D1 dopamine receptor agonists affecting trafficking, stability and striatal neuron excitability. In vivo, they found that mice injected s.c. with CPF-oxon at 30 mg/kg/day daily for 7 days had a 1.36-fold increase in the phosphorylation of striatal GluR1, but no hyperphosphorylation was seen in mice injected s.c. with CPF-oxon at 1 or 2.5 mg/kg for the same period. Hyperphosphorylation of the neurofilament, tau, by the cyclin-dependent kinase, Cdk5, has been associated with the loss of neuronal function and cell death and has been suggested as a biomarker for Alzheimer's disease. Cleavage of the Cdk5-activating neuronal cofactor p35 to p25 by calpain results in hyperactivation and redirection of Cdk-5 towards aberrant substrates such as tau. However, CPF-oxon administered to mice at 1 or 2.5 mg/kg s.c. for 7 days did not result in significant p25 generation. They also examined the electrophysiological changes in corticostriatal glutamatergic neurotransmission with CPF-oxon in rat brains *ex vivo* at 100 μM and found that CPF-oxon did not affect the miniature excitatory post-synaptic current (mEPSC) amplitude, but did cause a significant decrease in the inter-event interval of mEPSC events (i.e., increased the frequency). They suggested this indicates that CPF-oxon alters striatal neurotransmission by enhancing glutamate release from corticostriatal terminals in an action potential-independent manner.

Mitochondrial Dysfunction: Middlemore-Risher et al. (2011) reported that chlorpyrifos (1-20 μM) and CPF-oxon (0.005-20 μM) in rat primary cortical neurons resulted in dose-dependent increase in mitochondrial length and decrease in mitochondrial number and their movement in axons. These changes were seen at concentrations that did not inhibit AChE (5 μM CPF, 0.01 μM CPF-oxon) and were not blocked by cholinergic receptor agonists, such as atropine (muscarinic) and mecamylamine (nicotinic). However, these changes did not seem to affect mitochondrial viability or function based on mitochondrial membrane potential or ATP production. The mechanism of these mitochondrial changes is uncertain, but the authors postulated that it involved fusion and/or fission proteins and that reduced movement of mitochondria in the axons could lead to lead to compromised neuronal function and promote apoptosis.

Yamada et al. (2017) reported mitochondrial dysfunction in human induced pluripotent stem cells (iPSCs) exposed to chlorpyrifos at 30μM based on decrease in ATP levels and mitochondrial fragmentation. To investigate the possible role of the mitochondrial fusion protein,

mitofusin 1 (Mfn1), they performed knockdown of the *Mfn1* gene using a lentivirus-delivered shRNAs. Mfn1 is known to be involved in the fusion of mitochondria to form tubular networks which are a normal part of the cell homeostasis. With knockdown of *Mfn1*, chlorpyrifos reduced the expression of several neural differentiation marker genes in iPSCs. Specifically, knockdown of *Mfn1* increased phosphorylation of ERK and reduced the expression of *PAX6*, a key transcription factor that regulates neurogenesis. Based on these findings, these investigators proposed that chlorpyrifos reduced Mfn1 which lead to mitochondrial dysfunction evoking ERK phosphorylation, leading to suppression of *PAX6*.

Proposed Adverse Outcome Pathways for PD and Pesticides: After performing a systematic review of the literature associating exposure to pesticides and risk for Parkinson's disease, the European Food Safety Authority (EFSA) used the Adverse Outcome Pathway (AOP) conceptual framework to define biological plausibility in relation to epidemiological studies (EFSA, 2017). In this approach, they identified two AOPs for PD with molecular initiating events (MIEs) and key events (KEs). In AOP1, the MIE is the binding to Complex I. KE1 is the inhibition of Complex I with KE2 being mitochondrial dysfunction. The evidence used to build this model came from MPTP and rotenone. KE3 involves impaired proteostasis which refers to the homeostasis of proteins in space and time. Two major degradation systems that are part of this proteostasis are the ubiquitin-proteasome system (UPS) and the autophagy-lysosome pathway (ALP). These systems are highly energy demanding and susceptible to oxidative stress. Exposure to pesticides known to inhibit UPS, such as benomyl, cyanazine, dieldrin, endosulfan, ferbam, metam, propargite, rotenone, triflumizole and ziram are thought to increase the risk for PD, especially among individuals with a genetic variant of the *SKP1* gene that is part of UPS pathway (Ritz *et al.*, 2016). Inhibition of the UPS pathway results in the accumulation of α-synuclein. Aggregation of α-synuclein can obstruct cellular transport, leading to impaired intracellular trafficking or trapping of cellular organelles, most importantly the mitochondria, in the wrong locations resulting in synaptic and cell dysfunction. KE4 is the degeneration of dopaminergic neurons that is associated with the presence of Lewy bodies that contain α-synuclein and other ubiquitin proteins. KE5 is the neuroinflammation that is the result of activation of glial cells due to the neural degeneration. Glial cell responses can be pro-inflammatory or anti-inflammatory depending on the activation states of the cells. Consequently, the neuroinflammatory response could increase or decrease the neurodegeneration in KE4. When the neural degeneration becomes severe enough it leads to the adverse outcome of Parkinsonism motor deficits. Motor deficits are the result of insufficient dopamine, leading to overactivation of both glutamatergic signaling and inhibitory GABAergic signaling. This results in an impaired feedback to the thalamus and cortex. The MIE for AOP2 is the redox cycling of a chemical initiated by electrons released by the mitochondrial respiratory chain. Evidence from paraquat and maneb was used to support this AOP. Paraquat does not inhibit Complex I, but it is a mitochondrial electron acceptor. KE1 is the generation of reactive oxygen species (ROS) in the mitochondria leading to mitochondrial dysfunction. The rest of the KEs are essentially the same as AOP1 with KE2, KE3 and KE4 being impaired proteostasis, neuroinflammation and dopaminergic neurodegeneration, respectively and the adverse outcome of PD.

II.M.5. Alzheimer's Disease

II.M.5.a. Human Epidemiological Studies of Alzheimer's Disease

There are no epidemiological studies that evaluated the association of Alzheimer's disease (AD) with exposure to chlorpyrifos specifically. However, a few studies evaluated the risk for AD with pesticide exposure in general. One of these was a prospective cohort study of elderly residents living in Cache County, Utah, in which the investigators performed baseline cognitive screening on 5,092 residents that were 65 years or older in 1995 and then re-evaluated them at 3, 7 and 10 years (Hayden *et al.*, 2001). For various reasons (prevalent dementia at start, death, moved away, refused participation, incomplete data) the number of subjects in the final analysis was reduced to 3,084. Of these, 572 reported pesticide exposure. Final diagnosis of dementia was assigned at consensus conferences using standard criteria. The pesticide exposure was self-reported based on interviews with questionnaires providing work histories and associated exposures. The adjusted Hazard Risk (HR) for those with any pesticide exposure was 1.38 (95% CI 1.09 – 1.76; p = 0.008). The adjusted HR for dementia in general in those with exposure to organophosphates was 1.31(95% CI 0.88 – 1.55), but was not statistically significant (p = 0.29). However, the adjusted HR increased when the diagnosis was limited to AD. Based on those cases, the adjusted HR for all pesticide exposure increased to 1.42 (95% CI 1.06 – 1.91; p = 0.02). When that was further narrowed to subjects with organophosphate exposure, the adjusted HR increased to 1.53 (95% CI 1.05 – 2.23) and was statistically significant (p = 0.03).

Yan et al. (2016) performed a literature review and meta-analysis of the epidemiological studies evaluating the risk for Alzheimer's disease with pesticide exposure. A total of seven studies were included in the meta-analysis. Most took place in other countries, including three in Canada, one in France, and another in Australia. The study conducted by Hayden et al. (2001) was one of two studies conducted in the US. The other study was conducted by French et al. (1985) and was a hospital-based case-control study. The overall OR for these 7 studies was significant at 1.34 (95% CI 1.08 – 1.67) without heterogeneity (p = 0.88, I^2 = 0.05%), indicating the selected studies were statistically homogeneous and, therefore, the results relatively reliable. Sensitivity analysis produced similar results indicating the relationships were relatively stable.

II.M.5.b. Animal Studies of Alzheimer's Disease

Three month old male Wistar rats were injected s.c with chlorpyrifos in peanut oil at 0, 2.5, 10, 18 or 25 mg/kg/day for 14 days and evaluated for effects on learning and memory in water maze 1 day and 14 days after the last dose (Terry *et al.*, 2003). Plasma cholinesterase activity was reduced at all levels with 30% reduction at the lowest dose. Decreased body weights and rearing and sniffing activity were seen at 10 mg/kg/day and higher. In the water maze test given one day after the last dose, significant longer time to the platform and distance to swim to get to the platform were seen at 18 and 25 mg/kg/day. There were no significant differences between groups with the 14-day recovery period before testing them in the water maze. The axonal transport was examined *ex vivo* with peripheral nerve axons from these rats after maze testing. Both anterograde and retrograde axonal transport were reduced at 10, 18 and 25 mg/kg/day one day after the last dose. A reduction in the axonal transport was still significant at 25 mg/kg/day with a 14-day recovery period. These investigators also tested the effect of a subthreshold dose of chlorpyrifos at 2.5 mg/kg/day for 5 days/wk for 4 weeks on grip strength. They found a significant reduction in grip strength after the end of this treatment regimen which was reversible with a 5-day recovery period.

Samsam *et al.* (2005) examined the learning ability and attention span of rats fed chlorpyrifos at low levels (0, 1, or 5 mg/kg/day) for one year with or without intermittent acute doses of chlorpyrifos (60 mg/kg initial dose and 5 doses at 45 mg/kg) in corn oil by oral gavage every 2 months. The chronic low doses facilitated learning based on lever press response for a food reward, but the acute high doses significantly reduced learning. The authors proposed that the facilitated response with chronic low exposure probably was the result of motor dysfunction although there was no direct evidence for this. The authors also evaluated sustained attention by having the rats perform a signal discrimination task (SDT). Two months after the end of dosing only the rats receiving acute doses of chlorpyrifos in addition to chronic chlorpyrifos at 5 mg/kg/day had reduced performances in the SDT. The authors concluded from these findings that permanent cognitive impairment occurs only in the presence of brain AChE inhibition followed by acute doses of chlorpyrifos high enough to elicit signs of toxicity.

The effect of several different dosing regimens with chlorpyrifos on the microtubule structures in brains of mice were examined by Jiang et al. (2010). One group of 4 female mice were injected s.c. with chlorpyrifos at 3 mg/kg/day for 14 consecutive days. Another group of 3 male mice received a single dose of CPF-oxon at 3 mg/kg. A third group of 2 female mice received with 6 doses of CPF-oxon at 1, 22, 48, 50 and 50.15 hrs. Oxon labeled tubulin at tyrosine 281 and serine 338 was found in the brains of mice receiving chlorpyrifos at 3 mg/kg/day for 14 days or single dose of CPF-oxon at 3 mg/kg based on the diethoxyphosphorylated tubulin residues. Six of 19 proteins involved in axonal transport were not detected in male mice treated with a single dose of CPF-oxon (heat-shock protein 84 kDa, alpha-internexin, Myosin Va, dynein cytoplasmic 1 light intermediate chain, cytoskeleton-associated protein 5 and microtubule-associated protein 2 isoform 1). These proteins were related to microtubule assembly, structure, stability and function. The microtubules from the oxon treated mice were shorter and narrower than controls. These investigators suggested that oxon exposure may have also triggered CaM Kinase II which could also have enhanced phosphorylation of proteins and contributed to the dissociation of the microtubules.

Salazar et al. (2011) examined the effects of an acute high dose of chlorpyrifos (50 mg/kg s.c.) on both transgenic (Tg) Swedish mice carrying the amyloid β precursor protein (AβPP) mutation for AD and wild type (WT) Swedish mice. The brain AChE inhibition in both Tg and WT treated mice was about 40% 72 hrs after treatment. These investigators evaluated the effect of chlorpyrifos on the neurobehavioral activity and learning in Tg and WT mice. The WT control mice exhibited significantly more climbing in the FOB than the other groups as well as resistance to removal from the cage. The control and treated Tg mice and the WT treated mice all had reduced touch and righting responses relative to WT controls. Differences in distance traveled in open field were reduced in Tg treated mice compared to Tg controls 7 months after treatment. Differences between control and treated WT mice were not significant. While learning acquisition in a water maze task was not affected in the Tg or WT mice 17 weeks after dosing, the retention of this learned task was significantly greater in the Tg treated mice compared to Tg control mice. Retention was slightly poorer in treated WT mice compared to control WT mice. In the rotorod test performed 19 weeks after treatment, Tg mice showed no significant increase in the time to fall between acquisition trial 1 and 2 while both the control and treated WT mice were able to spend significantly longer time on the rotorod in acquisition trial 2 compared to trial 1. Eight months after treatment, the amyloid β (Aβ) levels were significantly higher in brains of Tg treated mice compared to Tg controls. As expected, the amyloid β levels

Table 9. Studies Evaluating Effects Related to Alzheimer's Disease in Animals Exposed to Chlorpyrifos

Species, Sex, Age	Exposure Route & Duration	Effect[c]	LOEL mg/kg/day	Ref.[a]
Rats, M 3 months	CPF[b] s.c. in peanut oil daily for 14 days 0, 2.5, 10, 18 or 25 mg/kg/day	↓ BuChE (~30%) after single injection	2.5	1
		↓ BW, rearing & sniffing, ↓ axonal transport, transient	10	
		↓ performance in water maze, reversed with 14-day recovery	18	
		Irreversible ↓ axonal transport	25	
Rats, M 75 days 2 cohorts	CPF in diet, 1 year 0, 1 or 5 mg/kg/day +/- CPF at 45 mg/kg bimonthly by gavage in corn oil	**CPF diet only**: ↑ learning of LPR, no effect on SDT	1	2
		CPF diet + 6 acute doses: ↓ SDT 2 months after recovery	5	
		Control diet +6 acute CPF doses: ↓ learning of LPR & SDT	45	
Mice, F, 75-95 days	CPF s.c. for 14 days in corn oil/DMSO 0 or 3 mg/kg/day	↓ BuChE, CPO labeling of β-tubulin at tyrosine 281	3	3
M, 72 days	CPO s.c. once in EtOH 0 or 3 mg/kg	↓ AChE & BuChE (60-70%), ↓ body temp, motor activity, ↓ microtubule proteins (6/19), short & thin microtubules	3	
F, 127 days	CPO s.c. 6X in 50 hrs in EtOH 0 or 2.5 mg/kg	↓ AChE & BuChE in plasma (100%) & brain (45-50%), CPO labeling of β-tubulin serine 338	2.5	
Mice, M, 7 months Tg2576 (AD) & WT	S.C. once in olive oil, 0 or 50 mg/kg	**WT & Tg:** ↓ Brain AChE (40%), ↓ touch & righting **Tg only:** ↑ retention in treated vs. controls, ↓ rotorod time in both control & treated vs WT, ↑Aβ in treated vs. controls	50	4
Rats, M Age NR	CPF s.c. once in corn oil, 0 or 250 mg/kg +/- Aβ i.c.v. daily for 15 days	**+Aβ +/-CPF:** ↓ water maze performance, **+Aβ/-CPF:** ↓ MAP1A **-Aβ/+CPF:** ↓ MAP2	250	5
Rats, M & F 4 months Tg344-AD & WT	CPF s.c. daily in peanut oil/EtOH (90%/10%), 0, 3 or 10 mg/kg/day	**Tg +/- CPF:** hyperphosphorylated tau, amyloid plaques & vacuoles	--	6
		WT & Tg + CPF: ↓ BuChE (50%)	3	
		WT & Tg + CPF: ↓ BuChE (70%) ↓ NOR & BM & ↑ microglia (M) **Tg + CPF:** ↓ MWM tasks (M)	10	

a References: 1. (Terry *et al.*, 2003); 2. (Samsam *et al.*, 2005); 3. (Jiang *et al.*, 2010); 4. (Salazar *et al.*, 2011); 5. (Ruiz-Muñoz *et al.*, 2011); 6. (Voorhees, 2017).

b Abbreviations: CPF = chlorpyrifos; CPO = chlorpyrifos oxon; s.c. = subcutaneous injection; BuChE = butyrylcholinesterase; BW = body weight; LPR = lever press response for food reward; SDT = signal detection task; AChE = acetylcholinesterase; EtOH = ethanol; Tg = transgenic; AD = Alzheimer's disease; WT = wild type; Aβ = amyloid β; i.c.v. = intraecerebroventricular infusion; NR = not reported; MAP = microtubule-associated protein; NOR = novel object recognition; BM = Barnes maze; MWM = Morris water maze.

c Bolding denotes which effects are associated with which phase of the experiment, and are for organization purposes only.

were low in both control and treated WT mice. The investigators suggested the increase in treated mice may be due to the inhibition of acyl peptide hydrolase (APH) by chlorpyrifos which is a serine hydrolase involved in the clearance of amyloid β. The IC_{50} by CPF-oxon is approximately the same for APH and AChE around 20 nM (Casida and Quistad, 2005).

Ruiz-Muñoz et al. (2011) examined the effect of chlorpyrifos (250 mg/kg s.c.) in rats with and without subsequent intracerebroventricular (i.c.v.) infusions of Aβ for 15 days on learning and memory in a water maze test, on histological staining for Aβ deposits in the brain and on microtubule-associated protein (MAP) levels in the brain. There was no effect on performance in the classic water maze test on Days1-5 until the hidden platform was moved on Day 7. When that happened, the animals receiving the Aβ infusions with or without chlorpyrifos performed worse, although those receiving both chlorpyrifos and the Aβ infusions had the worst performance. The investigators suggested the difference was due to difficulty in developing new navigation plans and impaired cognitive flexibility or an impaired memory problem that was not detected in the early phase. No Aβ deposits or signs of cell death were found in any of the rat brains, but the Aβ infusions without chlorpyrifos caused reduced MAP1A levels in hippocampus and prefrontal cortex while chlorpyrifos with the Aβ infusions caused reduced MAP2 levels in the prefrontal cortex. MAPs can polymerize tubulin to form microtubules. MAP1A is related to spine plasticity while MAP2 is considered a dendritic marker. They interpreted these changes to indicate that chlorpyrifos and Aβ transiently induce a decrease in dendritic and synaptic connections.

Voorhees (2017) examined the effect of chlorpyrifos on the progression of AD in WT and transgenic (TgF344-AD) rats when injected s.c. at 0, 3 or 10 mg/kg/day for 21 days. BuChE was inhibited 50 and 70% in males and 75 and 90 % in females at 3 and 10 mg/kg/day, respectively. AChE activity was not measured. No overt cholinergic signs were seen, although the chlorpyrifos treated rats were more agitated as indicated by their tail writhing behavior. Very few WT male rats exhibited agitation even with chlorpyrifos exposure. Female WT and both sexes of TgF344-AD rats showed increased agitation with chlorpyrifos exposure. Based on performance in several types of tasks [novel object recognition (NOR) task, Barnes maze (BM), and elevated-plus maze (EPM)], no differences were seen in chlorpyrifos treated rats of either sex at 3 mg/kg/day or in female chlorpyrifos treated rats at 10 mg/kg/day compared to WT controls. Cognitive deficits were seen in the NOR and BM performances in TgF344-AD rats with chlorpyrifos at 10 mg/kg/day relative to WT controls at 6, 16 and 24 months with intermittent recovery at 9 and 12 months. No difference in EPM was seen with chlorpyrifos exposure in either WT or TgF344-AD rats. At 24 months, rats were also tested in the Morris water maze (MWM) and as with earlier time points only the males showed deficits. These deficits were seen in both WT and TgF344-AD rats receiving chlorpyrifos at 10 mg/kg/day. The neuronal damage (vacuoles in cortex and hippocampus) was seen in both sexes of TgF344-AD rats and was further exacerbated by chlorpyrifos exposure, especially in males at 10 mg/kg/day. Amyloid plaque deposition were seen in TgF344-AD rats at 12-24 months, but was not affected by chlorpyrifos exposure. Chlorpyrifos treatment had no effect on levels of either total tau or abnormally phosphorylated tau in TGF344-AD rats. However, neuroinflammation based on CD68 immunoreactivity that is a biomarker for microglia activation was seen with chlorpyrifos at 10 mg/kg/day that was significant in both WT and TGF344-AD rats compared to their respective controls. GFAP, a biomarker for astrocyte activity, was elevated in TgF344-AD control rats

when compared to WT rats, but was reduced in TgF344-AD rats receiving chlorpyrifos at 10 mg/kg compared to TgF344-AD control rats.

II.M.5.c. Mechanistic Studies of Alzheimer's Disease

In 1986, (Iqbal *et al.*) reported that the protein tau which stimulates the assembly of microtubules was abnormally phosphorylated in the brains of patients with Alzheimer's disease. Microtubule assembly was only observed in control brains, but not Alzheimer's brains. The Alzheimer's brains did not have any inhibitor of microtubule assembly or abnormality of tubulin. Assembly could be stimulated in the Alzheimer's brains with DEAE-dextran that mimics tau.

Prendergast et al. (2007) examined the immunoreactivity (IR) of microtubule-associated proteins in rat hippocampal slices exposed to CPF-oxon at 0.1-10 μM for 1-7 days which produced 15-60% AChE inhibition. Reduction in MAP2 IR were seen as early as 24 hrs even at CPF-oxon concentrations as low as 0.1 μM. The α-tubulin IR was not affected at any time point or concentration. Cell damage was also evaluated in these hippocampal slices using fluorescent microscopy. With fluorescent microscopy, injury to CA1 and CA3 pyramidal cells and dentate cells were seen 3 days after exposure at all concentrations. Effect of CPF-oxon (0.1-10 μM) on polymerization was also examined with purified bovine tubulin dimer. CPF-oxon reduced polymerization 60-70% in MAP deficient tubulin that was not concentration dependent, but with MAP-rich tubulin, the reduction in polymerization by CPF-oxon was 2-fold greater and was dose-dependent. Based on these findings, the investigators proposed that phosphorylation of MAPs lead to their destabilization which results in disassembly of microtubules.

Grigoryan and Lockridge (2009) exposed purified bovine tubulin (0.1mM) to CPF-oxon for 30 min. at 5-100 μM and then polymerized by at 1mM GTP to generate microtubules. At 5 and 10 μM, CPF-oxon inhibited polymerization with a reduction the number of microtubules and the microtubules were thinner and shorter. However, at 25 μM, CPF-oxon stimulated polymerization with an increase in the number microtubules and in their length compared to controls. At 50-100 μM CPF-oxon, aggregates were formed. The investigators suggested at lower concentrations CPF-oxon partially blocked polymerization, but at 25 μM CPF-oxon stabilized the microtubule structure. At 50-100 μM, CPF-oxon began to destabilize the microtubules by covalently binding to the tyrosine residues. Nanoimaging showed that CPF-oxon was noncovalently bound to 17 of 35 tyrosines in the unpolymerized α- and β-tubulin. Grigoryan et al. (2009) used LC/MS/MS mass spectrometry to confirm the identity of the oxon phosphorylated tyrosines in treated tubulin. Tyr 83 was the most extensively labeled residue (61%) on α-tubulin at high concentration tested (500 μM). On β-tubulin, Tyr 281 had the most labeling (34%). The tyrosines most commonly labeled with CPF-oxon were on the exposed surface of the tubulin.

In a review of the role of tau protein in the development of AD, Gendron and Petrucelli (2009) noted that tau is one of several proteins that can polymerize tubulin into microtubules. Other proteins that are known to polymerize tubulin include MAP1 and MAP2. Tau is primarily found in neuronal axons. The neurofibrillary tangles (NFT) associated with AD are also associated with other tauopathies, although in AD the NFT only occur in the neurons whereas with other tauopathies they can also occur in glial cells. Mutations in the gene *MAPT* that encodes tau are not genetically linked to AD, but other neurodegenerative diseases have been. The exact

neurotoxic species of tau has not been identified, but both a toxic gain of function (e.g., hyperphosphorylation of tau) and the loss of normal tau functions are thought to contribute to AD progression. Hyperphosphorylated tau has been found in AD brains and it has lower microtubule promoting activity in vitro. The hyperphosphorylation of tau may be the result of several mechanisms, including: 1) the activation of cdk5 via overexpression of p25; 2) the decreased expression of protein phosphatase 2A (PP2A) which can dephosphorylate tau; or 3) decreased expression of Pin1 which is a protein involved in the assembly, folding and transport of cellular proteins. Decreased levels of both PPA2 and Pin1 have been found in AD brains. Hyperphosphorylated tau is thought to interfere with axonal transport and lead to synaptic damage either by causing microtubule disassembly and loss of tracks for axonal transport or by displacing cargo on tracks by binding to kinesin motor proteins that move cargo in the anterograde direction. Synaptic loss is an early event in AD and is more strongly associated with cognitive declines than NFT. NFT may initially be formed as a protective mechanism to sequester hyperphosphorylated forms of tau, but may eventually contribute to neuronal death by acting as physical barriers in the cytoplasm, displacing organelles and further interfering with axonal transport.

Morfini et al. (2009) proposed that defects in axonal transport are common in many adult-onset neurodegenerative diseases (AONDs) through different pathways. A common characteristic of these AONDs is the age-dependent decline in neuronal function which is initially associated with loss of synaptic activity rather than neuronal cell death that is a late event in the disease process. Axonal transport is essential for proper axonal and synaptic function because axons lack protein synthesis and the distance from cell body to synapses can be large. Microtubule-based motor proteins called kinesins transport organelles including mitochondria, synaptic vesicles and axolemmal precursors in an anterograde direction (from cell body to synapse) while cytoplasmic dynein acts as a motor in the retrograde direction carrying degradation products from the synapses to cell bodies. The phosphorylation of these motor proteins regulates axonal transport. Multiple kinases regulate the phosphorylation of these motor proteins and many of these are increased in AONDs indicating aberrant protein phosphorylation. Genetic mutations in these motor proteins have resulted in neuropathies that can vary depending on which subunit of the motor protein is mutated. However, most AONDs are not associated with genetic mutations in these motors. Instead, abnormal protein kinases and aberrant protein phosphorylation are considered the major hallmarks of AONDs. Studies with MPP^+ found that retrograde transport was increased while anterograde transport was reduced, suggesting that a proper balance in anterograde and retrograde transport are also necessary for neuronal function.

More recently there has been research suggesting that misfolding of proteins and disruption of the retromer complex are common mechanisms in neurodegenerative diseases (Tyson *et al.*, 2016; Sweeney *et al.*, 2017; Victoria and Zurzolo, 2017). Its role is closely related to proteostasis and axonal transport. Misfolding of proteins is a common event and removal of these misfolded proteins involves several systems. The ubiquitin proteasome system (UPS) is responsible for the removal of monomeric misfolded proteins while the autophagy-lysosomal pathway (AL) is responsible for removing oligomers of misfolded proteins to lysosomes. Deficiencies in the retromer complex can cause lysosomal deficiencies. The retromer is a pentameric complex of vacuole sorting proteins and sorting nexins that are responsible for sorting the endosomal compartments and depending on their on its cargo and their interactions with other complexes

directs them to the Golgi apparatus for recycling or to lysosomes for degradation. Mutations in the proteins forming the retromer have been associated with familial forms of AD and PD.

II.M.6. Conclusion

Exposure to chlorpyrifos has been associated with neurodegenerative conditions such as OPIDN, PD and AD that may occur through shared mechanisms, such as misfolding of proteins, disruption of axonal transport, and mitochondrial dysfunction. Based on animal studies, AD could occur with repeated exposures to chlorpyrifos (3-10 mg/kg/day) through hyper-phosphorylation of tau and other proteins involved in axonal transport. It is important to note that significant RBC and brain AChE inhibition would also occur at these same dose levels. Hyperphosphorylated tau and MAP proteins are thought to lead to synaptic damage either by loss of microtubule tracks for axonal transport or by displacing cargo on tracks by binding to kinesin motor proteins that move cargo in the anterograde direction. NFTs are formed from hyperphosphorylated tau and may initially be a protective mechanism to sequester the toxic (hyperphosphorylated) form of tau, but these NFTs may eventually contribute to neuronal death by acting as physical barriers in the cytoplasm, displacing organelles and further interfering with axonal transport. Synaptic loss is an early event in AD and is more strongly associated with cognitive declines than NFTs. The plaques are also from the accumulation of misfolded Aβ. By itself, chlorpyrifos does not appear to increase Aβ levels, but in Tg-AD mice and rats treated with chlorpyrifos, the Aβ levels were higher than in the Tg-AD controls. Hyperphosphorylation of α-synuclein can also lead to its misfolding and formation of aggregates referred to as Lewy bodies that are the hallmark of PD. In one epidemiological study in handlers they saw no increase in α-synuclein levels nor did they find an increase in α-synuclein gene expression in mice treated with chlorpyrifos at 75 mg/kg. Chlorpyrifos was associated with significant inhibition (69%) of the mitochondrial respiratory enzyme, Complex I, in hens at 150 mg/kg. Mitochondrial dysfunction can lead to impaired proteostasis through disruption of the major protein degradation systems including UPS and ALP which are highly energy demanding. The impaired proteostasis can result in protein misfolding and aggregation which can then interfere with axonal transport and lead to neurodegeneration from organelles, especially mitochondria, and nutrients not being where they are needed. Neuroinflammation in response to protein aggregates and neuronal damage can contribute to further neuronal damage. At supralethal doses chlorpyrifos causes significant inhibition of NTE (> 70%) that can cause further mitochondrial dysfunction by disrupting calcium homeostasis leading to its accumulation in the mitochondria which increases its permeability. There may also be some disruption of dopaminergic signaling and gene expression at low doses of chlorpyrifos which could lead to PD later in life, but this has not been demonstrated in animals yet. Chlorpyrifos may also contribute to AD by the inhibition of another serine hydrolase, APH, which is involved in the clearance of Aβ. At higher doses, oxidative stress related to the AChE inhibition may also contribute to mitochondrial dysfunction.

Collectively, it appears that high doses/exposures of chlorpyrifos are associated with various types of neurodegeneration. At present, there is no evidence suggesting that chlorpyrifos-related neurodegeneration occurs at lower doses, such as those below the level that inhibits AChE.

II.N. Additional Effects of Chlorpyrifos

II.N.1. Chlorpyrifos Effects on the Respiratory System

In its findings on the December 2017 Draft TAC Evaluation, the Office of Environmental Health Hazard Assessment (OEHHA) suggested that the respiratory effects associated with chlorpyrifos exposure be considered when establishing potential critical toxicity endpoints. OEHHA cited published epidemiological data from the Agricultural Health Study (AHS) that associated exposure to certain OPs with wheeze in exposed occupational and bystander cohorts (Hoppin *et al.*, 2006b). As such, HHA re-evaluated the public and occupational health studies that investigated respiratory outcomes.

Hoppin et al. (2006) showed a dose-related increase in the odds ratio of wheeze episodes with increasing days of chlorpyrifos application. However, the authors did not indicate the exact amount of chlorpyrifos applied and, as such, quantitative assessment of the dose response cannot be performed with these data. The study by Hoppin et al. (2006), along with a series of papers on respiratory effects of chlorpyrifos, including the newest 2017 AHS results by the same investigators (Hoppin *et al.*, 2017), are summarized in Table 10.

Respiratory effects were reported in four studies. However, in each case the data were not adequate for the development of PoDs because of uncertainties intrinsic to the assignment of the dose levels. Nevertheless, the review provided evidence to support the role of chlorpyrifos as a putative respiratory toxicant.

Table 10. Published Studies Reviewed to Evaluate Potential Respiratory Effects Related to Occupational and Bystander Exposure to Chlorpyrifos

Reference	Type of Study/Design	Key Findings
(An *et al.*, 2014)	Worker exposure study in China; dermal (DE) and inhalation exposures (IE) of CPF applicators (backpack pump with EC 48% CPF) were evaluated using personal dosimetry for sample collection and gas chromatography for quantification; maize fields of increasing heights (3 levels: 62, 108, and 212 cm) and increasing levels of personal protective equipment (PPE: 1 or 2 additional layers of cotton garment and cotton gloves; base included socks, rubber boots, and cotton inner/outer hats) were evaluated; estimated exposures (using DE and IE data) were compared to an acceptable exposure factor (AE) = 0.01 mg/kg day (per UK-CDR doc 2009) x 61.26 kg to calculate a margin of safety (MOS) (≥ 1 considered "safe"); safe work time (SWT) was also estimated.	Exposures increased with increasing crop height whether or not additional PPE was used (1 or 2 layers of additional garment and gloves). Decreases were observed for corresponding MOS and SWT parameters. IE below LOD for all but tallest crops. No data were reported that could be used to develop a PoD based on respiratory effects.

Reference	Type of Study/Design	Key Findings
(Bouchard *et al.*, 2010)	A multi-compartment model was developed to describe the human "biodisposition kinetics" of CPF and its metabolites 3,5,6-trichloro-2-pyridinol (3,5,6-TCP) and alkyl phosphates (APs) diethyl thiophosphate (DETP) and diethyl phosphate (DEP); the model was validated using levels of the above species in human blood and urine; biological reference values (BRVs) (safe levels of absorption or exposure (primarily dermal) for workers) based on a repeated-dose NOEL for AChEI (0.1 mg/kg/day) were proposed.	BRVs were proposed for 3,5,6-TCP and APs in 0-24 and 0-48 hour urine pools based on an 8 hour exposure period at an absorbed dose level of a 0.08 mg/kg (0.1 mg/kg x 0.798 "the oral absorption fraction" and a dermal absorb rate = 0.04 $hour^{-1}$). No data were reported that could be used to develop a PoD based on respiratory effects.
(Burns *et al.*, 1998)	A continuation of a retrospective, case-control study of Dow employees that worked in CPF manufacturing areas between 1977 and 1994 (n = 496); the study included age-matched controls (n = 911); exposed cohort grouped into four exposure classifications (negligible: < 0.01 mg/m^3 or negligible potential dermal, low: < 0.03 ≥ 0.01 mg/m^3 or low potential dermal, moderate: < 0.2 ≥ 0.03 mg/m^3 or moderate potential dermal, and high: ≥ 0.2 mg/m^3 or high potential dermal); the study involved a questionnaire and a review of medical records; Blood cholinesterase activity date were available for all but 32 cases.	Most case were classified as having had moderate exposure (n =345) while a single case was classified as having had high exposure. The following respiratory effects with odds ratios (ORs) > 1 included): Acute respiratory infections (RI) (OR 1.39; CI 1.08 to 1.79) Acute RI (OR 1.49; CI 1.08 to 2.05) Other diseases of upper respiratory tract (OR 1.07; CI 0.76 to 1.50) Chronic obstructive pulmonary disease and allied conditions (OR 1.41; CI 0.95 to 2.09) Other diseases of respiratory system (OR 2.80; CI 1.18 to 6.65) The following effects had ORs > 1* but no continuous response when correlated with exposure level, mean ChE activity, or minimum ChE activity: Diseases of the ear and mastoid process *Mean ChE activity ≤ 50% (highest dose group) had an OR = 0.30 Acute respiratory infections While relevant respiratory effects data were reported, they were not adequate for the development of a PoD because of the uncertainties intrinsic to the assignment of the dose classifications.

Reference	Type of Study/Design	Key Findings
(Byrne *et al.*, 1998)	Residential exposure study designed to assess oral, dermal, and inhalation pathways after crack and crevice and spot treatment with CPF (0.5% water emulsion; 663 to 718 mL or 3.32 to 3.94 g) in 3 occupied, single family, multi-room houses (Ind., IA); 2 adult volunteers per house observed label recommendations about access to treated areas but otherwise followed normal routines; samples collected for analysis included urine (day -1 to +10; 3,5,6-TCP and creatinine (CR)), air (day 0 to +10; CPF), floor deposition pads (CPF), and dislodgeable residues on hard toy surfaces and carpet (CPF).	There was variability in the timing and magnitude of average peak air concentrations for the 3 houses: Average peak concentrations /Day (µg/m^3/day): 0.301/1, 0.903/6, 0.669/2 There was variability in the loading of deposition pads between rooms and between houses. Pre-exposure 3,5,6-TCP in urine raged from 0.04 to 0.35 µg/kg/day 11-day cumulative excretion of 3,5,6-TCP in urine ranged from 0.01 to 0.40 µg/kg/day Average daily excretion of CPF-equivalents in urine ranged from 0.001 to 0.037 µg/kg/day Estimates of cumulative (respiratory, dermal, and oral) absorbed doses by children ranges from 0.26 to 2.10 µg/kg or 0.26 to 2.1% of the NOEL used for comparison (100 µg/kg/day; plasma ChEI). Corresponding MOEs were 48 to 385. No data were reported that could be used to develop a PoD based on respiratory effects.
(Callahan *et al.*, 2014)	Prospective, cohort study conducted during cotton season (~10 months duration) in Cairo, Egypt; cohorts included pesticide (CPF, etc.) applicators (18 years old or less; average = 15.6) (n = 38) and non-applicator controls (18 years old or less; average = 15.4) (n = 24); end-points included 3,5,6-trichloro-2-pyridinol (TCPy) levels in urine (days 73, 146, 269), pulmonary function testing with spirometry (2 assessments; forced expiratory volume (FEV) and forced vital capacity (FVC)), and self-reported wheezing.	There was no significant correlation between TCPy levels in urine and changes to FEV and FCV measurements between groups or between assessments. Wheeze ORs for applicators were (unadjusted/age-adjusted): Day 146- 1.66 (CI 0.54 to 5.13)/1.71 (CI 0.55 to 5.36) Day 269-3.40 (CI 1.02 to 11.32)/3.27 (CI 0.97 to 11.08) While respiratory effects data were reported, they were not adequate for the development of a PoD because of a lack of dose data and uncertainties arising because of insufficient study power.
(Eddleston *et al.*, 2007)	Clinical review of the effects of acute poisoning by organophosphates (OPs) and the effectiveness of standard clinical interventions.	Respiratory infections can result from acute OP poisoning but may be the result of the need for ventilation. No data were reported that could be used to develop a PoD based on respiratory effects.

Reference	Type of Study/Design	Key Findings
(Fieten *et al.*, 2009)	A retrospective, cross-sectional study conducted in 2007 in Costa Rica; exposed (pesticides) (n = 69 plantain plantation workers) and unexposed cohorts (n = 58 banana plantation workers); study used a questionnaire and included spirometric evaluations.	No significant differences were observed between exposed and unexposed cohorts for FVC, FEV, or FEV/FCV ratio. ORs > 1 were observed for CPF and the following effects (all/weighted after stratification for smoking/non-smokers only): wheeze 2.7/3.5/6.7 shortness of breath 2.2/2.5/2.6 chronic cough 1.7/1.7/1.3 ORs for wheezing consistently increased with increased dose estimates for nonsmoking women. While respiratory effects data were reported, they were not adequate for the development of a PoD because of a lack of dose data.
(Gao *et al.*, 2014)	Worker exposure study in China; dermal exposures of CPF applicators (backpack pump with formulations containing 30 to 48% CPF) were evaluated; sample collection included a sorbent tube, skin swipes, and garment samples; gas chromatography was used for quantification; maize fields of increasing heights (3 levels: < 80, 80-130, and >130 cm); workers wore (pg. 637) " underwear, long pants, a long-sleeved shirt, cotton socks, rubber shoes, two-layer gloves, eight layers of gauze (20 × 40 cm) on the head, a half-facemask and a wide-brimmed hat to shield the head and neck from downward drift. Because pesticides could reach the body via openings in garments (e.g. unbuttoned shirts, unzipped suits, loose cuffs), it was ensured that shirts were fastened at the neck, that sleeves covered the gloves and that trouser legs covered the outside of the shoes".	Dermal exposures increased with increasing crop height and decreased with increased experience and increased layers of clothing. The inhalation exposures for mixers were higher than that for applicators. Dermal and inhalation exposures varied with the type of formulation used. No data were reported that could be used to develop a PoD based on respiratory effects.

Reference	Type of Study/Design	Key Findings
(Hoppin *et al.*, 2002)	Agricultural Health Study (AHS) study of pesticide applicators in IA (commercial applicators, farmers, family members) and NC (commercial applicators, farmers); 52000 applicators from 1994 to 1997. Two questionnaires were collected – one at certification enrollment and the second questionnaire was mailed (with 44% return rate); frequency of wheezing or whistling in the past year was analyzed in relation to modeled-exposures for dose-response assessment.	Of the 20,468 applicators, 19% reported at least one episode of wheezing and 5% reported diagnosed asthma or atopy. NC residents, smokers were more likely to report wheeze Total years-of-pesticide application was not a factor. Exposure was modelled and no estimates were presented. Total days of organophosphate use had not effect on elevation of wheeze risk. OR for wheeze in chlorpyrifos users was 1.12 (1.01 to 1.25) ORs for wheeze increased with increase in frequency of use <5 uses: OR 1.01 (CI 0.86 to 1.18) 5-9 uses: OR 1.33 (CI 1.13 to1.57) 10-19 uses: OR 0.91 (CI 0.71 to 1.15) ≥20 uses: OR 1.61 (CI 1.12 to 2.31) While relevant respiratory effects data were reported, they were not adequate for the development of a PoD because of the uncertainties intrinsic to the assignment of the dose classifications.
(Hoppin *et al.*, 2006b)	Cross-sectional AHS study of commercial pesticide applicator (not farmers or their family members) from IA; Commercial applicators that were certified as private applicators were considered as farmers, and not included in this analysis; 2255 participants from 1993-1997; data collected using self-administered questionnaires; exposures were modelled based on self-reported average number of days applied per year; exposure was modelled and presented as "number of days pesticide used in a year"	OR for wheeze in chlorpyrifos users was 1.47 (1.09 to 1.99) OR for wheeze increased with increase in frequency of chlorpyrifos use: <5 uses: OR 1.00 (CI 0.56 to 1.80) 5-9 uses: OR 1.10 (CI 0.58 to 2.08) 10-19 uses: OR 0.77 (CI 0.39 to 1.49) 20-39 uses: OR 1.96 (CI 1.05 to 3.66) ≥40 uses: OR 2.40 (CI 1.24 to 4.65) Authors refer to experimental evidence that airway hyperactivity occurs by decreasing neuronal M2 receptor function independent of AChE inhibition. While relevant respiratory effects data were reported, they were not adequate for the development of a PoD because of the uncertainties intrinsic to the assignment of the dose classifications.
(Hoppin *et al.*, 2006a)	Comparison of commercial applicator and farmer data from 2002 and 2006 AHS study publications.	No relevant data were reported that could be used to develop a PoD based on respiratory effects.
(Lee *et al.*, 2002)	CA Pesticide Air Monitoring data modelled to estimate CPF exposure levels.	No data were reported that could be used to develop a PoD based on respiratory effects.

Reference	Type of Study/Design	Key Findings
(Munoz-Quezada *et al.*, 2017)	Retrospective study to evaluate exposure and health status in Chilean farm workers (n=207); agricultural and non-agricultural workers were included.	47% of respondents reported using CPF. OP poisoning symptoms were reported. PPE were not followed in many cases. No quantitative exposure data were reported. No data were reported that could be used to develop a PoD based on respiratory effects.
(Perera *et al.*, 2005)	Prospective bystander exposure study; included 459 pregnant women in urban setting; personal air samples and blood specimens were collected and analyzed for OPs including CPF.	CPF detected in air samples and in 74% of the blood samples collected from mothers and newborn infants. An association was found between levels of OPs in umbilical cord and decreased infant birth weight and length. Birth weight decreased by 42.6 g and length by 0.24 cm for each log unit increase in cord plasma CPF levels. Respiratory effects were not reported. No data were reported that could be used to develop a PoD based on respiratory effects.
(Putnam *et al.*, 2008)	Simulated exposure study; respiratory and dermal exposure of golfers to CPF following application on turf grass was evaluated; CPF was applied at the maximum US EPA-approved rate; 8 volunteers (4 for dosimetry measurements and 4 for biomonitoring) played 18-holes of simulated golf over 4 hours; the inhalation dose was measured by personal air samplers; urine TCP levels were measured for biomonitoring; CPF exposure levels were estimated.	The dermal route was the dominant exposure pathway. No respiratory effects were studied. No data were reported that could be used to develop a PoD based on respiratory effects.
(Raanan *et al.*, 2015)	Prospective, population-based Center for the Health Assessment of Mothers and Children of Salinas (CHAMACOS) study; 526 of 601 enrolled pregnant women with live-born children; mothers and children (at 5 to 7 years of age) were evaluated for respiratory symptoms: 3 DEP metabolites were measured in urine samples of mothers (twice during pregnancy) and children (at ages 0.5, 1, 2,3.5 and 5 years); the relationship between DEP metabolites in urine (mother and child) and respiratory symptoms in children was evaluated.	OR for DEP metabolites in children's urine was 2.35 (1.27 to 4.34). Levels of DEP metabolites were associated with increased odds of reported respiratory symptoms 5 to 7 years later (OR 1.61 (CI 1.08 to 2.39)). Postnatal exposure to OPs over the course of childhood was associated with ORs > 1 of reported respiratory symptoms in children assessed at 5 and 7 years of age. While relevant respiratory effects data were reported, they were not adequate for the development of a PoD because of the uncertainties intrinsic to the assignment of the dose classifications.

II.N.2. Chlorpyrifos Effects on Metabolism and Obesity

As recommended at the January and March 2018 SRP hearings, HHA reviewed recent studies investigating potential association between organophosphate exposure and preconditions for Type 2 diabetes, obesity, and other metabolic disorders. Evidence from animal studies suggests that exposure to chlorpyrifos or organophosphate pesticides in general may disrupt metabolic regulation of glucose metabolism and insulin, with potential implications for the development of metabolic disorders and obesity in later life (Slotkin *et al.*, 2005; Lassiter and Brimijoin, 2008; Seidler and Slotkin, 2011; Reygner *et al.*, 2016; Fang *et al.*, 2018). However, the evidence from human studies is incomplete. Below is a summary of selected human and animal studies.

II.N.2.a. Human Studies on Metabolism and Obesity

In a prenatal study that involved 268 newborns in France, the level of the non-specific OP dialkyl phosphate (DAP) metabolites in maternal urine was found to correlate with the insulin level in cord blood serum (Debost-Legrand *et al.*, 2016). In a cross-sectional study involving 2227 adults in the 1999-2008 NHANES datasets, individuals with detectable urinary DAP levels were found to have higher diastolic blood pressure, lower HDL, and higher triglyceride than those below detection (Ranjbar *et al.*, 2015). However, no human study has shown the direct connection between early-life exposures to chlorpyrifos and later-life effects.

As summarized in Section II.K.1. Biomarkers of Human Chlorpyrifos Metabolism in the December 2017 Draft TAC Evaluation, DAPs metabolites are considered general metabolites of all OP-containing compounds in the environment. Because each urinary metabolite has multiple sources, the presence of any DAP metabolite in urine may result from exposure an O,O-diethyl pesticide or an environmental degradate, but cannot correlated to exposure to a specific active ingredient (Barr and Angerer, 2006).

A few human studies have also investigated whether developmental susceptibility to chlorpyrifos and OPs may vary with genetic polymorphisms. Paraoxonase 1 (PON1), a multifunctional enzyme that is involved in antioxidant defense, plays an important role in detoxification of chlorpyrifos and other organophosphate pesticides. Specifically, the PON1192 genotype has been shown to affect catalytic efficiency of the enzyme (Holland *et al.*, 2015). As part of the CHAMACOS cohort, 373 Mexican-American children in an agricultural community in California were analyzed for PON1 genotypic variations. The PON1192 genotype was found to link to higher odds of childhood obesity at the age of two (Huen *et al.*, 2013). However, it was unclear whether exposure to chlorpyrifos or OPs in general played a role in causing obesity in the genetically susceptible population.

Recently, the gut microbiome has been studied as a potential target for the diabetogenic effect of OPs. The gut microbiota can metabolize OPs into acetic acid, which is then converted into glucose by gluconeogenesis in the intestine and liver and accounts for glucose intolerance (Velmurugan *et al.*, 2017). A recent study in rural India showed a correlation between fecal esterase activity and self-reported exposure to OPs in humans (Velmurugan *et al.*, 2017). The same study also demonstrated a link between the fecal acetate and plasma OP level in diabetic individuals. Yet, it was unclear whether the glucose intolerance was caused by metabolic change in the gut microbiota at early life stage in these individuals.

II.N.2.b. Gestational or Neonatal Animal Studies on Metabolism and Obesity

In some animal studies there are indications that chlorpyrifos exposure may lead to metabolic disorders and obesity. Rats treated in utero through weaning showed increased body weights, increased fat, decreased insulin receptors, some body weight changes, and some evidence of hyperglycemia and hyperinsulinemia at doses of chlorpyrifos equal to or greater than 1.0 mg/kg/d (Reygner et al, 2016; Lassiter and Brimijoin, 2008). Neonatal rats treated on PND 1-4 showed increased insulin, cholesterol and triglycerides, factors that the authors associate with metabolic changes and cardiovascular disease later in life (Slotkin et al. 2005). Pups treated in utero exhibited different effects on gluconeogenic stimulation that again according to the authors may have long term effects on cardiovascular and liver function (Seidler and Slotkin, 2011). The majority of studies on energy balance and metabolism were performed in adult rats or mice, with most shoring effects on various aspects of energy metabolism, including increased body weights, affected total cholesterol, triglycerides, the insulin and leptin-signaling pathways, oxidative stress, and changes to gut microflora. A summary of pertinent studies is found below.

Slotkin et al., 2005. This study was performed to examine whether male Sprague-Dawley rats treated neonatally show the two main risk factors for type 2 diabetes and atherosclerosis (hyperinsulinemia and hyperlipidemia) as adults. Male pups were treated by subcutaneous injection (s.c.) at 0 (DMSO 1 ml/kg) and 1.0 mg/kg/d PND 1-4 (8/sex/dose), then pups were weaned at PND 21. There were no effects on pup growth, viability, body weight, or plasma levels of nonesterified free fatty acids or glycerol. The authors noted increases in cholesterol and triglycerides in fed and fasted animals but lipids, glucose concentrations, and percent of glycosylated hemoglobin and hemoglobin were within the normal range for males and females. Males (fed) had markedly increased insulin (returned to normal in fasted animals). Metabolic effects were more prevalent in males than females.

Lassiter and Brimijoin, 2008. This study was designed to examine the effects of chlorpyrifos on rat pup developmental neurotoxicity and weight gain after exposure in utero through weaning. Pregnant Long-Evans rats were treated by gavage at 0 (corn oil), 1.0, 2.5 and 4.0 mg/kg/d from GD 7 through PND 21. There were no maternal effects on body weight or clinical signs at termination. Body weights were significantly increased in males from PND 51 to 100 (maximum of 10.5% on PND 72). The authors also noted a 12% increase in male body volume and a decrease in specific gravity, and ascribed the change to increased fat, as it is a less dense tissue. Although not significantly different for treated versus control, the authors noted that leptin production was disrupted or clearance was increased in the treated animals versus controls, potentially leading to increased body weight gain in sexually mature animals.

Seidler and Slotkin, 2011. An investigation was performed to examine in utero and neonatal/perinatal chlorpyrifos exposure and disruption to β-andrenergic receptor mediated signaling associated with hepatic gluconeogenesis. Effects of chlorpyrifos treatment during different stages of early development on norepinephrine (NE) levels in liver were measured during adolescence and adulthood. Sprague-Dawley dams were treated s.c. with 0 (DMSO), 1 or 5 mg/kg/d during GD9-12 or 17-20. Neonatal treatment was PND 1-4 at 1.0 mg/kg/d or PND 11-14 at 5.0 mg/kg/d. Animals were then tested on PND 30 or PND 30 and 60 for norepinephrine (NE) in heart and liver. GD 9-12 treated pups showed statistically significantly increased NE in heart and liver on PND30. GD17-20 treated pups showed significantly decreased NE on PND 60

at 5.0 mg/kg/d in liver and at 1.0 and 5.0 mg/kg/d in heart. PND 1-4 and PND 11-14 treatment groups showed no effects on NE levels. Overall there were two distinct windows of treatment with opposite effects: early gestation exposure (GD9-12) resulted in increased NE where late gestation (GD 17-20) exposure resulted in decreased NE levels.

Reygner et al., 2016. This study examined the effects of chlorpyrifos on lipid and glucose metabolism, insulin and leptin, gut microbiota composition and short-chain fatty acids (SCFA) production in the developing rat. Pregnant Wistar females were treated with chlorpyrifos at 0 (rapeseed oil), 1, and 3.5 mg/kg/d with or without inulin from GD 1 through PND 21. At PND 21, male pups were weaned and then treated with the same dosing regimen as the dams. There were no effects on dams for body weight, food or water consumption or cholinergic signs. Males at both doses showed increased body weights at birth but body weights and body weight gain were comparable to control (1.0 mg/kg/d) or decreased (3.5 mg/kg/d) at PND 60. Insulin receptor β was decreased and hyperinsulinemia was increased at 1.0 mg/kg/d, while at 3.5 mg/kg/d, males showed decreased insulin and increased hyperglycemia. Both doses showed effects on gut microbiota. The authors conclude that chlorpyrifos may alter body weights, insulin receptors (at the low dose), and induce hyperglycemia and hyperinsulinemia at or above doses associated with ChE inhibition. Leptin levels were not affected and effects did not last into adulthood.

II.N.2.c. Adult Animal Studies on Metabolism and Obesity

Meggs and Brewer, 2007. This study investigated effects of low doses of chlorpyrifos on parameters of weight gain after four months of treatment. Female Long-Evans rats (10/dose) were treated by s.c. injection for four months at 0 (DMSO + saline) and 5.0 mg/kg/d. Animals were examined for cholinergic signs and were weighed at baseline, 2, 3 and 4 months. Body weights increased significantly at 2, 3 and 4 months. Significantly increased perinephric fat pads were measured at termination. Liver weights were slightly increased. Pre-differentiated fat cells were treated with chlorpyrifos in vitro at 0.008 µg/ml or 10 µl DMSO and there was no effect on normal cell growth. There was fat accumulation but no increase in number of cells or increased cell growth. There were, however increases in cell death compared to control.

Wang et al., 2009. The metabolic profiles of serum were examined after chlorpyrifos treatment in adult (M/F; 6-8 week old) Wistar rats to evaluate their metabolic status. The profiles are indicators of metabolite (low molecular weight), proteins (high molecular weight) and lipoprotein particles (supramolecular weight) levels that are detected by ^{3}H-nuclear magnetic resonance (^{3}H-NMR). Rats were treated at 1.30, 3.26, and 8.15 mg/kg/day chlorpyrifos (M) or 1.08, 2.70, and 6.75 mg/kg/d (F) by gavage (corn oil vehicle) for 90 days. Results indicated that serum aminotransferase (ALT) and total bilirubin levels from rats treated at the high dose increased by 29 and 35%, respectively in the absence of histopathology at any dose. Metabolic profiles showed that males and females had similar changes at the mid and high doses compared to controls. Chlorpyrifos treatment led to disruption of key ketone-metabolizing enzymes in the liver mitochondria and protein metabolism in the liver was also affected, as shown by a high level of glycoprotein. The authors conclude that chlorpyrifos at doses of 2.7 mg/kg/d and greater can disrupt energy production and fatty acid metabolism in the absence of histopathology in the liver and blood chemistry changes.

Peris-Sampedro et al., 2015b. A strain of mice expressing the human apolipoprotein E3 (apoE3) genetic isoform were used in this study to examine the association between this gene and obesity and related metabolic disorders. ApoE3, from the apoE gene, is a protein that combines with lipids (e.g., cholesterol and other fats) to form lipoproteins which can then be transported through the blood. Male TR apoE3 mice (homozygous for the human E3 allele) and C57BL/6N male mice were treated with CPF in diet at 0 or 2.0 mg/kg/d for 8 weeks. Animals were checked for cholinergic signs twice per week, bodyweights and food and water consumption were measured and plasma ChE activity was assayed. Metabolic biomarkers (total cholesterol, triglycerides, albumin, creatinine, aspartate (AST) and alanine (ALT) transaminases) and insulin sensitivity were measured. Insulin sensitivity was estimated by measuring fasting plasma insulin and calculating an insulin resistance score (homeostatic model assessment for insulin resistance [IR]; HOMA-IR = (fasting insulin x fasting glucose)/22.5). Plasma leptin, total ghrelin (orexigenic [appetite-stimulating] hormone from stomach or brain) and acyl ghrelin (circulating form of ghrelin) levels were quantified. Plasma ChE was inhibited by 68% after 8 weeks in both CPF-treated genotypes. In chlorpyrifos-treated mice, food intake (both genotypes) and body weights were statistically significantly increased weeks 4 through 8 in apoE3 mice as compared with week 8 only in C57BL/6N mice. Plasma metabolic biomarkers (cholesterol and triglycerides) in chlorpyrifos-treated apoE3 mice were increased.

Fang et al., 2018. This study was performed to investigate the effect of chlorpyrifos on the microbiota in relation to potential risk factors for obesity, diabetes, and neurotoxicity. Adult male Wistar rats (8 weeks old) were fed a normal fat (NF) or high fat (HF) diet and were gavaged with either 0 (DMSO in saline + tween), 0.3 (normal fat-low, NF-L or high fat-low, HF-L), or 3.0 mg/kg/d chlorpyrifos (normal fat-high, NF-H or high fat-high, HF-H; 6/dose) for 9 weeks. Plasma glucose was decreased in the normal fat/low dose animals, but only at 60 and 90 minutes, not at 9 weeks. There were no significant effects on total triglycerides, total cholesterol, HDL-C or LDL-C. However, animals in the high fat diet group showed increased triglycerides. Animals receiving doses of 0.3 mg/kg/d chlorpyrifos showed decreases in peptides compared to controls, although the effect was not shown at the higher dose.

II.O. Recent Advances in Chlorpyrifos PBPK Modeling

A recent study by Zurlinden and Reisfeld (2018) proposed a method to use a health-based end point in conjunction with the existing validated PBPK-PD model to estimate a benchmark dose for chlorpyrifos. The authors first generated an exposure space database by running the PBPK-PD model for a total of 10,000 Monte-Carlo sampling draws based on four exposure parameters (exposure route, dose, exposure periodicity, and exposure duration) in a 30-day subchronic exposure setting. They then selected an in vivo rat study (Yan *et al.*, 2012) as a validation dataset to connect an internal dose metric (peak brain chlorpyrifos concentration) to a health-based end point (a cognitive deficit in spatial learning from Yan study). The PBPK model was then used to derive corresponding peak brain chlorpyrifos concentrations for different exposure doses (0, 1, 5, 10 mg/kg). A mathematic dose-response model-Emax (Hill) equation was used to describe the relationship between predicted peak brain chlorpyrifos concentration and observed fractional cognitive deficit. The peak brain chlorpyrifos concentration giving rise to a 15% cognitive deficit was selected as the PoD benchmark dose, which corresponded to a peak brain chlorpyrifos

concentration of 8.82 x 10^{-6} µM. This concentration is approximately 19.6-fold lower than the peak brain chlorpyrifos associated with 20% RBC AChE inhibition and 54.8-fold lower than the peak brain chlorpyrifos associated with 10% brain AChE inhibition (Zurlinden and Reisfeld, 2018). This dose-response model was subsequently used to generate a corresponding fractional cognitive deficit data point for each simulated exposure scenario based on the predicted peak brain chlorpyrifos concentration from the exposure space database generated at the beginning for both rats and humans. The authors then used a mathematic equation to relate the cognitive deficit end point to predicted plasma chlorpyrifos concentration in rats.

Additional explanation of the author's findings are beyond the scope of this assessment, however HHA concludes that successful application of this novel approach requires a validated interspecies PBPK-PD model for internal dose prediction, a critical dose metric to serve as the internal dose across species, and a quantifiable behavioral outcome observed in dose-response in animals. Some of the main limitations of the study include: 1) behavioral endpoints in the rats are not adequately correlated to cognitive deficits in humans; 2) use of a validation dataset based on chlorpyrifos dose levels that can be overtly toxic; and, 3) the assumption that chlorpyrifos parent is the penultimate toxicant associated with neurobehavioral deficits. Additionally, HHA is concerned with several mathematical errors found in the publication including in the formula used to convert enzyme availability to inhibition and in calculations for percent of enzyme inhibition corresponding to the threshold cognitive deficit. As such, HHA will reevaluate this approach as appropriate when new data become available.

III. HAZARD IDENTIFICATION

III.A. Introduction

Critical points of departure (PoD) for chlorpyrifos were established from animal studies reporting DNT effects at dose levels that are generally considered lower than those necessary for RBC AChE inhibition. As defined by US EPA (2012a), a point of departure is the dose-response point that marks the starting point for low-dose extrapolation, and the PoD generally corresponds to a selected estimated low-level of response. For the in vivo animal DNT studies used in this risk assessment, the primary exposure route is oral.

III.B. Acute and Short-Term Toxicity

III.B.1. Oral Toxicity

The human epidemiological studies that showed association between chlorpyrifos exposure during gestation and impacts on human growth and development could not be used to establish critical PoDs for DNT because exposure-effect relationships were not completely elucidated and because of concerns with analytical methodologies used for quantifying exposure. While many DNT studies in animals were available for chlorpyrifos, the focus for this assessment was on studies that reported neurodevelopmental effects occurring at doses lower than those causing AChE inhibition. The toxicity studies that were considered for establishing critical neurodevelopmental PoDs are listed in Table 11.

Five recently published studies reported developmental toxicity in rodents at doses causing minimal or no brain AChE inhibition. Four of these studies used rats and one study was conducted in mice. In every case, exposure was by the oral route (three by gavage, two through the diet). Two studies employed both gestational and lactational exposure through the dams (a total of 35 doses, 14 consecutive daily doses during pregnancy and 21 doses during lactation). Two studies employed direct pup exposure for either one or seven days starting at PND 10. Neurodevelopmental responses in offspring were tested either in in young pups (PNDs 21-25) or in adults (60-90 days). Three studies reported increased motor or total activity, two studies showed altered anxiety levels (decreased or increased), and one study detected impaired spatial learning. LOELs for the observed neurodevelopmental effects were 0.1-0.5 mg/kg/day. In four of the studies, the LOEL was the lowest tested dose. Applying an uncertainty factor of 10 to those LOELs would result in an estimated no effect level (ENEL) for DNT of 0.01-0.05 mg/kg/day. One study included a NOEL dose based on increased anxiety and motor activity in rats that were exposed in utero with chlorpyrifos for 6 days (Silva *et al.*, 2017). Only one study concurrently measured AChE activity, setting the LOEL for brain AChE inhibition at 1.0 mg/kg/day (Carr *et al.*, 2017).

A registrant-submitted DNT study measured brain, RBC, and plasma ChE in addition to neurodevelopmental outcomes (Hoberman, 1998). This study employed both gestational and lactational exposure through the dams (a total of 26 doses, 15 consecutive daily doses during pregnancy and 11 doses during lactation). RBC AChE inhibition was the most sensitive endpoint in this study, with a $BMDL_{10}$ / BMD_{10} of 0.03 / 0.06 mg/kg/day. HHA set the developmental LOEL at 1 mg/kg/day for reduced cortex and hippocampal dimensions in PND 66-71 females. This LOEL was 10 fold higher than the LOEL for DNT reported in the published studies.

In conclusion, new findings from published animal studies indicated that the developing nervous system is sensitive to low doses of chlorpyrifos that are not expected to inhibit brain or RBC AChE activities. Based on the five studies in Table 11, the collective LOEL for neurodevelopmental effects including in cognition, motor control, and behavior in rats and mice is 0.1 mg/kg/day. A NOEL of 0.01 mg/kg/day was established by Silva et al., (2017) based on increased anxiety and motor activity in rat pups. This NOEL is supported by the ENELs of 0.05-0.01 mg/kg/day estimated from the DNT LOELs of 0.5-0.1 by applying a 10 fold UF. The exposure duration in the 5 published studies varied from 1 to 35 days. Therefore, the NOEL of 0.01 mg/kg/day could be applicable to acute and repeated exposures to chlorpyrifos in infants, children, and females of childbearing age. A more conservative approach when considering developmental effects is that they occur as the result of a single acute exposure, rather than ongoing or cumulative exposures. Therefore in the remainder of this assessment, HHA uses the assumption that chlorpyrifos-mediated developmental toxicity may result from a single exposure equivalent to 0.01 mg/kg/day.

Table 11. Selected Developmental Neurotoxicity Studies in Rats and Mice

Species, Dosing Period, Doses (mg/kg/day)	Cholinesterase Inhibition				Developmental Neurotoxicity		Study
	Time tested	LOEL NOEL			Effects	LOEL NOEL	
		Plasma	RBC	Brain			
Gestation and postnatal exposure							
Rat Gavage GD 6-LD 11 0.3, 1.0, 5.0	Dam LD 22	0.3 --	0.06[a] **0.03[b]**	0.65[a] **0.54[b]**	Reduced parietal cortex and hippocampal dimensions in PND 66-71 females	1.0 --	Hoberman, 1998
Rat Diet GD 7- PND 21 0.1, 0.3, 1.0	Not tested	--	--	--	Decreased spatial learning in 2-3 month old males	0.1 --	Gómez-Giménez et al., 2017
Rat Diet GD 7- PND 21 0.1, 0.3, 1.0	Not tested	--	--	--	Increased spontaneous motor activity in 2-3 month old males and females	0.1 --	Gómez-Giménez et al., 2018
Gestation-only exposure							
Rat Gavage GD 14-20 0.01, 0.1, 1.0, 10	Not tested	--	--	--	Increased anxiety and locomotor activity in PND21 males	0.1 **0.01**	Silva et al., 2017
Postnatal- only exposure							
Rat Gavage PND 10-16 0.5, 0.75 & 1.0	Pups PND 16	--	--	1.0 **0.75**	Decreased anxiety in PND25 males and females	0.5 --	Carr et al., 2017
Mouse Gavage PND 10 0.1, 1.0, 5.0	Pups PND 10	--	--	5.0 --	Increased total activity in PND 60 males	0.1 --	Lee et al., 2015

[a] BMD_{10} –BMD analysis in US EPA, 2011
[b] $BMDL_{10}$ –BMD analysis in US EPA, 2011
Abbreviations: LOEL, lowest observed effect level; NOEL, no observed effect level ; GD, gestation day; LD, lactation day; PND, postnatal day
Red text denotes the study NOEL, if available

III.B.2. Dermal and Inhalation Toxicity

Studies were not available to establish dermal and inhalation PODs for developmental neurotoxicity. Therefore, the acute oral PoD of 0.01 mg/kg/day was used to evaluate acute dermal and inhalation exposures using route-to-route extrapolation.

IV. EXPOSURE ASSESSMENT

The following is an update to the exposure assessment from the December 2017 Draft TAC Evaluation.

IV.A. Introduction

Spray Drift Exposure Estimates

Exposure associated with chlorpyrifos spray drift near an application site was evaluated for four population subgroups: infants, children 1-2 years old, children 6-12 years old, and females of childbearing age (13-49 years old). These groups were chosen because of the assumed susceptibility to chlorpyrifos-related developmental neurotoxicity, the critical endpoint used in this risk assessment. The standard operating procedure (SOP) assumed that the turf contact duration of exposure for infants, children 1-2 years old, children 6-12 years old, and females of childbearing age (13-49 years old) near the application sites would be 1.5 hours and inhalation exposure duration is 1 hour. The US EPA Residential SOP (Addenda 1: Consideration of Spray Drift) argues that children 1-2 years old exhibit the highest exposure potential to pesticides on contaminated lawn from spray drift because of dermal contact and different mouthing activities such as hand-to-mouth, object-to-mouth, and incidental soil ingestion (US EPA, 2012a). As such, US EPA determined that children 1 – 2 years old represent the most appropriate index childhood life stage for most individual SOPs. However, for completeness and following suggestions made at the January and March 2018 SRP hearings, HHA has expanded this exposure assessment to include infants (< 1 year old) as well as children 6 – 12 years old.

Values for all assumptions necessary in estimating exposures are not available for all four age groups, so several replacement values were used. Exposure routes for children 1 – 2 years old are well characterized (including for incidental oral exposure). The same is not true for infants between 6 – 12 months. As such, this exposure assessment used the transfer coefficient for children 1 – 2 years old combined with the infant body weight and breathing weight assumptions to estimate dermal exposure for infants. The same held true for mouthing activities, where the assumptions for children 1 – 2 years old are better characterized than they are for infants. Therefore, the dermal exposure and incidental oral exposure from hand-to-mouth and object-to-mouth activities derived for infants may be overestimates of the actual exposure values. To estimate exposures for children 6-12 years old, it was necessary to use the adult transfer coefficient for dermal contact, although age specific body weight and breathing rates were available to complete the exposure characterization. Incidental oral exposure from hand-to-mouth or object-to-mouth activities was not estimated for children 6 – 12 years old or for females of childbearing age (13 – 49 years old) because that type of activity have a very low occurrence in those age groups (Xue *et al.*, 2010).

Aerial Applications

Single application exposure estimates via horizontal deposition (in mg/kg/day) and inhalation as both inhalation exposure (in mg/kg/day) and 1 hour time-weighted average air concentrations (in mg/m^3) of chlorpyrifos were considered for four subpopulations: infants, children 1-2 years old, children 6-12 years old, and females of childbearing age (13-49 years old) and three application rates for two types of aircraft: fixed-wing (AT802A airplane) and rotary (Bell 205 helicopters). Increases in chlorpyrifos application rates resulted in a corresponding increase in the exposure estimates.

The standard practice at DPR is to calculate exposure estimates based on single application scenarios. Exposure estimates for multiple or simultaneous applications are considered the purview of risk mitigation and management and, as such, are not included in the exposure

analysis of a specific pesticide. For this exposure assessment, and later for evaluating the margins of exposure, HHA used a fixed wing aerial application of chlorpyrifos with 2 gallons/acre finished spray volume and 2 lbs/acre application rate as its standard exposure scenario. This reflects the most common aircraft used for aerial applications in California, as well as the most common and reasonable "worst case" scenario for application rates and volumes. The reader will find calculated estimates for dermal, oral, and inhalation doses and air concentrations for several other application rates and volumes for fixed wing aircraft in Tables 12 – 17, below. A complete listing of exposure estimates for all aircraft types, application rates and volumes, and application types can be found in Appendix 2 herein. Additional background information about the assumptions used in the exposure analysis can be found in the December 2017 Draft TAC Evaluation.

Ground-Based Applications

Horizontal deposition exposure estimates (in mg/kg/day) of chlorpyrifos were evaluated for the same four population subgroups at four application rates, up to the labeled maximum rate, with two ground-based application methods: ground boom and airblast. For ground boom, horizontal deposition estimates were derived using two swath percentiles: 50^{th} and 90^{th}. Horizontal deposition exposure estimates of chlorpyrifos after ground boom or airblast application showed that exposure increases with increasing application rates. The higher horizontal deposition exposure estimates of the high-boom compared with the low-boom is consistent with the difference in the spray release height above the target between high- and low-boom (50 and 20 inches above the target, respectively). All other factors held constant, horizontal deposition increases as a function of boom height above the target. The higher near-field horizontal deposition exposure estimates shown by orchard airblast compared to ground boom are consistent with the much finer droplet spectrum of the airblast sprayer application method and the upward direction by the airblast sprayer of fine spray into the orchard canopy. See Appendix 2 for complete results of the exposure estimations for ground boom and airblast.

IV.B. Spray Drift Exposure Assessment Approach

For assessing the short-term exposure due to off-site movement of chlorpyrifos, this exposure assessment adopted the method of US EPA (Dawson et al., 2012); that is, spray drift modeling coupled with post-application assessment of dermal and inhalation exposures. For the spray drift modeling, two computer models were employed: AgDRIFT (spray drift regression model version 2.0.05) for ground boom and orchard airblast applications; and, AGDISP (AGricultural DISPersal near-wake Lagrangian model version 8.28) for aerial applications (Barry, 2015). For the post-application assessment, the US EPA SOP for residential exposure assessment was followed (US EPA, 2013). Spray drift air concentrations were modeled from 25 to 2608 feet. The range of modeled distances was chosen because a buffer zone of 25 feet is required for aerial application of chlorpyrifos and 2608 feet is the computational limit of the model.

Technical description of these models and exposure estimation methods have been detailed elsewhere (Teske *et al.*, 2002a; Teske *et al.*, 2002b; Barry, 2015). Both AgDRIFT and AGDISP models were used to estimate off-site horizontal deposition of chlorpyrifos at different distances downwind. Scenarios and input parameter values were chosen to represent the reasonable worst case application conditions so that spray drift is not underestimated for the application scenarios

assessed. AGDISP was used to estimate horizontal deposition and 1 hour time-weighted average air concentrations (mg/m^3) of chlorpyrifos at vertical heights of 1.7 ft, and 5 ft. The vertical heights of 1.7 ft represents the breathing zones of infants and children 1-2 years old, 5 ft represents the breathing zones of children 6-12 years old, and females 13-49 years old. The aerial application exposure scenarios evaluated in this exposure assessment used the estimated air concentrations for each specific scenario. For airblast and ground boom, horizontal deposition was estimated with AgDRIFT but the AGDISP model was used to produce surrogate air concentrations using a default aerial application (fixed wing AT802A aircraft with a finished spray volume of 2 gal/acre) and the specific application rates for each airblast and ground boom scenario evaluated in this exposure assessment. This choice of surrogate air concentrations has been previously used by US EPA to characterize inhalation exposures due to spray drift associated with orchard airblast and ground boom applications (Dawson *et al.*, 2012); US EPA 2012b). The AGDISP model is a mass conserving model and provides an air concentration calculated based on the airborne mass passing through a flux plane at specific distances. The mass includes all active ingredient material still airborne when the spray drift cloud passes a particular flux plane. HHA assumes that all mass in the air is 100% available and absorbed.

IV.C. Spray Drift Exposure Estimates

A complete analysis of spray drift exposure estimates along with margins of exposure can be found in Appendix 2 of this document.

IV.C.1. Aerial Applications

Tables 12 and 13 show primary spray drift exposure estimates for fixed wing aircraft applying 2 lbs chlorpyrifos /acre application rate and 2 gallons/acre (GPA) finished spray. Exposures due to contact with chlorpyrifos deposited on turf and to inhalation of chlorpyrifos residues in the air are shown. The Infant age group shows the highest exposure due to the smallest body weight and the highest breathing rate. In addition, exposures for all age groups increase with increasing application rate but within a single application rate exposures decrease with increasing distance downwind from the application. A full set of exposure estimates for additional aerial application exposure scenarios can be found in Appendix 2. These additional scenarios include fixed wing and helicopter application methods in addition to application rates of 1, 2, and 2.3 lbs chlorpyrifos /acre application rates at 2 GPA and 15 GPA finished spray volumes. A full discussion on aerial application scenario development methods and primary spray drift can be found in (Barry, 2017).

IV.C.2.Ground-Based Applications

Tables 14 and 15 show primary spray drift exposure due to horizontal deposition onto turf from a dormant apple orchard airblast application at 2 lbs chlorpyrifos/acre application rate. In addition, primary spray drift exposure due to inhalation of chlorpyrifos residues in air is estimated using surrogate air concentrations from the default aerial scenario of fixed wing aircraft applying 2 lbs chlorpyrifos /acre application rate and 2 gallons/acre (GPA) finished spray. Exposure estimates were developed for two types of orchards (dormant apple and sparse orchard) and 4 application rates (1, 2, 4, and 6 lbs chlorpyrifos /acre). The full set of orchard airblast application exposure

estimates can be found in Appendix 2. Discussion on orchard airblast application method scenario development and primary spray drift can be found in Barry, 2017.

Table 16 and 17 show primary spray drift exposure due to horizontal deposition onto turf from a ground boom high boom application. In addition, primary spray drift exposure due to inhalation of chlorpyrifos residues in air is estimated using surrogate air concentrations from the default aerial scenario of fixed wing aircraft applying 2 lbs chlorpyrifos /acre application rate and 2 gallons/acre (GPA) finished spray. For ground boom spray drift deposition estimates were derived for two boom heights (low and high), 4 application rates (1, 2, 4, and 6 lbs chlorpyrifos /acre), and two statistical percentiles (50^{th} and 90^{th}). The full set ground boom application exposure estimates can be found in in Appendix 2. Discussion on ground boom application method scenario development and primary spray drift can be found in Barry, 2017.

For both orchard airblast and ground boom, the infant age group shows the highest exposure due to the smallest body weight and the highest breathing rate. In addition, exposures for all age groups increase with increasing application rate, but within a single application rate exposures decrease with increasing distance downwind from the application.

Table 12. Dermal, Oral, Inhalation Doses, and Inhalation Concentration for Infants and Children 1-2 years old at Various Distances Downwind from the Fields Treated with Chlorpyrifos by AT802A Fixed Wing Aircraft at 2 gallons/acre[a] Finished Spray Volume and 2 lb/acre Chlorpyrifos Application Rate

Age group	Downwind Distance (feet)	Dermal 9.6% Absorption[e] (mg/kg/day)	Hand-to-Mouth (mg/kg/day)	Object-to-Mouth (mg/kg/day)	Soil Ingestion (mg/kg/day)	Inhalation (mg/kg/day)	Inhalation 1-hr TWA Air Concentration (mg/m^3)
Infants[b]	25[d]	0.009937	0.002153	0.000066	0.000016	0.001212	0.0493
	50	0.007792	0.001689	0.000052	0.000013	0.001074	0.0437
	100	0.005205	0.001128	0.000035	0.000008	0.000860	0.0350
	250	0.002605	0.000565	0.000017	0.000004	0.000583	0.0237
	500	0.001418	0.000307	0.000009	0.000002	0.000376	0.0153
	1000	0.000557	0.000121	0.000004	0.000001	0.000177	0.0072
	1320	0.000327	0.000071	0.000002	0.000001	0.000121	0.0049
	2608	0.000061	0.000013	0.000000	0.000000	0.000040	0.0016
Children 1-2 years old[c]	25	0.00581	0.00126	0.000039	0.000009	0.001085	0.0493
	50	0.00456	0.00099	0.000030	0.000007	0.000961	0.0437
	100	0.00304	0.00066	0.000020	0.000005	0.000770	0.0350
	250	0.00152	0.00033	0.000010	0.000002	0.000521	0.0237
	500	0.00083	0.00018	0.000006	0.000001	0.000337	0.0153
	1000	0.00033	0.00007	0.000002	0.000001	0.000158	0.0072
	1320	0.00019	0.00004	0.000001	0.000000	0.000108	0.0049
	2608	0.00004	0.00001	0.000000	0.000000	0.000036	0.0016

[a] Minimum spray volume as specified on some chlorpyrifos product labels for the aerial application.
[b] Infants: Transfer Coefficient (cm^2/hr) = 49000 (US EPA, 2012a); body weight = 7.6 kg; normalized daily average breathing rate = (0.59 m^3/kg/day)/24 hr= 0.025 m^3/kg/hr; breathing height = 1.7 ft (Andrews and Patterson, 2000; See Appendix 4)
[c] Children 1-2 years old: Transfer Coefficient (cm^2/hr) = 49000 (US EPA, 2012a); body weight = 13 kg; normalized daily average breathing rate = (0.52 m^3/kg/day)/24 hr = 0.022 m^3/kg/hr; breathing height = 1.7 ft (Andrews and Patterson, 2000; See Appendix 4)
[d] Buffer zone of 25 feet is required for aerial application of chlorpyrifos.
[e] Data derived chlorpyrifos dermal absorption rate (Thongsinthusak, 1991).

Table 13. Dermal, Oral, Inhalation Doses, and Inhalation Concentration for Children 6-12 years old and Females 13- 49 years old at Various Distances Downwind from the Fields Treated with Chlorpyrifos by AT802A Fixed Wing Aircraft at 2 lb/acre Application Rate and 2 gallons/acre[a] Finished Spray Volume

Age group	Downwind Distance (feet)	Dermal 9.6% Absorption[e] (mg/kg/day)	Inhalation (mg/kg/day)	Inhalation 1-hr TWA Air Concentration (mg/m^3)
Children 6-12 years old[b]	25[d]	0.010670	0.000587	0.0367
	50	0.008367	0.000512	0.0320
	100	0.005589	0.000414	0.0259
	250	0.002798	0.000278	0.0174
	500	0.001522	0.000178	0.0111
	1000	0.000599	0.000083	0.0052
	1320	0.000351	0.000058	0.0036
	2608	0.000065	0.000019	0.0012
Females 13-49 years old[c]	25	0.003864	0.000440	0.0367
	50	0.003030	0.000384	0.0320
	100	0.002024	0.000311	0.0259
	250	0.001013	0.000209	0.0174
	500	0.000551	0.000133	0.0111
	1000	0.000217	0.000062	0.0052
	1320	0.000127	0.000043	0.0036
	2608	0.000024	0.000014	0.0012

[a] Minimum spray volume as specified on some chlorpyrifos product labels for the aerial application.
[b] Children 6-12 years old: Transfer Coefficient (cm^2/hr) = 180000 (US EPA, 2012a); body weight = 26 kg; normalized daily average breathing rate = (0.38 $m^3/kg/day$)/24 hr = 0.016 $m^3/kg/hr$; breathing height = 5 ft (Andrews and Patterson, 2000; See Appendix 4)
[c] Females 13-49 years old: Transfer Coefficient (cm^2/hr) = 180000 (US EPA, 2012a); body weight = 71.8 kg; normalized daily average breathing rate = (0.28 $m^3/kg/day$)/24 hr = 0.012 $m^3/kg/hr$; breathing height = 5 ft (Andrews and Patterson, 2000; See Appendix 4)
[d] Buffer zone of 25 feet is required for aerial application of chlorpyrifos.
[e] Data derived chlorpyrifos dermal absorption rate (Thongsinthusak, 1991).

Table 14. Dermal, Oral, Inhalation Doses, and Inhalation Concentration for Infants and Children 1-2 years old at Various Distances Downwind from the Fields Treated with Chlorpyrifos by Dormant Apple Orchard Airblast 2 lb/acre Application Rate and Surrogate Air Concentrations using Wing Aircraft at 2 gallons/acre[a] Finished Spray Volume and 2 lb/acre Application Rate

Age group	Downwind Distance (feet)	Dermal 9.6% Absorption[e] (mg/kg/day)	Hand-to-Mouth (mg/kg/day)	Object-to-Mouth (mg/kg/day)	Soil Ingestion (mg/kg/day)	Inhalation (mg/kg/day)	Inhalation 1-hr TWA Air Concentration (mg/m^3)
Infants[b]	25[d]	0.003354	0.000727	0.000022	0.000005	0.001212	0.0493
	50	0.001276	0.000277	0.000008	0.000002	0.001074	0.0437
	100	0.000356	0.000077	0.000002	0.000001	0.000860	0.0350
	250	0.000048	0.000010	0.000000	0.000000	0.000583	0.0237
	500	0.000008	0.000002	0.000000	0.000000	0.000376	0.0153
	1000	0.000002	0.000000	0.000000	0.000000	0.000177	0.0072
	1320	0.000001	0.000000	0.000000	0.000000	0.000120	0.0049
	2608	0.000000	0.000000	0.000000	0.000000	0.000039	0.0016
Children 1-2 years old[c]	25	0.001961	0.000425	0.000013	0.000003	0.001085	0.0493
	50	0.000746	0.000162	0.000005	0.000001	0.000961	0.0437
	100	0.000208	0.000045	0.000001	0.000000	0.000770	0.0350
	250	0.000028	0.000006	0.000000	0.000000	0.000521	0.0237
	500	0.000005	0.000001	0.000000	0.000000	0.000337	0.0153
	1000	0.000001	0.000000	0.000000	0.000000	0.000158	0.0072
	1320	0.000000	0.000000	0.000000	0.000000	0.000108	0.0049
	2608	0.000000	0.000000	0.000000	0.000000	0.000036	0.0016

[a] Minimum spray volume as specified on some chlorpyrifos product labels for the aerial application.
[b] Infants: Transfer Coefficient (cm^2/hr) = 49000 (US EPA, 2012a); body weight = 7.6 kg; normalized daily average breathing rate = (0.59 m^3/kg/day)/24 hr = 0.025 m^3/kg/hr; breathing height = 1.7 ft (Andrews and Patterson, 2000; See Appendix 4)
[c] Children 1-2 years old: Transfer Coefficient (cm^2/hr) = 49000 (US EPA, 2012a); body weight = 13 kg; normalized daily average breathing rate = (0.52 m^3/kg/day)/24 hr = 0.022 m^3/kg/hr; breathing height = 1.7 ft (Andrews and Patterson, 2000; See Appendix 4)
[d] Buffer zone of 25 feet is required for aerial application of chlorpyrifos.
[e] Data derived chlorpyrifos dermal absorption rate (Thongsinthusak, 1991).

Table 15. Dermal, Oral, Inhalation Doses, and Inhalation Concentration for Children 6-12 years old and Females 13- 49 years old at Various Distances Downwind from the Fields Treated with Chlorpyrifos by Dormant Apple Orchard Airblast 2 lb/acre Application Rate and Surrogate Air Concentrations using Wing Aircraft at 2 lb/acre Application Rate and 2 gallons/acre[a] Finished Spray Volume

Age group	Downwind Distance (feet)	Dermal 9.6% Absorption[e] (mg/kg/day)	Inhalation (mg/kg/day)	Inhalation 1-hr TWA Air Concentration (mg/m^3)
Children 6-12 years old[b]	25[d]	0.003601	0.000587	0.0367
	50	0.001370	0.000512	0.0320
	100	0.000382	0.000414	0.0259
	250	0.000051	0.000278	0.0174
	500	0.000009	0.000178	0.0111
	1000	0.000002	0.000083	0.0052
	1320	0.000001	0.000058	0.0036
	2608	0.000000	0.000019	0.0012
Females 13-49 years old[c]	25	0.001304	0.000440	0.0367
	50	0.000496	0.000384	0.0320
	100	0.000138	0.000311	0.0259
	250	0.000019	0.000209	0.0174
	500	0.000003	0.000133	0.0111
	1000	0.000001	0.000062	0.0052
	1320	0.000000	0.000043	0.0036
	2608	0.000000	0.000014	0.0012

[a] Minimum spray volume as specified on some chlorpyrifos product labels for the aerial application.
[b] Children 6-12 years old: Transfer Coefficient (cm^2/hr) = 180000 (US EPA, 2012a); body weight = 26 kg; normalized daily average breathing rate = (0.38 $m^3/kg/day$)/24 hr = 0.016 $m^3/kg/hr$; breathing height = 5 ft (Andrews and Patterson, 2000; See Appendix 4)
[c] Females 13-49 years old: Transfer Coefficient (cm^2/hr) = 180000 (US EPA, 2012a); body weight = 71.8 kg; normalized daily average breathing rate = (0.28 $m^3/kg/day$)/24 hr = 0.012 $m^3/kg/hr$; breathing height = 5 ft (Andrews and Patterson, 2000; See Appendix 4)
[d] Buffer zone of 25 feet is required for aerial application of chlorpyrifos.
[e] Data derived chlorpyrifos dermal absorption rate (Thongsinthusak, 1991).

Table 16. Dermal, Oral, Inhalation Doses, and Inhalation Concentration for Infants and Children 1-2 years old at Various Distances Downwind from the Fields Treated with Chlorpyrifos by Ground Boom High Boom at 2 lb/acre Application Rate and Surrogate Air Concentrations using Wing Aircraft at 2 lb/acre Application Rate and 2 gallons/acre[a] Finished Spray Volume

Age group	Downwind Distance (feet)	Dermal 9.6% Absorption[e] (mg/kg/day)	Hand-to-Mouth (mg/kg/day)	Object-to-Mouth (mg/kg/day)	Soil Ingestion (mg/kg/day)	Inhalation (mg/kg/day)	Inhalation 1-hr TWA Air Concentration (mg/m^3)
Infants[b]	25[d]	0.000576	0.000125	0.000004	0.000001	0.001212	0.0493
	50	0.000382	0.000083	0.000003	0.000001	0.001074	0.0437
	100	0.000224	0.000049	0.000001	0.000000	0.000860	0.0350
	250	0.000103	0.000022	0.000001	0.000000	0.000583	0.0237
	500	0.000044	0.000010	0.000000	0.000000	0.000376	0.0153
	1000	0.000013	0.000003	0.000000	0.000000	0.000177	0.0072
	1320	0.000007	0.000002	0.000000	0.000000	0.000120	0.0049
	2608	0.000001	0.000000	0.000000	0.000000	0.000039	0.0016
Children 1-2 years old[c]	25	0.000337	0.000073	0.000002	0.000001	0.001085	0.0493
	50	0.000223	0.000048	0.000001	0.000000	0.000961	0.0437
	100	0.000131	0.000028	0.000001	0.000000	0.000770	0.0350
	250	0.000060	0.000013	0.000000	0.000000	0.000521	0.0237
	500	0.000026	0.000006	0.000000	0.000000	0.000337	0.0153
	1000	0.000008	0.000002	0.000000	0.000000	0.000158	0.0072
	1320	0.000004	0.000001	0.000000	0.000000	0.000108	0.0049
	2608	0.000001	0.000000	0.000000	0.000000	0.000036	0.0016

[a] Minimum spray volume as specified on some chlorpyrifos product labels for the aerial application.
[b] Infants: Transfer Coefficient (cm^2/hr) = 49000 (US EPA, 2012a); body weight = 7.6 kg; normalized daily average breathing rate = (0.59 m^3/kg/day)/24 hr = 0.025 m^3/kg/hr; breathing height = 1.7 ft (Andrews and Patterson, 2000; See Appendix 4)
[c] Children 1-2 years old: Transfer Coefficient (cm^2/hr) = 49000 (US EPA, 2012a); body weight = 13 kg; normalized daily average breathing rate = (0.52 m^3/kg/day)/24hr = 0.022 m^3/kg/hr; breathing height = 1.7 ft (Andrews and Patterson, 2000; See Appendix 4)
[d] Buffer zone of 25 feet is required for aerial application of chlorpyrifos.
[e] Data derived chlorpyrifos dermal absorption rate (Thongsinthusak, 1991).

Table 17. Dermal, Oral, Inhalation Doses, and Inhalation Concentration for Children 6-12 years old and Females 13- 49 years old at Various Distances Downwind from the Fields Treated with Chlorpyrifos by Ground Boom High Boom at 2 lb/acre Application Rate and Surrogate Air Concentrations using Wing Aircraft at 2 lb/acre Application Rate and 2 gallons/acre[a] Finished Spray Volume

Age group	Downwind Distance (feet)	Dermal 9.6% Absorption[e] (mg/kg/day)	Inhalation (mg/kg/day)	Inhalation 1-hr TWA Air Concentration (mg/m^3)
Children 6-12 years old[b]	25[d]	0.000618	0.000587	0.0367
	50	0.000410	0.000512	0.0320
	100	0.000241	0.000414	0.0259
	250	0.000111	0.000278	0.0174
	500	0.000047	0.000178	0.0111
	1000	0.000014	0.000083	0.0052
	1320	0.000008	0.000058	0.0036
	2608	0.000001	0.000019	0.0012
Females 13-49 years old[c]	25	0.000224	0.000440	0.0367
	50	0.000148	0.000384	0.0320
	100	0.000087	0.000311	0.0259
	250	0.000040	0.000209	0.0174
	500	0.000017	0.000133	0.0111
	1000	0.000005	0.000062	0.0052
	1320	0.000003	0.000043	0.0036
	2608	0.000000	0.000014	0.0012

[a] Minimum spray volume as specified on some chlorpyrifos product labels for the aerial application.
[b] Children 6-12 years old: Transfer Coefficient (cm^2/hr) = 180000 (US EPA, 2012a); body weight = 26 kg; normalized daily average breathing rate = (0.38 m^3/kg/day)/24 hr = 0.016 m^3/kg/hr; breathing height = 5 ft (Andrews and Patterson, 2000; See Appendix 4)
[c] Females 13-49 years old: Transfer Coefficient (cm^2/hr) = 180000 (US EPA, 2012a); body weight = 71.8 kg; normalized daily average breathing rate = (0.28 m^3/kg/day)/24 hr = 0.012 m^3/kg/hr; breathing height = 5 ft (Andrews and Patterson, 2000; See Appendix 4)
[d] Buffer zone of 25 feet is required for aerial application of chlorpyrifos.
[e] Data derived chlorpyrifos dermal absorption rate (Thongsinthusak, 1991.

IV.D. Secondary Drift Exposure Estimates

As suggested at the January and March 2018 SRP hearings, HHA re-evaluated the potential influence of secondary drift on total exposure risk to chlorpyrifos. The most recent 5 years of data within the DPR Air Monitoring Network (AMN) (http://www.cdpr.ca.gov/docs/emon/airinit/air_network_results.htm) were used to assess the potential for exposure due to secondary drift (re-volatilization). Air concentrations and 24-hr inhalation exposures are shown in Table 18. The 24-hr TWA air samples collected by the AMN include both primary drift from applications in the area close to a particular sampler in addition to any secondary drift from those applications. Thus, the results shown in Table 18 are likely overestimates of secondary drift exposures. Because of the very small influence of secondary drift on the total exposure estimates as calculated herein, the influence of secondary drift was excluded from further exposure analysis calculations. Note that both the modeled air concentrations (above) and the monitored air concentrations (Table 18) are denoted in units of mg chlorpyrifos/m^3 air.

Table 18. Air Monitoring Network Highest Ambient Air Concentrations over the Most Recent Five Years and the 24-hr Inhalation Exposure Based on those Air Concentrations for Infants, Children 1-2 years old, Children 6-12 years old, and Females 13-49 years old

	Summary of Samples				24-hr Inhalation Exposure (mg/kg/day)			
Year	Total number of samples	Detections	Quantified	Highest 24-hr concentration (mg/m^3)	Infant[a]	Child 1-2 years old[b]	Child 6-12 years old[c]	Females 13-49 years old[d]
2016	156	21	3	0.0000521	0.000031	0.000027	0.000020	0.000015
2015	155	45	6	0.0000778	0.000046	0.000040	0.000030	0.000022
2014	157	38	4	0.0003379	0.000199	0.000176	0.000128	0.000095
2013	159	52	5	0.0004225	0.000249	0.000220	0.000161	0.000118
2012	156	44	3	0.0001309	0.000077	0.000068	0.000050	0.000037

[a] Infants: body weight = 7.6 kg; normalized daily average breathing rate = (0.59 m^3/kg/day)
[b] Children 1-2 years old: body weight = 13 kg; normalized daily average breathing rate = (0.52 m^3/kg/day)
[c] Children 6-12 years old: body weight = 26 kg; normalized daily average breathing rate = (0.38 m^3/kg/day)
[d] Females 13-49 years old: body weight = 71.8 kg; normalized daily average breathing rate = (0.28 m^3/kg/day)
For references see Andrews and Patterson, 2000; Appendix 4.

IV.E. Exposure from House Dust

As suggested at the January and March 2018 SRP hearings, HHA re-evaluated potential exposure to chlorpyrifos through contaminated house dust. Inhalation of airborne material, dermal contact with contaminated surfaces, and non-dietary oral ingestion (e.g., pica) are all potential exposures of chlorpyrifos associated with spray drift following pesticide applications. Young children tend to spend more time on the floor and have more incidental oral exposure (hand-to-mouth, object-to-mouth) than older children or adults (Xue *et al.*, 2010; Dawson *et al.*, 2012). Therefore it is important to assess potential chlorpyrifos exposures that may occur via

incidental ingestion of contaminated indoor dust, especially in young children in agricultural families or who live in agricultural areas (Quiros-Alcala *et al.*, 2011; Gunier *et al.*, 2016). Prior to the restrictions of indoor use, house dust may have been contaminated with chlorpyrifos residues derived from the indoor applications (e.g., in home insect control) (Lewis *et al.*, 2001) or from "take-home" exposure from occupational settings (Fenske *et al.*, 2013; Gibbs *et al.*, 2017; Smith *et al.*, 2017). In 2000, US EPA heavily restricted indoor chlorpyrifos use, leaving only roach baits in child resistant packaging registered for indoor use.[3] Therefore, sources outside of the home can now be assumed to be the sole contributors to chlorpyrifos residues in house dust.

Chlorpyrifos concentrations were measured in house dust samples collected from farmworker residences in the Salinas Valley, CA in 1999 and 2002 (Bradman *et al.*, 2007; Harnly *et al.*, 2009). In the studies by Bradman et al. (2007) and Harnly et al. (2009), a high-volume surface sampler with a cyclone was used to collect dust samples then analyzed by GC-MS for residual chlorpyrifos concentration. The authors reported that maximum concentrations in house dust decreased from 9810 ng/g dust in 1999 to 1200 ng/g dust in 2002. Because these household dust samples were collected from homes of farmworkers within the same agricultural area, the substantial decrease in the maximum house dust concentrations over this time period suggests that indoor use may have been the major source of chlorpyrifos in contaminated house dust. After the restrictions of home use, outdoor sources such as "take-home" by farmworkers became the dominant source of chlorpyrifos in the home. Likewise, Quiros-Alcala and colleagues compared 15 farmworker residences in the same area of Salinas, CA as the 1999-2002 study and found that chlorpyrifos concentrations in house dust were approximately 40% lower in 2006 (Quiros-Alcala *et al.*, 2011).

In another study, Gunier et al. (2016) collected house dust samples from 434 California homes of study subjects enrolled in either the Northern California Childhood Leukemia Study (n=413) or the Fresno-County based Agricultural Pesticide Study (n=21). Of the samples collected, 388 (89%) had detectable chlorpyrifos concentrations above the limit of detection (3 ng/g dust), with a 90th percentile of 220 ng/g dust and the geometric mean of 34 (±5) ng/g dust across the study period of 2001 – 2006 (Gunier et al., 2016). Chlorpyrifos concentrations in house dust decreased an average of 31% per year ($p < 0.0001$) across all samples. When homes in the Central Valley were analyzed separately, the decrease was not as large (27% decrease), but still highly significant (Gunier et al., 2016). Dust samples collected from the Fresno County homes from 2003 – 2005 did not shown the same year over year decrease; the authors postulate that this is due to a fairly steady agricultural use of chlorpyrifos during the same time. These study values are plotted against the pounds of chlorpyrifos used in California from 1999 to 2006 (Figure 1). Based on this analysis, indoor chlorpyrifos concentrations have continued a precipitous decline from 1999 to 2006 in California, although the pounds of chlorpyrifos applied agriculturally do

[3] Chlorpyrifos; Cancellation Order. A Notice by the Environmental Protection Agency on 12/06/2000. Federal Register, https://www.federalregister.gov/documents/2000/12/06/00-30917/chlorpyrifos-cancellation-order

not mirror the same decline. This supports several authors' supposition that the major reason for reductions in indoor concentrations comes from the federal cancellation of indoor use.

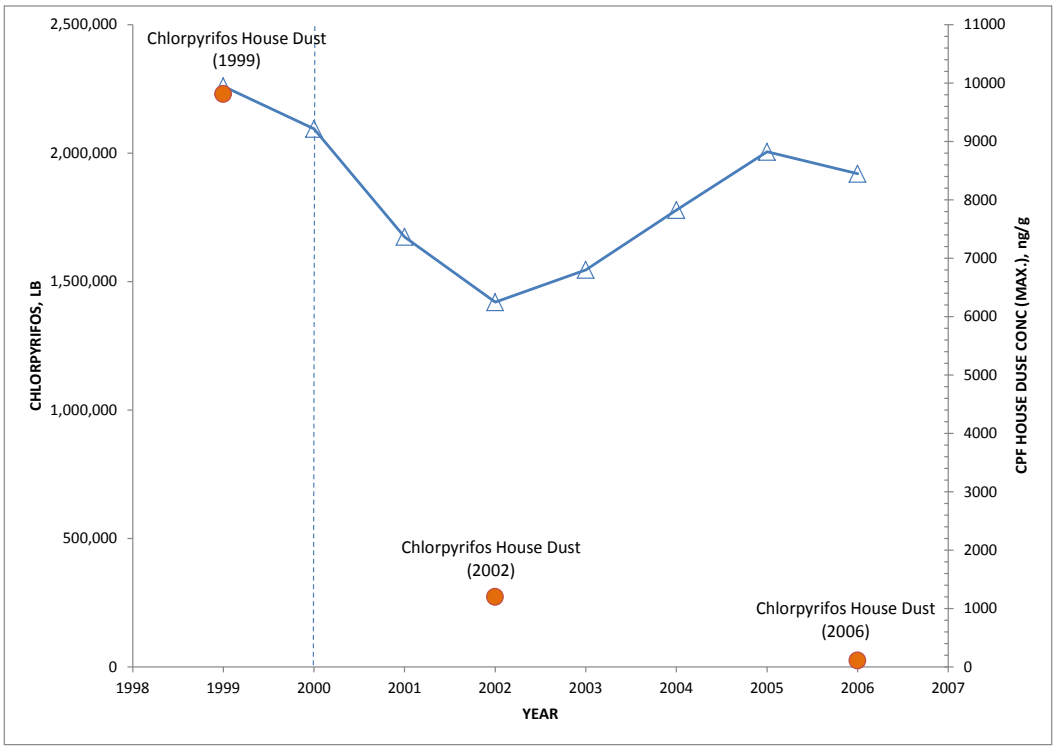

Figure 1. Pounds of chlorpyrifos applied in California from 1999 to 2006 and maximum concentrations of chlorpyrifos measured in house dust samples collected from inside California homes in 1999, 2002, and 2006

Studies have shown that chlorpyrifos concentrations in house dust are higher in farmworker homes than non-farmworker homes in both California (Quiros-Alcala *et al.*, 2011) and Washington states (Gibbs *et al.*, 2017; Smith *et al.*, 2017). Accordingly, assessing the house dust exposure in farmworker homes with a life stage that has the highest estimate of soil ingestion rate (i.e., children <2 years old) would constitute a reasonable "worst case" estimate of chlorpyrifos exposure in children. To evaluate children's exposure to chlorpyrifos via house dust, this assessment employs house dust concentrations of chlorpyrifos collected in California after the indoor use cancellation. Combining the highest measured concentration (i.e., 1200 ng/g) from Bradman et al., (2007) with a daily dust ingestion rate for children 0 - 2 years old (95^{th}%-ile; (OEHHA, 2012), and assuming an infant body (i.e., <1 yr old) weight of 7.6 kg (DPR, 2000), and 100% oral absorption, a short term absorbed daily dose (STADD) can be estimated as 0.048 µg/kg/day. If using the maximum chlorpyrifos house dust concentration measured in 2006 (Gunier *et al.*, 2016) instead, the estimated STADD is 0.0044 µg/kg/day. With these updated exposure estimates from house dust, it is clear that chlorpyrifos exposure via house dust would only contribute minimally to the overall or aggregate exposure estimates. Therefore, house dust was removed from further exposure analysis calculations.

IV.F. Dietary Exposure (Food and Drinking Water)

The following is a new analysis of the risk from food and drinking water and has been completely updated from the December 2017 Draft TAC Evaluation. For complete background information and methodology on how HHA conducts dietary exposure assessment, the reader is directed to Section IV.B. Dietary Exposure (Food and Drinking Water), in the December 2017 Draft TAC Evaluation.

Briefly, HHA utilized the 2014 US EPA food-only exposure estimates to evaluate the risk from chlorpyrifos exposure from food (US EPA, 2014). HHA conducted an independent drinking water exposure assessment employing residue data from refined, surface, and ground water in California.

US EPA estimated dietary (food only) acute and steady-state exposures for infants (< 1 year old), children (1-2 years old), children (6-12 years old), and females (13-49 years old). The dietary analyses were conducted with Dietary Exposure Evaluation Model (DEEM) and Calendex software with the Food Commodity Intake Database (FCID). The food consumption data in the software was based on the 2003-2008 from the U.S. Department of Agriculture's (USDA's) National Health and Nutrition Examination Survey, What We Eat in America, (NHANES/ WWEIA). Dietary consumption data were combined with residue data from the US Department of Agriculture Pesticide Data Program (through 2012) to estimate exposures based on probabilistic analysis. The steady-state exposure estimates were determined using the Calendex-FCID program, which utilizes the same consumption database and residue data as DEEM-FCID. The steady-state or steady-state exposures were derived for 21-day period. The exposure values are shown in the Tables 19 and 20. Children 1-2 year old were identified to receive the highest exposure from food at the 99.9th percentile in both acute and steady-state exposure scenarios.

Table 19. Acute Dietary Exposure for Chlorpyrifos

Population Subgroup	Dietary Exposure (mg/kg/d)		
	95th Percentile	99th Percentile	99.9th Percentile
All Infants < 1 year old	0.000050	0.000088	0.000273
Children 1-2 years old	0.000082	0.000143	0.000423
Children 6-12 years old	0.000040	0.000072	0.000189
Females 13-49 years old	0.000021	0.000041	0.000150

Table 20. Steady-State Dietary Exposure for Chlorpyrifos

Population Subgroup	Dietary Exposure (mg/kg/d)		
	70th Percentile	95th Percentile	99.9th Percentile
All Infants < 1 year old	0.000020	0.000045	0.000186
Children 1-2 years old	0.000038	0.000072	0.000242
Children 6-12 years old	0.000019	0.000039	0.000128
Females 13-49 years old	0.000009	0.000018	0.000075

The drinking water exposure was calculated based on residues from PDP and DPR surface and ground water programs. The probabilistic exposures at the 95th, 99th and 99.9th percentiles are shown in Table 21. Infants were identified as the most highly exposed subpopulation.

Table 21. Acute Drinking Water Exposure for Chlorpyrifos

Drinking Water Exposure (mg/kg/day)			
2001-2013 PDP Residue Data			
Population Subgroup	95th	99th	99.9th
All Infants (< 1 year old)	0.000004	0.000064	0.000113
Children 1-2 years old	0.000002	0.000026	0.000060
Children 6-12 years old	0.000002	0.000016	0.000038
Females 13-49 years old	0.000001	0.000018	0.000038
2005-2014 DPR Surface Water Residue Data			
Population Subgroup	95th	99th	99.9th
All Infants (< 1 year old)	0.000008	0.000051	0.000439
Children 1-2 years old	0.000004	0.000024	0.000186
Children 6-12 years old	0.000002	0.000015	0.000115
Females 13-49 years old	0.000002	0.000016	0.000125
2004-2013 DPR Ground Water Residue Data			
Population Subgroup	95th	99th	99.9th
All Infants (< 1 year old)	0.000019	0.000133	0.000233
Children 1-2 years old	0.000013	0.000057	0.000121
Children 6-12 years old	0.000008	0.000032	0.000079
Females 13-49 years old	0.000009	0.000038	0.000077

The PDP data indicate that chlorpyrifos residues are frequently detected on crops that lack chlorpyrifos tolerances. This could result from illegal applications on these crops, drift from applications to nearby fields, or soil residues remaining from applications to an earlier crop previously grown in the same field. From 2008 to 2012, PDP detected illegal chlorpyrifos residues on catfish, cilantro, cherry tomatoes, green onions, spinach, and five other crops. From 2015 to 2017, DPR's California Pesticide Residue Monitoring Program (CPRMP) had 280 detections of chlorpyrifos from more than 3602 samples tested. A total of 58 detections were illegal (Table 22). Litchi, cactus, longan, and oriental pear had frequent illegal chlorpyrifos detections. Most of these were imported produce. US EPA sets the legal limit (tolerance) for the amount of pesticide residues allowed in food. Over the years, DPR's residue monitoring program has detected illegal chlorpyrifos residues on various commodities, most or all of which were imported (Table 22) for residues detected from 2015-2017). Neither DPR nor US EPA assesses the health implications of illegal residues on agricultural commodities in their dietary exposure assessments, which are restricted to analyzing the health implications of legal residues. However, DPR's Enforcement Branch enforces US EPA tolerances under the CPRMP, which collects domestic and imported produce samples throughout the channels of trade, including wholesale and retail outlets, distribution centers, and farmers markets. These samples are analyzed for pesticide residues at laboratories run by the California Department of Food and Agriculture (CDFA). When a pesticide residue is determined to be illegal by virtue of (a) its occurrence on a commodity for which there is no established tolerance; or (b) its level exceeding the established tolerance, HHA conducts a special dietary exposure assessment to determine if an acute health risk exists from consumption of that lot. The results are then communicated to the Enforcement Branch, which has the authority to remove affected produce from channels of trade.

Table 22. Commodities Sampled by DPR's Pesticide Residue Monitoring Program Containing Chlorpyrifos Residues from 2015 to 2017

Commodities with CPF detections	Total no. samples tested	Samples with detections	No. illegal samples[a]
LITCHI NUTS	26	16	16
PEAR, ASIAN (ORIENTAL PEAR)	69	18	10
PRICKLYPEAR CACTUS PADS	94	9	9
PRICKLYPEAR (CACTUS PEAR)	40	11	8
LONGAN (LONGAN FRUIT)	31	7	7
TOMATILLO	187	5	2
BEANS (GREEN, STRING)	203	2	1
CHAYOTE (CHRISTOPHENES)	114	2	1
TARO (DASHEEN) (ROOT CROP) (WETLAND, UPLAND, ETC.)	17	1	1
RAMBUTAN	5	1	1
PASSION FRUIT (TAMARILLO, PURPLE GRANADILLA)	4	1	1
ARROWHEAD (SAGITTARIA SPP.)	1	1	1
ORANGE (ALL OR UNSPEC)	270	65	0
PEPPERS (FRUITING VEGETABLE), (BELL,CHILI, ETC.)	545	50	0
TANGERINE (MANDARIN, SATSUMA, MURCOTT, ETC.)	213	33	0
BANANA	155	22	0
LEMON	80	8	0
LIME (MEXICAN LIME, PERSIAN, ETC.)	143	5	0
RADISH TOPS	29	4	0
NECTARINE	246	3	0
ASPARAGUS (SPEARS, FERNS, ETC.)	168	3	0
TURNIPS (ALL OR UNSPEC)	17	3	0
KALE	327	2	0
KIWI FRUIT	106	2	0
PEA, SNOW (SUGAR PEA)	125	1	0
CHINESE RADISH/DAIKON (LOBOK, JAPANESE RADISH)	118	1	0
BOK CHOY (WONG BOK)	109	1	0
PINEAPPLE (FRESH MKT. PINEAPPLE)	90	1	0
RADISH	58	1	0
PLANTAIN	12	1	0
Totals	**3602**	**280**	**58**

[a] Illegal samples are those in which a pesticide residue occurs on a commodity for which there is no established tolerance; or its level exceeding the established tolerance; data from the California Pesticide Residue Monitoring Program.

Following suggestions received during the 2018 SRP hearings, HHA also looked more closely at the risk to children of consuming almond milk as a potential means of exposure to chlorpyrifos. The following acute exposure and risk calculation for chlorpyrifos residue in almond milk is based on consumption data in 1-12 year old children in NHANES (2011-2014). Because almond milk is not an agricultural crop, HHA had to research manufacturing based recipes to determine the equivalent quantity of almonds in almond milk. The most popular commercial brand of almond milk contains 2% almonds. Using the maximum individual consumption rate of almond

milk for children 1 - 12 years old, the assumption that almond milk is comprised of 2% almonds, and the 99th percentile chlorpyrifos residue measured in whole almonds, the acute exposure level is estimated at 0.000076 mg/kg/day. This is compared to the maximum individual consumption rate of the same age group for whole almonds which is 0.0038 mg/kg/day. The calculated residue levels in almond milk ranging from 0.000036 to 0.000956 ppm (for 99th percentile to the highest residue respectively) are less than the tolerance for almonds, and are below the CDFA and PDP detection limits of 0.01 ppm and 0.001 ppm, respectively. Using the DNT PoD, consumption of whole almonds would be below the MOE and considered a potential health risk, while the consumption of almond milk because of its small percentage of almonds would not.

V. RISK CHARACTERIZATION

V.A. Introduction

For this risk assessment, the risk for threshold effects is expressed as a margin of exposure (MOE). The MOE is the ratio of the critical NOEL or PoD to the estimated human exposure level.

V.B. Risk Characterization using PoDs for Developmental Neurotoxicity

The neurodevelopmental effects analyzed in this assessment can be grouped as changes in cognition, motor control, or behavior. None of the in vivo animal studies used inhalation or dermal exposure routes; only oral dosing was used (diet or gavage). A NOEL of 0.01 mg/kg/day was observed in only one DNT study and based on increased anxiety and motor activity in PND21 male rat pups at 0.1 mg/kg/day (Silva *et al.*, 2017). The NOEL of 0.01 mg/kg/day is similar to an estimated no effect level (ENEL) if the LOELs from the other four studies had been divided by a default uncertainty factor of 10 (summarized in Table 11). Therefore, the critical NOEL selected to evaluate the risk for potential neurodevelopmental effects from acute exposures to chlorpyrifos was 0.01 mg/kg/day based on the NOEL from Silva et al. (2017) and the ENELs from the other DNT studies (Lee *et al.*, 2015; Carr *et al.*, 2017; Gomez-Gimenez *et al.*, 2017; Gomez-Gimenez *et al.*, 2018).

Table 23. Critical NOELs for Developmental Neurotoxicity used for the Risk Characterization of Chlorpyrifos

Route	PoD[a]	RfD[b] or RfC
Uncertainty Factors (UF)		**10 inter 10 intra 1 DNT**
Acute Oral [mg/kg/day] Infants Children 1-2 Children 6-12 Females 13-49	0.01	0.0001
Acute Dermal [mg/kg/day][c] Infants Children 1-2 Children 6-12 Females 13-49	0.104	0.001
Acute Inhalation [mg/m^3][c] Infants Children 1-2 Children 6-12 Females 13-49	 0.405 0.459 0.624 0.862	 0.004 0.005 0.006 0.009

[a] Point of Departure (PoD): The critical acute oral PoD for CPF is a NOEL (No-Observed Effect Level) for developmental neurotoxicity based on changes in cognition, motor control and behavior in rats and mice (Lee et al, 2015, Silva et al, 2017, Carr et al, 2017, Gómez-Giménez, 2017, 2018).

[b] Reference Dose (RfD) or Reference Concentration (RfC): RfDs and RfCs are derived by dividing the appropriate PoD by the product of all uncertainty factors (UF).

[c] Route to route extrapolation:

Dermal: Route specific dermal PoD: oral PoD in animals (mg/kg/day) / dermal absorption in human (9.6% ; Thongsinthusak, 1991).

Inhalation: Route specific inhalation PoD: oral dose mg/kg/day / [Breathing Rate (BR) m^3/hr/Body Weight (BW) kg]; Oral PoD=0.01 mg/kg/day; Infants BR=0.188 m^3/h BW= 7.6 kg; Children 1-2 yrs BR=0.283 m^3/h BW=13 kg; Children 6-12 yrs BR= 0.417 m^3/h, BW=26 kg; Females 13-49 yrs BR=0.833 m^3/h, BW 71.8 kg (derived from Andrews and Patterson (2000) assuming 24-hr breathing rates of 0.59, 0.52, 0.38 and 0.28 m^3/kg/24 hr for infants, children 1-2 yr, children 6-12 yr and females 13-49 yr, respectively.) [See Appendix 4.]

V.C. Spray-Drift Bystander (Non-Occupational/Residential)

Risks for bystanders were calculated for exposures from a standard scenario using fixed wing aerial application of chlorpyrifos with 2 gallons/acre finished spray volume and 2 lbs/acre application rate. This scenario reflects the most common aircraft used for aerial applications in California, as well as the most common and a reasonable "worst case" estimate. The exposure assessment calculations for all other scenarios, application methods, and application rates and volumes can be found in Appendix 2. Only acute exposure to spray drift from single aerial applications of chlorpyrifos was evaluated in this assessment, as is the standard practice for DPR exposure estimates calculations. Exposure estimates for multiple or simultaneous applications are considered the purview of risk mitigation and management and, as such, are not included in the exposure analysis of a specific pesticide. Air concentrations were modeled to the computation downwind distance limit, e.g., 2608 feet downwind from an application. HHA

acknowledges that it is possible to detect concentrations of chlorpyrifos in ambient air at levels at or above the analytical limit of quantitation at distances farther downwind from an application than ½ mile (2640 feet).

Route-to-route extrapolation was performed by converting the external dermal and inhalation doses to internal doses. This was necessary since inhalation specific NOELs were not available to evaluate the potential risk for neurodevelopmental effects from inhalation of chlorpyrifos (required for the evaluation of toxic air contaminants). For calculating inhalation doses, the estimated air concentrations (found in Section IV earlier in this document) were multiplied by a default breathing rate of 0.59, 0.52 and 0.38 m^3/kg/day (or 0.025, 0.022 and 0.016 m^3/kg/hr) for infants, children 1-2 years old and children 6-12 years old, respectively, or by 0.28 m^3/kg/day (or 0.0112 m^3/kg/hr) for females 13-49 years old (Andrews and Patterson, 2000, Appendix 4). A default absorption rate of 100% was assumed for inhalation exposure. For dermal doses, the external dermal dose was multiplied by a dermal absorption factor of 9.6% based on evaluation of the available chlorpyrifos dermal absorption studies (Thongsinthusak, 1991).

When inhalation, dermal, and incidental oral exposures from spray drift were evaluated using the DNT NOEL of 0.01 mg/kg/day, the combined drift MOEs were less than 100 at ≤ 1320 feet from the treated field for all of the evaluated populations, indicating a health concern. The dermal MOEs were lower than the inhalation MOEs at each distance. As a result, the combined drift MOEs were lower than the dermal MOEs. The combined drift MOEs were greater than 100 only at 2608 feet for all four sensitive population subgroups, indicating that at this distance and at distances further downwind, there is not a health concern for aggregate exposure from inhalation or deposition from spray drift. The margins of exposure are summarized in Table 24, below. Values below the target of 100 are denoted with red shading.

Table 24. Margins of Exposure using the Developmental Neurotoxicity NOEL for Infants, Children, and Females of Childbearing Age at Various Distances Downwind from the Fields Treated with Chlorpyrifos by Fixed Wing Aircraft at 2 gallons/acre Spray Volume and 2 lb/acre Application Rate

Age group	Downwind Distance (ft)	Margins of Exposure [a]			
		Dermal	Combined Incidental Oral	Inhalation	Combined Drift
Infants < 1 year	25	1	4	8	<1
	50	1	6	9	<1
	100	2	9	12	1
	250	4	17	17	3
	500	7	31	27	5
	1000	18	80	56	12
	1320	31	136	83	19
	2608	165	734	250	87
Children 1-2 years	25	2	8	9	1
	50	2	10	10	2
	100	3	15	13	3
	250	7	29	19	5
	500	12	54	30	9
	1000	31	136	63	21
	1320	52	232	92	33
	2608	282	1255	279	140
Children 6-12 years	25	1	--	17	1
	50	1	--	20	1
	100	2	--	24	2
	250	4	--	36	3
	500	7	--	56	6
	1000	17	--	120	15
	1320	28	--	174	24
	2608	154	--	521	119
Females 13-49 years	25	3	--	23	2
	50	3	--	26	3
	100	5	--	32	4
	250	10	--	48	8
	500	18	--	75	15
	1000	46	--	160	36
	1320	79	--	231	59
	2608	424	--	694	263

[a] Risks were calculated as a margin of exposure (MOE) for infants, children, youths, and females of childbearing age. A target MOE of 100 was selected to be protective of human health (10x for interspecies sensitivity, 10x for intraspecies variability). DNT NOEL = 0.01 mg/kg/day based on changes in cognition, motor control and behavior in rats and mice (Lee et al, 2015, Silva et al, 2017, Carr et al, 2017, Gómez-Giménez , 2017, 2018).
Red shading indicates MOEs that are below the target of 100, thus indicating a potential health concern.

V.D. Dietary Exposure

The acute dietary and drinking water MOEs were calculated using the oral NOEL of 0.01 mg/kg/day for developmental neurotoxicity in rats and mice. The DNT effects were seen after single day exposure or repeated treatments. Therefore the same NOEL is applicable to repeated (steady-state) exposures to chlorpyrifos. The acute dietary MOEs ranged from 122 to 476 at the 95th percentile, from 70 to 244 at the 99th percentile and from 24 to 67 at the 99.9th percentile. The steady state MOEs ranged from 139 to 556 (95th percentile) and from 41to 133 (99.9th percentile). Children 1-2 yrs were identified as the most highly exposed population. In a probabilistic dietary analysis, both DPR and US EPA present the risk using dietary exposures at the 99.9th percentile. The margins of exposure for acute and steady-state dietary exposures are summarized in Table 25 and for drinking water in Table 26. Values below the target of 100 in both tables are denoted with red shading.

Table 25. Acute and Steady-State Dietary (food only) Exposure and Margins of Exposure for Chlorpyrifos

ACUTE DIETARY EXPOSURE[a]				
Population Subgroup	**aPoD[b] (mg/kg)**	**MOE[c]**		
		95th Percentile	**99th Percentile**	**99.9th Percentile**
All Infants: < 1 yr	0.01	200	114	37
Children: 1-2 yrs	0.01	122	70	24
Children: 6-12 yrs	0.01	250	139	53
Females: 13-49 yrs	0.01	476	244	67
STEADY-STATE DIETARY EXPOSURE[a]				
Population Subgroup	**ssPoD[b] (mg/kg)**	**MOE[c]**		
		70th Percentile	**95th Percentile**	**99.9th Percentile**
All Infants: < 1 yr	0.01	500	222	54
Children: 1-2 yrs	0.01	263	139	41
Children: 6-12 yrs	0.01	526	256	78
Females: 13-49 yrs	0.01	1111	556	133

[a] Exposures are from the US EPA dietary exposure assessment to support registration review (US EPA, 2014b)
[b] aPoD = acute point of departure
[c] Margin of Exposure (MOE) = PoD ÷ Dietary Exposure. Target MOE is 100 for every population.
Red shading indicates MOEs that are below the target of 100.

For drinking water exposure, the risks were calculated using the NOEL of 0.01 mg/kg/day for DNT effects and probabilistic exposures based on residues from PDP and DPR surface and ground water programs (Table 26). The exposure levels at the 99.9th percentile, the MOEs were higher for PDP (88 – 263) and lower for surface water (23 – 87). Infants were identified as the most highly exposed population from drinking water.

Table 26. Acute Margins of Exposure for Chlorpyrifos in Drinking Water

Population Subgroup	2001-2013 PDP Residue Data			2005-2014 Surface Water Residue Data		
	MOE			MOE		
	95th	99th	99.9th	95th	99th	99.9th
All Infants (< 1 year old)	2500	156	88	1250	196	23
Children 1-2 years old	5000	385	167	2500	417	54
Children 6-12 years old	5000	625	263	5000	625	80
Females 13-49 years old	10000	556	263	5000	667	87

Population Subgroup	2004-2013 Ground Water Residue Data		
	MOE		
	95th	99th	99.9th
All Infants (< 1 year old)	526	75	43
Children 1-2 years old	769	175	83
Children 6-12 years old	1250	313	127
Females 13-49 years old	1111	263	130

V.D. Aggregate Exposure (Spray Drift, Dietary, and Drinking Water)

Combined spray drift exposures estimates at 2608 feet for dermal, incidental oral, and inhalation routes were combined with the 99.9th percentile exposures from dietary and drinking water for chlorpyrifos. At 2608 feet from a field treated with chlorpyrifos, the combined spray drift MOEs for three of the sensitive population subgroups were equal to or greater than the target of 100. However, when dietary and drinking water exposures were added in, the aggregate MOEs for these combined routes and sources of exposure were below all the target of 100 (Table 27).

Table 27. Margins of Exposure using the DNT NOEL for Combined Spray Drift, Dietary and Drinking Water Exposure at 2608 ft from Field Treated with Chlorpyrifos for Infants, Children and Females of Childbearing Age

Population Subgroup	Margin of Exposure[a]			
	Diet Only[b]	Drinking Water Only[b,c]	Combined Spray Drift[d]	Combined Spray Drift, Diet and Drinking Water[e]
All Infants < 1 year	37	23	87	12
Children 1-2 years	24	54	140	15
Children 6-12 years	53	87	119	26
Females 13-49 years	67	80	263	32

Abbreviations: DNT = Developmental Neurotoxicity, NOEL = No-Observed-Effect Level.

[a] Margin of Exposure (MOE) = NOEL / Exposure ; DNT NOEL = 0.01 mg/kg/day based on changes in cognition, motor control and behavior in rats and mice (Lee et al, 2015, Silva et al, 2017, Carr et al, 2017, Gómez-Giménez, 2017, 2018)

[b] Dietary exposure estimate at the 99.9th percentile was used in the MOE calculation

[c] Drinking water exposure estimate based on the 99.9th percentile from DPR surface water monitoring was used in the MOE calculation

[d] Combined Spray Drift MOE is the MOE for the combined dermal, incidental oral and inhalation exposure from spray drift at 2608 ft from the treated field which is the only distance where MOEs were greater than 100 for all routes (see Table 24).

[e] Combined MOE = DNT NOEL (0.01) / (Diet + Drinking Water + Combined Spray Drift) Exposure.

Red shading indicates MOEs that are below the target of 100.

VI. RISK APPRAISAL

VI.A. Introduction

This final TAC evaluation of chlorpyrifos explores in greater depth the potential for adverse impacts on the developing nervous system. The December 2017 draft recognized developmental neurotoxicity as likely to be biologically significant, but did not carry the analysis further, opting instead to apply a 10-fold uncertainty factor to the cholinesterase-based endpoints to account for potential neurodevelopmental effects. Original selection of RBC AChE inhibition as the critical toxicity endpoint was intended to protect human populations from impacts on other neurological endpoints that are not as easily measured. However, collective results from epidemiology and animal toxicity studies indicate that chlorpyrifos may cause neurodevelopmental and neurobehavioral effects in the absence AChE inhibition.

This risk assessment evaluated the dietary, spray drift, and aggregate risks that accompany exposure to chlorpyrifos. Every risk assessment has inherent limitations with the application of existing data to estimate potential risk to human health. Therefore, certain assumptions and extrapolations are incorporated into the hazard identification, dose-response assessment, and exposure assessment processes. These, in turn, result in uncertainty in the risk characterization which integrates all the information from the previous three processes. Qualitatively, risk assessments for all chemicals have similar uncertainties. However, the degree or magnitude of the uncertainty can vary depending on the availability and quality of the data and the types of exposure scenarios being assessed. Specific areas of uncertainty associated with this risk assessment for chlorpyrifos are delineated in the following discussion.

VI.B. Uncertainties Associated with the Toxicology and Hazard Identification

Comprehensive analysis of the developmental toxicity database has now allowed HHA to set a critical acute NOEL for neurodevelopmental effects at 0.01 mg/kg based on a limited number of studies in rats and mice. Most relevant in this regard is the observation of increased anxiogenic behavior in the elevated plus-maze test and motor activity in PND 21 rat pups exposed in utero (GD 14-20) to a maternal gavage dose of 0.1 mg/kg/day (gestation only) (Silva et al., 2017). Similar motor effects were observed by Gómez-Giménez et al. (2017) in PND 60-90 rat pups and by Lee et al. (2015) in PND 60 mouse pups both at doses of 0.1 mg/kg. However in Gómez-Giménez et al., (2017), the treatment period was gestational and postnatal, while the treatment period in Lee et al. (2015) was postnatal only. In both cases, observations were made long after cessation of dosing, suggesting that the neurotoxic impacts of early life exposure have the potential to be long-lasting. In addition, Gómez-Giménez et al. (2017) observed cognitive deficits at 0.1 mg/kg/d and Carr et al. (2017) showed decreased anxiety in PND 25 male rats following gavage exposure to 0.5 mg/kg/d on PND 10 – 16.

Because neurodevelopmental observations were made at similar doses by several laboratories, HHA considered the critical NOEL to be reasonably supported. Nonetheless, there were several factors associated with uncertainty in the NOEL designation:

1) One detailed study failed to show cognitive effects in maze testing even at gestational / postnatal doses as high as 5 mg/kg/day (Hoberman, 1998). This was surprising in light of

the observations in later studies of effects at 0.1 mg/kg. Since there are some epidemiology studies showing an association of chlorpyrifos exposure and changes in growth and development, the rodent studies were considered relevant because they yielded qualitative similar responses.

2) Both anxiogenic and anti-anxiogenic responses were observed in the DNT studies, highlighting the possibility that the effects were mutable and possibly toxicologically insignificant. However, HHA notes that the anxiogenic behavior observed by Silva et al. (2017) resulted from gestational exposure, while the anti-anxiogenic behavior observed by Carr et al. (2017) resulted from postnatal exposure. As the developmental status of the very young organism changes with time, the precise staging of chlorpyrifos exposures likely affects the nature of the response.

3) Use of maze-based behaviors as the method for discerning cognitive deficits may not cover the more complex neurological functions in humans. Therefore, its direct relevancy is unknown.

4) Hoberman (1998) observed brain morphometric changes at doses as low as 1 mg/kg/day. Unfortunately, none of the more recent studies reviewed herein attempted such detailed histological or morphometric measurements. It is possible that more contemporary techniques might allow detection of subtle changes in physical parameters.

5) The motor / behavioral data which showing effects at 0.1 mg/kg (and in the case of Silva et al., 2017, a NOEL of 0.01 mg/kg) were not amenable to further analysis because they were presented largely as summary data without reporting individual data, means, or standard deviations. Dose-response relationship not always evident and often missing. Without individual data it is difficult to ascertain the details of what were often subtle effects.

In conclusion, the developmental neurotoxicity database for chlorpyrifos is evolving and currently contains five in vivo animal studies that permit the establishment of a critical oral NOEL. The neurodevelopmental effects in these studies were similar regardless of the exposure window or the duration of the exposure. The most important implication of the five studies is that the threshold for chlorpyrifos-induced neurodevelopmental effects following exposure in early life may be 10-fold lower than the reported threshold of 1 mg/kg/day established for RBC AChE inhibition.

VI.C. Uncertainties Related to Exposure Assessment

This revised exposure assessment evaluated risk to bystanders from spray drift from aerial and ground-based applications of chlorpyrifos and estimated exposures from dermal, inhalation, and incidental oral exposure routes. Inhalation and dermal bystander exposures were evaluated for all four population subgroups. The evaluated exposure scenarios were based on standard operating procedures for lawns and turf post-application, and assumed exposure times near the application site of 1-1.5 hr. In addition, infants and children 1-2 yrs were assumed to receive additional exposure (incidental oral) from spray drift deposition through mouthing activities, such as hand-

to-mouth and object-to-mouth activities, as well as incidental soil ingestion. Several uncertainties exist with the exposure analysis for chlorpyrifos, many of which result from the use of standard default assumptions. A synopsis of these uncertainties follows:

1) For the horizontal deposition exposure calculations, California-specific turf transferable residue (TTR) values obtained from the study by Stafford and Robb (1999) were used. In the same study by these investigators, the mean $TTR_{Day\ 0}$ data ($\mu g/cm^2$) were also obtained from two other states (mean values in parentheses): Indiana (0.09 ± 0.005) and Mississippi (0.146 ± 0.005). Although the value from Mississippi (i.e., the highest value) is not used in the horizontal deposition estimates because California specific data is more appropriate. In addition, this value is comparable to the TTR value obtained in California (0.124 ± 0.004).

2) For acute spray drift exposure estimates, the main uncertainties associated with the computer models used to estimate the exposure to residential bystanders were discussed in the December 2017 Draft TAC Evaluation (DPR, 2017). Those estimates largely depend on the distances from the application site and the model used parameters (wind speed, wind direction, physicochemical properties of chlorpyrifos vapor and aerosol, etc.) that maximized offsite drift estimates.

3) From the revised calculations, it was found that there was minimal contribution to overall exposure from 1) secondary spray drift following the re-volatilization of applied chlorpyrifos and 2) chlorpyrifos-contaminated house dust that was used to calculate the short-term absorbed daily dose. Neither value will alter the combined (inhalation, dermal, and incidental oral) exposures estimates from primary spray drift and deposition. Therefore, these values were removed from the final exposure analysis. The re-analysis of potential exposure from these additional sources was based on the best available and most current data. If new data or analyses become available, HHA will reconsider the contribution of either secondary spray drift or dust exposures to the exposure estimates for chlorpyrifos.

4) Additional uncertainties were associated with use of default physiological parameters, such as body weight and inhalation rates. Uncertainties also accompany the route-to-route extrapolation used in this risk assessment to convert modeled external dermal doses and inhalation concentrations to internal doses.

5) It is standard practice to use default assumptions when estimating exposure through various routes. In some instances this will overestimate actual exposure, such as applying the hand-to-mouth incidental oral exposure estimates for children 1-2 to infants. In some instances using default values may underestimate actual exposure, such as when using average breathing rates for young children who can have higher breathing rates when they are engaged in high intensity physical activity. Default values were not available for all subpopulations for all routes of exposure, such as pregnancy-specific breathing rates and body weight assumptions for children 6-12. Using the same default value for every individual in each age range renders the estimated exposures for the whole age range less representative of specific ages within that range. Some estimates, on the other hand, were specific to chlorpyrifos, such as the 9.6% dermal absorption rate.

VI.C.2. Uncertainties Relation to Dietary and Drinking Water Exposure Assessment

Exposures from diet and drinking water were estimated in the 2017 December Draft TAC Evaluation and the associated uncertainties can be found in the Risk Appraisal section of that document.

VI.D. Uncertainties in the Risk Characterization

VI.D.1. Developmental Neurotoxicity

The target MOE of 100 was considered sufficiently protective of human health. The MOE consisted of 10x for interspecies sensitivity and 10x for intraspecies variability.

VI.D.2. Cholinesterase Inhibition

In the 2017 Draft TAC Evaluation, HHA set a target MOE of 100 (1 for interspecies sensitivity, 10 for intraspecies variability, and 10 for potential neurodevelopmental effects) when exposures were evaluated with the PBPK-PD derived human PoDs for 10% RBC AChE inhibition. Based on suggestions received during the January and March 2018 SRP hearings, and after further evaluation of the PBPK model, the interspecies sensitivity component of the UF was increased 3x to account for PBPK-PD model deficiencies in human inhalation parameters. While a control human study on inhalation exposure was available for the chlorpyrifos model evaluation (Vaccaro *et al.*, 1993), inhalation toxicity data were limited in animals and not available for humans, and therefore not incorporated into the current version of the model (Poet *et al.*, 2017).

VI.E. Evaluation of the Points of Departure and Reference Concentration/Doses for Chlorpyrifos

For this final TAC evaluation of chlorpyrifos, HHA conducted a comprehensive review of animal studies published from 2015 – 2018, focused on the potential for evidence of neurodevelopmental toxicity at low dose levels. Critical PoDs were established from animal studies reporting developmental neurotoxicity at dose levels that are generally considered lower than those necessary for RBC AChE inhibition. A target MOE of 100 was comprised of 10x for interspecies sensitivity and 10x for intraspecies variability. There is no need for an additional UF for neurodevelopmental effects. RfDs and RfCs were calculated by dividing the DNT PoDs by the total UF of 100. These values are shown in Table 28, below. The PoDs for AChE inhibition along with the RfDs and RfCs calculated using both the original total UF of 100 and the revised total UF of 300 are also shown in Table 28 for comparison purposes only. The full analysis of the AChE inhibition based PoDs and MOEs are found in Appendix 3, herein.

Table 28. Points of Departure and Reference Doses or Concentrations used to evaluate the Risk from Exposure to Chlorpyrifos in Selected Population Subgroups for Developmental Neurotoxicity (DNT) and Acetylcholinesterase (AChE) Inhibition

Route	DNT[a]		10% AChE Inhibition	
	PoD[b]	RfD[c] or RfC	PBPK-PD PoD[d]	RfD or RfC (PoD/UF of 300)
Uncertainty Factors (UF)		**10 interspecies 10 intraspecies 1 DNT**		**3 interspecies 10 intraspecies 10 DNT**
Acute Oral [mg/kg/day] Infants Children 1-2 Children 6-12 Females 13-49	0.01	0.0001	 0.600 0.581 0.530 0.469	 0.002 0.002 0.002 0.002
Acute Dermal* [mg/kg/day] Infants Children 1-2 Children 6-12 Females 13-49	0.104	0.001	 NA 134.3 NA 23.6	 NA 0.448 NA 0.079
Acute Inhalation* [mg/m^3] Infants Children 1-2 Children 6-12 Females 13-49	0.405 0.459 0.624 0.862	0.004 0.005 0.006 0.009	NA 2.85 NA 6.15	NA 0.0095 NA 0.0205

[a] DNT, Developmental Neurotoxicity

[b] PoD, Point of Departure (PoD): a starting dose point for low-dose extrapolation. The critical acute oral PoD for chlorpyrifos is NOEL (No-Observed Effect Level) for developmental neurotoxicity in animals based on changes in cognition, motor control and behavior in rats and mice (Lee et al, 2015, Silva et al, 2017, Carr et al, 2017, Gómez-Giménez, 2017, 2018).

[c] RfD, Reference Dose or Reference Concentration (RfC): As defined by US EPA, RfC or RfD is an estimate of the concentration or dose of a substance to which a human populations can be exposed (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime; derived by dividing the appropriate PoD by the product of all uncertainty factors (UF).

[d] The PoDs are Physiologically-Based Pharmacokinetic-Pharmacodynamic (PBPK-PD) model derived human equivalent doses based on 10% inhibition of acetylcholinesterase (AChE) in red blood cells after an acute (single day, 24 hr) or steady-state (21-day) exposure to chlorpyrifos. PBPK-derived PoDs were used in the December 2017 Draft Evaluation of Chlorpyrifos as a Toxic Air Contaminant (Appendix 6) to derive RfDs/RfCs and to calculate risk from exposure to chlorpyrifos.

* Route to route extrapolation:

Dermal: Route specific dermal PoD: oral PoD in animals (mg/kg/day) / dermal absorption in human (9.6%; Thongsinthusak, 1991)

Inhalation: Route specific inhalation PoD: oral dose mg/kg/day / [Breathing Rate (BR) m^3/hr/Body Weight (BW) kg]; Oral PoD=0.01 mg/kg/day; Infants BR=0.188 m^3/h BW= 7.6 kg; Children 1-2 yrs BR=0.283 m^3/h BW=13 kg; Children 6-12 yrs BR= 0.417 m^3/h, BW=26 kg; Females 13-49 yrs BR=0.833 m^3/h, BW 71.8 kg (derived from Andrews and Patterson (2000) assuming 24-hr breathing rates of 0.59, 0.52, 0.38 and 0.28 m^3/kg/24 hr for infants, children 1-2 yr, children 6-12 yr and females 13-49 yr, respectively.) [See Appendix 4.]

NA – Not available for this population

VI.F. Criteria for Evaluating Chlorpyrifos as a Toxic Air Contaminant

For the designation of a pesticide as a TAC, according to the California Code of Regulations, Title 3, Section 6864, for noncancer effects, the threshold levels is 10x below the air concentration which has been determined by the Director of DPR to be protective of human health. The purpose of this assessment is to provide the scientific evidence and evaluation of data that support the designation of chlorpyrifos as a TAC. As such, this evaluation had to assess the following:

- The availability and quality of data on health effects
- The potency, mode of action, and other relevant biological factors
- An estimate of the levels of exposure that may cause or contribute to adverse health effects; and,
- The range of risk to humans resulting from current or anticipated exposure (Food and Agriculture Code § 14023(a)).

A pesticide TAC can be defined as the air concentration, either measured or modeled, that exceeds the reference concentration (RfC) divided by 10. Chlorpyrifos meets the criteria of TAC designation by using either the developmental neurotoxicity endpoint or the AChE inhibition endpoint. If using the acute inhalation RfC for children 1-2 years old based on the DNT endpoint (0.005 mg/m^3; Table 28), chlorpyrifos would be designated a TAC if ambient air concentrations were > 0.0005 mg/m^3. If using the acute inhalation RfC for children 1-2 years old based on the AChE inhibition endpoint (0.0095 mg/m^3; Table 28), chlorpyrifos would be designated a TAC if ambient air concentrations were > 0.00095 mg/m^3. If using a fixed wing aerial application of chlorpyrifos with 2 gallons/acre finished spray volume and 2 lbs/acre application rate as its standard exposure scenario (the most common aircraft used for aerial applications in California and a reasonable "worst case" scenario), and comparing to inhalation RfCs for children 1-2 years old based on the DNT endpoint, this assessment has concluded that modeled air concentrations at all distances exceed the RfC/10 TAC designated air concentration of 0.0005 mg/m^3. See Table 29 below.

Table 29. Modeled Spray Drift Air Concentrations (1hr TWA) of Chlorpyrifos Compared with the Reference Concentration/10 for a Child 1-2 Years Old based on a the Developmental Neurotoxicity Endpoint

Downwind Distance (ft)	1-hr TWA Modeled Air Concentrations (mg/m3)	RfC/10 for a Child 1-2 years old (mg/m3) [TAC designation]
25	0.0493	>0.0005
50	0.0437	
100	0.035	
250	0.0237	
500	0.0153	
1000	0.0072	
1320	0.00492	
2608	0.00163	

CONCLUSION

HHA's comprehensive human health risk assessment involved rigorous analysis of results from in vivo and in vitro experiments, computational toxicology, epidemiology, diet and drinking water assessments, pesticide illness reports, and exposure analysis and modeling in order to determine the risks from exposure to chlorpyrifos. In the December 2017 Draft TAC Evaluation (Appendix 6), HHA reviewed the comprehensive database for AChE inhibition and based the critical PoDs on that parameter. This final TAC evaluation presents a comprehensive analysis of all currently available data to establish a PoD based directly on developmental neurotoxicity.

Available animal studies support the establishment of a PoD based directly on developmental neurotoxicity effects. HHA conducted a comprehensive review of recently available animal studies and focused on the evidence of neurodevelopmental toxicity at low dose levels. Critical PoDs were established from animal studies reporting effects at dose levels that were approximately 10-fold lower than those that inhibit red blood cell AChE. A target MOE of 100 was selected to be protective of human health for the neurodevelopmental endpoint and is comprised of 10x for interspecies sensitivity and 10x for intraspecies variability. There is no need for an additional UF for neurodevelopmental effects. The risk of exposures to inhalation and spray drift is exacerbated by consumption of food and drinking water in this approach. The database for developmental neurotoxicity is evolving, and as new data become available HHA can further refine this assessment.

Adding an additional 10x UF to an AChE inhibition endpoint would indirectly account for the possibility of neurodevelopmental effects, thus increasing the protection factor of the estimated RfC and RfDs for chlorpyrifos. By adding an additional 3x uncertainty factor for PBPK-PD model insufficiencies, the protectiveness in the proposed target RfCs and RfDs has been further increased. The database which supports the AChE endpoint is robust, covering many hundreds of research papers over several decades, with consistency across laboratories and studies for the level of chlorpyrifos that inhibits AChE in red blood cells in both animals and humans. The magnitude of the 10x UF to account for possible developmental effects is well supported by existing data. The use of the AChE inhibition endpoint with the addition of the 10x UF can be considered a surrogate for the more sensitive DNT endpoint.

In conclusion, DPR evaluated the strengths and uncertainties associated with the use of the available database for deriving critical endpoints for chlorpyrifos. Following the recommendation of the SRP, DPR thoroughly evaluated developmental neurotoxicity as the critical endpoint for the chlorpyrifos risk assessment. Based on the evaluation of the toxicity database and exposure analyses, this assessment supports the finding that chlorpyrifos meets the criteria to be listed as a TAC pursuant to the law of California.

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APPENDIX 1.

SUMMARY OF TOXICOLOGY FOR CHLORPYRIFOS

Updated April 20, 2018

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY
DEPARTMENT OF PESTICIDE REGULATION
HUMAN HEALTH ASSESSMENT BRANCH

SUMMARY OF TOXICOLOGY DATA
CHLORPYRIFOS

Chemical Code # 00253 Document Processing Number (DPN) # 0342
SB 950 # 221
Summary initiated: 5/8/86

Revisions on 8/11/86, 11/24/86, 6/5/87, 4/25/89, 11/09/89, 3/16/90, 11/8/90, 5/11/92, 6/28/93, 7/19/94, 9/3/97, 11/13/98, 10/13/99, 9/27/01, 6/5/13, 11/19/13, 6/8/15, and 4/20/18

DATA GAP STATUS

Chronic toxicity, rat:	No data gap, possible adverse effect
Chronic toxicity, dog:	No data gap, no adverse effect
Oncogenicity, rat:	No data gap, no adverse effect
Oncogenicity, mouse:	No data gap, no adverse effect
Reproduction, rat:	No data gap, no adverse effect
Developmental toxicity, rat:	No data gap, no adverse effect
Developmental toxicity, rabbit:	No data gap, no adverse effect
Gene mutation:	No data gap, no adverse effect
Chromosome effects:	No data gap, no adverse effect
DNA damage:	No data gap, possible adverse effect
Neurotoxicity:	No data gap, no adverse effect

Toxicology one-liners are attached.

All record numbers for the above study types through 299293 (Document No. 342-1014) were examined. This includes all relevant studies indexed by DPR as of April 10, 2018.

In the 1-liners below:
** indicates an acceptable study.
Bold face indicates a possible adverse effect.
indicates a study on file but not yet reviewed.

File name: t20180420 chlorpyrifos
Current revision by C. Aldous, April 20, 2018

NOTE: The following symbols may be used in the Table of Contents which follows:
** = data adequately address FIFRA requirement
† = study(ies) flagged as "possible adverse effect"
(N/A) = study type not currently required

This record contains summaries of studies. Individual worksheets may be useful for detailed assessment.

Table of Contents

HAZARD IDENTIFICATION SUMMARY FOR CHLORPYRIFOS

Metabolism: Chlorpyrifos was efficiently absorbed by rats following gavage dosing of chlorpyrifos in corn oil, as indicated by approximately 90% of a labeled dose being found in urine. Humans absorbed about 72% of an oral dose from a lactose tablet, compared to about 1.35% of a dermal dose. About 50% of administered dose was captured in urine of rats within 12 hours of dosing. Major urinary metabolites in rats and in humans were 3,5,6-trichloro-2-pyridinol (TCP) and (at least in rats) its glucuronide conjugation products. The elimination half-life of TCP in humans is about 27 hours, making TCP concentration a rough indicator of recent chlorpyrifos exposure. Oral absorption in humans dosed with 0.5 to 2 mg/kg chlorpyrifos in gelatin capsules was 30-35%. Generally, the low doses used in human and monkey studies found blood chlorpyrifos levels near to the limits of detection. A rat study with single oral dose levels of 0.5, 1, 5, 10, 50, and 100 mg/kg chlorpyrifos, found peak (3-hour) blood levels of chlorpyrifos of 3, 30, 113, 444, and 798 ng/g blood at 1 to 100 mg/kg, respectively (not detectable at 0.5 mg/kg). Estimated half-life for chlorpyrifos in blood was 2.7, 1.5, 2.1, or 7.3 hours for 5, 10, 50, or 100 mg/kg chlorpyrifos dose levels, respectively. In the same study, chlorpyrifos oxon was detected at a maximum of 2.5 ng/g blood, this being 1 hour after dosing with 50 mg/kg chlorpyrifos.

Acute Toxicity: Oral dosing found rat LD_{50} of 144-223 mg/kg, with clinical signs at high doses such as fecal soiling, lacrimation, urine soiling, salivation, and decreased activity. Dermal LD_{50} was greater than 5000 mg/kg, with limited clinical signs (soiled fur). Inhalation LC_{50} was over 4.07 mg/L (male) and 2.87 mg/L (female), accompanied by clinical signs similar to those of oral dosing. Primary eye irritation and primary dermal irritation studies showed mild effects (Category III and IV). Chlorpyrifos is not a sensitizer.

Subchronic Toxicity: Available subchronic studies were generally performed as pilot studies for longer-term studies, or to evaluate cholinesterase (ChE) effects (reported separately in this section). The subchronic rat study found slight ChE reduction (in plasma ChE) at 0.1 mg/kg/day, even though only limited ChE-related clinical signs could be found at a much higher dose (10 mg/kg/day). The dog subchronic study found that about 50% brain ChE inhibition was observed at 200 ppm, and gross cholinergic symptoms were observed at 600 ppm.

Chronic Toxicity and Oncogenicity: A lifetime rat oncogenicity study (Record No. 153114) reported findings at 100 ppm including modest body weight decrements and over 50% brain ChE inhibition in both sexes, and an increase over baseline incidences of diffuse retinal atrophy and cataracts in 100 ppm females. Associated overall achieved dose levels were in the range of 5 to 6 mg/kg/day for males and 6 to 7 mg/kg/day for females. The latter dose did not elicit definitive cholinergic signs such as were reported in acute oral testing, above. A mouse oncogenicity (79-week) study found severe brain ChE inhibition at 250 ppm (residual brain ChE activity about 20% or less in both sexes), without clearly-associated cholinergic signs. That study achieved dose levels of 45-46 mg/kg/day in either sex at 250 ppm midway through the study. There were no treatment-related tumors in either species.

Genotoxicity: mutation studies in bacteria and mammalian cells were negative, as were cytogenetics assays. An acceptable unscheduled DNA synthesis (UDS) assay was negative. Two studies designed to evaluate DNA damage were reportedly positive, but could not be fully evaluated by DPR because the underlying data were not available. The positive findings of the DNA damage tests thus cannot be dismissed at this time.

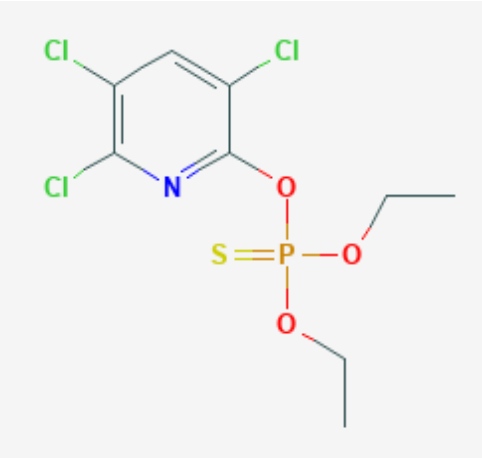
Reproductive and Developmental Studies: The reproduction study found a statistically significant reduction in pup weights in the first generation, and a slight reduction in pup survival in the second generation, both at 5 mg/kg/day. Pup losses tended to be specific to particular litters, often associated with signs of maternal neglect, such as multiple pups which were weak, pale, cold, or with no milk in the stomach. As maternal brain ChE at 5 mg/kg/day was severely inhibited (51% of control in F0 dams and 42% of control in F1 dams), the findings in pups were attributed to maternal toxicity. Two valid rat developmental toxicity studies dosed the dams up to a maternally toxic level (tremors at 15 mg/kg/day). One study was negative for developmental effects, and the other study reported a slight increase in early resorptions at that dose. Neither of these studies was considered "adverse" with respect to developmental toxicity. A rabbit developmental toxicity study found maternal body weight gain decrements at 140 mg/kg/day, associated with developmental delays in fetuses. There were no effects on either dams or fetuses at the next lower dose of 81 mg/kg/day. No adverse effects were indicated. An acceptable mouse developmental toxicity study found slight developmental delays at 25 mg/kg/day, with a NOEL of 10 mg/kg/day. This was not considered to be "adverse," considering that the dams had clinical signs of tremors and excessive salivation at 10 and 25 mg/kg/day.

Neurotoxicity: An acute neurotoxicity study found transitory effects shortly after dosing: reduced body weights and perineal soiling at 50 and 100 mg/kg/day, in addition to FOB observations of incoordination, decreased muscle tone, tremor, increased lacrimation and salivation at 100 mg/kg/day in females immediately after dosing on day 1. Motor activity was reduced at 50 and 100 mg/kg/day on day 1; some reductions persisted to day 8 in 100 mg/kg/day females. NOEL

was 10 mg/kg. There were no histopathologic changes. Findings were not considered to be "adverse" in the context of the study objectives. A 90-day neurotoxicity study found reduced motor activity at 15 mg/kg/day at observation week 4, but not subsequently. Perineal soiling was occasionally observed at 5 and 15 mg/kg/day. There were no neurohistopathological findings. In the absence of substantial or progressive changes, this study was not considered to indicate "adverse" effects. A developmental neurotoxicity study dosed dams from gestation day 6 through lactation day 11. Maternal brain ChE activity at gestation day 20 was inhibited by 90% at 5 mg/kg/day, and by 18% at 1 mg/kg/day. Dams displayed clinical signs during gestation (fasciculations), and additionally hyperreactivity and hyperpnea at lactation at 5 mg/kg/day, but not at lower dose levels. Pups suffered early neonatal losses, body weight losses, and developmental delays at 5 mg/kg/day, with no changes at 1 mg/kg/day. Considering the extreme toxicity to the dams at 5 mg/kg/day, no findings in offspring were of sufficient magnitude to designate the study as "adverse" with respect to offspring.

Immunotoxicity: A valid immunotoxicity study found no adverse effects.

Cholinesterase (ChE) Inhibition: Plasma cholinesterase (ChE) is a relatively sensitive indicator of recent chlorpyrifos exposure (i.e., a few hours). Male human volunteers administered a 0.5 mg/kg single oral dose of chlorpyrifos had plasma ChE inhibited to about 15% of baseline, with maximal inhibition at 0.5 to 2 hrs after dosing. By 8 hours, plasma ChE levels had substantially recovered. By 27 to 30 hours, plasma ChE activity had returned to baseline. RBC ChE was not measurably inhibited at 0.5 mg/kg, but appeared to have been inhibited in a human subject following a single oral dose of 2 mg/kg in another study. In a gavage single dose study in rats, brain ChE inhibition was evident at 10 mg/kg and above, with brain ChE activity (as percent of control) at 6-hour peak response being 88%, 30%, and 28% in 10, 50, and 100 mg/kg groups, respectively.



Chlorpyrifos

Active Ingredient structure from https://pubchem.ncbi.nlm.nih.gov

METABOLISM AND PHARMACOKINETICS ** (based on collective data)

NOTE: A number of studies in the Miscellaneous section near the end of this Summary include metabolism, pharmacokinetics, and cholinesterase inhibition data.

342-0343 071390 Nolan, R. J., M. D. Dryzga, B. D. Landenberger, and P. E. Kastl, "Chlorpyrifos: tissue distribution and metabolism of orally administered ^{14}C-labeled chlorpyrifos in Fischer 344 rats," The Dow Chemical Company, Midland, MI, 12/23/87. Laboratory Study # K-044793-(76). Five rats/sex/group were dosed by gavage in 2 ml/kg corn oil in single labeled doses of 0.5 or 25 mg/kg or 15 consecutive daily doses of unlabeled chlorpyrifos at 0.5 mg/kg/day, followed 1 day after the 15th dose with a single labeled dose of 0.5 mg/kg. Labeled chlorpyrifos (>99% radiopurity) was 12 µCi per gram of corn oil regardless of dose. Only the 3,5,6-trichloro-2-pyridinol group was labeled. Unlabeled chlorpyrifos, used to dilute the high dose group, was 99.9% purity. Investigators evaluated label in urine, feces, and tissues, and identified the three significant urinary metabolites. Urine plus cage wash accounted for 86 to 93% of administered label, regardless of sex or dosing regimen. Six to 11% of label was found in feces. Urinary excretion was rapid: usually over 50% of administered dose was collected in urine within the first 12 hours ($T_{1/2}$ was 8-9 hours for single or multiple 0.5 mg/kg treatments, and somewhat longer for 25 mg/kg rats). Urinary metabolites were composed chiefly of 3,5,6-trichloro-2-pyridinol, and usually slightly more of its glucuronide, collectively accounting for over 90% of urinary metabolites. About 5% of urinary residues consisted of the sulfate conjugate of 3,5,6-trichloro-2-pyridinol. Parent chlorpyrifos was not found in urine. Most fecal label was obtained within the first 24 hours. Exhaled CO_2 was trapped for radioanalysis from the 25 mg/kg group. This collection accounted for <0.01% of administered dose. Fecal metabolites were not assessed. Tissue residues were assessed at 72 hrs (M) and at 144 hrs (F). Total tissue residues were very small (0.2% of administered dose in 25 mg/kg group) to negligible (<0.01%), and generally only quantifiable in peri-renal fat (M and F). In the 25 mg/kg groups only, tiny but quantifiable residues were also found in liver (M) and ovaries. This is a valid supplementary study. Aldous, June 5, 2015.

GUIDELINE ACUTE STUDIES ON ACTIVE INGREDIENT

Acute oral toxicity, rat **

**342-716; 154442; Stebbins, K. E., "Dursban F Insecticidal Chemical: Acute Oral Toxicity Study in Fischer 344 rats," study type 811; The Toxicology Research Laboratory, Health and Environmental Sciences, The Dow Chemical Company, Midland, MI; Study No. K-044793-102A; 11/27/96; Dursban F Insecticidal Chemical (purity: 97.6%); 5 animals/sex/group; Doses: 50, 100, 500 mg/kg as 3% suspension in 0.5% aqueous solution of Methocel A4M; Mortality: 50 (M/F:0/5), 100 (M/F:0/5), 500 (M/F:5/5), deaths occurring with 3 days after dosing; Clinical Observations: fecal soiling, lacrimation, urine soiling, salivation, decreased activity; Necropsy: no treatment-related lesions noted; LD50 (M/F): 223 mg/kg; Toxicity Category II; Study acceptable. (Moore, 5/29/97)

**342-708; 154314; Nissimov, S. and A. Nyska, "Pyrinex Tech.: Acute Oral Toxicity in the rat," study type 811; Life Science Research Israel Ltd., Ness Ziona 70451, Israel; Study No. MAK/056/PYR; 5/12/84; Pyrinex Tech; 5 animals/sex/group; Doses: 90, 164, 298, 543, 987 mg/kg, in corn oil; Mortality: 90 (M/F:0/5), 164 (M:0/5, F:4/5), 298 (M/F:5/5), 543 (M/F:5/5), 987 (M/F:5/5); Clinical Observations: tremors, hunched posture, salivation, diarrhea, decreased motor activity, ataxia; Necropsy: hemorrhagic and/or ulcerated stomach and intestines; LD50

(95% confidence interval): (M) 221 (181 to 269) mg/kg, (F) 144 (105 to 200) mg/kg; Toxicity Category II; Study acceptable. (Moore, 6/10/97)

Acute dermal toxicity **

**342-716; 154444; Stebbins, K. E., "Dursban F Insecticidal Chemical: Acute Dermal Toxicity Study in New Zealand White Rabbits," study type 812; The Toxicology Research Laboratory, Health and Environmental Sciences, The Dow Chemical Company, Midland, MI; Study No. K-044793-102D; 11/27/96; Dursban F Insecticidal Chemical (purity: 97.6%); 5 animals/sex/group; Doses: 2000, 5000 mg/kg, test material liquefied prior to application, 24 hour exposure; No mortality; Clinical Observations: fecal soiling, dermal irritation at the site of application; Necropsy: no treatment-related lesions; LD50 (M/F) > 5000 mg/kg; Toxicity Category IV; Study acceptable. (Moore, 5/30/97)

**342-709; 154315; Nissimov, S. and A. Nyska, "Pyrinex Tech.: Acute Dermal Toxicity in rabbits," study type 812; Life Science Research Israel Ltd., Ness Ziona 70451, Israel; Study No. MAK/059/PYR; 5/12/84; Pyrinex Tech; 5 animals/sex; Dose: 2000 mg/kg, liquefied prior to application, 24 hour exposure, semi-occlusive wrap; No mortality; Clinical Observations: no treatment-related signs; Necropsy: congested lungs, skin lesions, multiple petechiae on thymus; LD50 (M/F) > 2000 mg/kg; Toxicity Category III; Study acceptable. (Moore, 6/10/97)

Acute inhalation toxicity, rat **

**342-710; 154316; Buch, S. A., "Pyrinex Tech.: Acute Inhalation Toxicity in rats," study type 813; Life Science Research, Stock, Essex, England; Study No. 80/MAK025/362; 8/27/80; Pyrinex Tech (purity: 95.%); 5 animals/sex/group unless otherwise noted; Exposure Concentrations (gravimetric): 1.69 (F only), 2.23, 2.98, 3.56, 4.07 mg/l, MMAD (GSD): 7.4 (2.2), 7.9 (1.7), 8.2 (1.9), 8.0 (2.0), 8.6 (2.1) µm, respectively, respirable concentration (mass of particles < 10 µm): 1.40, 1.86, 2.61, 3.01, 3.47 mg/l, respectively, 4 hour nose-only exposure (test material was prepared as a 60% (w/v) in xylene) (concentrations based upon non-volatile portion of exposure atmosphere); Mortality: 1.69 (F:1/5), 2.23 (M:0/5, F:2/5), 2.98 (M:0/5, F:3/5), 3.56 (M:0/5, F:2/5), 4.07 (M:0/10, F:4/5); Clinical Observations: decreased motor activity, hunched posture, ataxia, tremor, hypothermia, piloerection, pigmented stain around eye and snout, gasping, bradypnea, muscle fasciculations; Necropsy: lungs pale and/or congested, liver pale with accentuation of lobular pattern, increased relative lung weights among the decedents; LC50 (95% confidence limit): (M) > 4.07 mg/l, (F) 2.89 (2.01 to 4.16) mg/l; Toxicity Category III; Study acceptable. (Moore, 6/11/97)

342-343; 71387; Landry, T. D., D. A. Dittenber, L. G. Lomax, and J. J. Momany-Pfruender, "Chlorpyrifos: an acute vapor inhalation toxicity study with Fischer 344 rats," study type 813; Dow Chemical Company, Mammalian and Environmental Toxicology Research Laboratory, Midland MI; Lab Study No. K-44793-74; 12/3/86; Chlorpyrifos (Reference No. AGR 219646; purity = 100%), used neat; 0 (air) (24M/24F), 3.5 (6M/6F), 6 (12M/12F), 14 (6M/6F) ppm (analytical); vapor inhalation, 6-hour, whole-body and nose-only exposures; Mortality- one male at 6 ppm (attributed to physical trauma); Clinical Observations- reduced plasma cholinesterase activity (13-24% reduction) in 6 ppm group only (attributed to oral ingestion or dermal absorption of the dose); hyperactivity (considered not exposure-related); Necropsy- no treatment-related findings; reported LC50 (M and F) > 14 ppm (0.22 mg/l); Supplemental. (Duncan, 6/21/91)

Primary eye irritation, rabbit **

**342-716; 154445; Stebbins, K. E., "Dursban F Insecticidal Chemical: Primary Eye Irritation Study in New Zealand White Rabbits," study type 814, The Toxicology Research Laboratory, Health and Environmental Sciences, The Dow Chemical Company, Midland, MI; Study No. K-044793-102C; 11/27/96; Dursban F Insecticidal Chemical (purity:97.6%); 6 animals; Dose: 0.1 ml/eye, liquefied prior to application; Observations: no ocular irritation evident at 24 hours; Toxicity Category IV; Study acceptable. (Moore, 5/30/97)

**342-711; 154317; Buch, S. A. and J. R. Gardner, "Pyrinex Tech.: Irritance to rabbit eye," study type 814; Life Science Research, Stock, Essex, England; Study No. 80/MAK023/143; 4/30/80; Pyrinex Tech; 6 animals (eyes not rinsed); Dose: 100 mg/eye; Observations: no corneal opacity nor iritis evident, Conjunctiva (redness)-grades 2 (1/6) and 1 (5/6) at 24 hours, grade 1 (1/6) through 7 days (termination), no chemosis nor discharge evident at 24 hours; Toxicity Category III; Study acceptable. (Moore, 6/11/97)

Primary dermal irritation **

**342-716; 154446; Stebbins, K. E., "Dursban F Insecticidal Chemical: Primary Dermal Irritation Study in New Zealand White Rabbits," study type 815; The Toxicology Research Laboratory, Health and Environmental Sciences, The Dow Chemical Company, Midland, MI; Study No. K-044973-102B; 11/27/96; Dursban F Insecticidal Chemical (purity: 97.6%); 6 animals; Dose: 0.5 ml/site, liquefied prior to application, 4 hour exposure; Observations: erythema-grade 1 (6/6) at 30 minutes post-exposure, grade 1 (4/6) at 24 hours, grade 1 (2/6) at 48 and 72 hours, clear by 7 days; Toxicity Category IV; Study acceptable. (Moore, 5/30/97)

**342-712; 154319; Buch, S. A. and J. R. Gardner, "Pyrinex Tech.: Irritance to rabbit skin," study type 815; Life Science Research, Stock, Essex, England; Study No. 80/MAK024/144; 4/30/80; Pyrinex Tech; 6 animals; Dose: 0.5 gm/site (4 sites, 2 intact, 2 abraded), moistened with 0.2 ml of physiological saline, 23 hour exposure, occlusive wrap; Observations: (intact sites) erythema-grades 2 (3/6) and 1 (3/6) at 24 hours post-dosing, grade 1 (1/6) at 72 hours and on day 8, edema-grade 1 (1/6) at 24 hours post-dosing, clear by 72 hours; Toxicity Category IV; Study acceptable. (Moore, 6/11/97)

Dermal sensitization **

**342-0716 154447 Stebbins, K. E., "Dursban F Insecticidal Chemical: Dermal Sensitization Potential in Hartley Albino Guinea Pigs," The Dow Chemical Company, Midland, MI, 11/27/96. Laboratory Study # K-044793-102E. Investigators first determined that the lowest non-irritating dose of Dursban F was 1% in dipropylene glycol monomethyl ether (DPGME). This dose level was used in the primary study. In all sensitization cases, induction was performed weekly for 3 weeks, and challenge followed two weeks after the third induction (with skin site examination 24 and 48 hrs after challenge). On each occasion, 0.4 ml of material was applied to clipped, intact skin for 6 hours. Test materials for positive controls were either DER 331 epoxy resin (neat) or dinitrochlorobenzene (DNCB, 0.5% in DPGME vehicle). Groups of five naïve animals were dosed twice (one week apart) with each of the three treatments as non-induced controls. Under these circumstances, Dursban F induction/challenge group showed erythema in only one animal (the same animal showing "slight" erythema during induction week 1 and again "slight" erythema 48 hrs after challenge). Main study positive controls were uniformly negative for skin irritation during the first two induction treatments, then frequently showed "slight" erythema at

the third induction treatment. Both positive controls typically displayed "slight" to "moderate" erythema at challenge. Treatments of naïve animals were uniformly negative, except for one Dursban F animal with "slight" erythema. Thus test system was viable, and **negative** for dermal sensitization for Dursban F. Study is **acceptable**, with no adverse effects. Aldous, 4/14/15.

342-0713 154320 Berman, C. L., "Evaluation of Chlorpyrifos (Pyrinex) for dermal sensitization of guinea pig," Arthur D. Little, Inc., Cambridge, MA, 10/21/1987. Test article was chlorpyrifos, 96.8% purity, Technical grade. This study was examined on 7/29/97 by C. Rech of DPR, who noted several deficiencies, and requested a replacement study. This unacceptable study did not indicate sensitization potential. (Aldous, June 3, 2015).

**342-0744 162453 Bassett, J. and M. Watson, "Dermal Sensitization study (closed-patch repeated insult) in guinea pigs with Chlorpyrifos Technical (Pyrinex)," Department of Toxicology, Ricerca, Inc., Painesville, OH, 3/31/98. Technical chlorpyrifos (97% purity) was administered to 20 Hartley guinea pigs for the induction phase at 50% concentration in peanut oil, 0.4 ml/site, administered to the shaved dorsal and lateral skin 3 times at weekly intervals. Challenge was 2 weeks after the last induction exposure, administered in 50% propylene glycol. Chlorpyrifos did not elicit a challenge response (i.e. is not a sensitizer). Positive control (DCNB) was effective. This study was considered as negative for sensitization and acceptable by DPR reviewers, D. E. Haskell and J. R. Sanborn (review of Dec. 2, 1998).

SUBCHRONIC STUDIES

Subchronic Oral toxicity, rat:

342-354 74494 Szabo, J. R., J. T. Young, and M. Grandjean, "Chlorpyrifos: 13-week dietary toxicity study in Fischer - 344 rats." Lake Jackson Research Center [The Dow Chemical Co.], Freeport, Texas, 12/28/88. This study was submitted by Dow to contest the CDFA decision of a cholinesterase (ChE) NOEL at 0.05 mg/kg/day in the 2-year study, 345:072300. No comprehensive CDFA review of this subchronic study is necessary at this time, since the purpose of the 13-week study was to set dose levels for the cited 2-year study, which has already been accepted by CDFA. This subchronic study found statistically reduced plasma ChE levels ($p < 0.05$, two tailed) at day 44, but not at day 91. Investigators concluded findings at day 44 "not considered to be of toxicologic or biologic significance." CDFA concludes that the findings are probably treatment effects, which however have no apparent toxicological consequence: the plasma ChE NOEL remains 0.05 mg/kg/day, but a practical NOAEL for ChE inhibition is 0.1 mg/kg/day. C. Aldous, 11/9/89.

Subchronic Oral toxicity, non-rodent: a supplementary 3-mo. dog study has been reviewed. No further non-rodent subchronic data are requested at this time.

342-306 063996 [Author appears to be McCollister, S. B.], "Results of 93-day dietary feeding studies of O,O-diethyl O-3,5,6-trichloro-2-pyridyl phosphorothioate in beagle hounds," 1/15/64. This study pre-dates modern guidelines, and should be considered only for information on major symptoms of toxicity. Dogs were initially administered chlorpyrifos (98% purity) at 0, 200, 600, or 2000 ppm (report designates units of initial exposure as 0, 0.02, 0.06, and 0.2 percent in diet). There were 4 controls/sex, and 2/sex for each of the other groups. None of these treated dose

levels were sustainable, due to cholinergic symptoms such as "dilated and watery eyes, loose stools, vomiting, rough coats, labored breathing and tremors of the legs and head." The 2000 ppm dogs were "essentially starving" as of treatment day 5, so that their diet was reduced to 0.006% (60 ppm) for the balance of the study. The dogs administered initially 600 ppm "were developing gross cholinergic symptoms," and had diets reduced to 0.002% (20 ppm) after 16 days. Dogs originally administered 200 ppm were placed on control diet from day 45 onward. An additional group (N = 2/sex) was administered 200 ppm chlorpyrifos for about 45 days prior to sacrifice (designated as "Group B," with estimated mean exposure of 3.4 mg/kg/day). Dogs were evaluated periodically for plasma and RBC cholinesterase (ChE), and brain acetylcholinesterase (AChE) was assessed at termination. Hematology, limited clinical chemistry, and terminal necropsy and histopathology were also recorded. These data were initially reviewed mainly to justify dose levels used in the chronic dog study (Record No. 036338). Small group sizes and altered dosing regimens limited the utility of this study. Group B 200 ppm dogs lost weight during their 45-day treatment, at a life stage when control dogs were still gaining weight. In particular one of the two Group B females lost 1.4 kg, and the other (which died shortly before scheduled sacrifice) lost 1.65 kg. The two Group B dogs surviving to termination and which had brain tissue assayed for AChE had brain AChE activities of about 50% of controls. The most relevant blood ChE data for these dogs was at 27 days of continuous treatment: at this time, the highly variable plasma ChE averaged about 10% of pre-exposure activity, and similarly variable RBC ChE activity was less than 20% of pre-exposure activity. Group A 200 ppm dogs had progressively diminishing plasma and RBC ChE activity over the time frame from 14 to 41 days of continuous exposure. When these dogs came off treatment, plasma ChE activity was visibly improving by 3 days, and was roughly 80% of pre-treatment levels by the 18th day off treatment. RBC ChE activity was slower to recover: with about 50% of pre-dosing activity between recovery days 18 and 32. RBC ChE activity was still below baseline at the last blood assay on recovery day 41. Brain AChE in these Group A 200 ppm dogs appeared to be in the normal range after 48 days of recovery. Dogs administered the medium dose (60 ppm for all but the first 5 study days) finished the study with plasma and RBC ChE activities at about 50% of pre-exposure values. At termination, males had brain AChE activity in the normal range, whereas females had implausibly low brain activities (i.e. lower than those observed in 200 ppm dogs after about 45 days of dosing). Dogs on the lowest sustained dose level (20 ppm) had plasma ChE activities of about 25% of pre-treatment levels, and RBC ChE activities of about 50% of pre-treatment levels. The 20 ppm males had normal brain AChE activity at termination, whereas one female had normal brain AChE activity, and one had about 40% of normal brain activity. In summary, although this study does not meet modern guidelines, had small group sizes and large variability in key responses, responses provide useful information on high dose effects to augment results from the later dog chronic studies. "One-liner" was re-written by Aldous on June 4, 2015 in support of risk assessment efforts in DPR.

Subchronic Inhalation toxicity, rat:

342-0967 284609 Newton, P. E., "A thirteen week nose-only inhalation toxicity study of chlorpyrifos technical (Pyrinex) in the rat," Bio/dynamics Inc., East Millstone, NJ, 11/14/88, Project No. 88-8058. Fifteen F344 rats/sex/group were dosed by nose-only inhalation to chlorpyrifos vapors (Pyrinex Technical, 95% purity) at targeted concentrations of 0, 5, 10, and 20 ppb, respectively [6 hours/day, 5 days/week, for 13 weeks]. There were no treatment effects on clinical signs (in chamber or at detailed weekly examinations), or on body weight, food

consumption, hematology, clinical chemistry [other than possible plasma cholinesterase (ChE)]. Ophthalmology, necropsy observations, and histopathology findings were negative. Brain and RBC ChE activities were unaffected. The 20 ppb male plasma ChE activities were lower than any other contemporary groups and also lower than the limited pre-test ChE activities available. This reviewer considers that this represents a plausible treatment effect, with a NOEL of 10 ppb. NOEL for females = 20 ppb (no changes observed). This is a valid supplementary study (not a study design routinely expected under FIFRA requirements). See also the 1986 study: 342-0343 071389 (Corley et al.), which did **not** find any ChE effects at similar dose levels in nose-only vapor subchronic inhalation conditions like the present study. These equivocal, marginal plasma ChE findings are not designated as "possible adverse effects" under these circumstances. Aldous, June 3, 2015.

342-0967 284608. This is a brief report of corrections to 342-0967 284609, above. The cause of death had been erroneously coded for two rats in the original report. Survival was not dose-related in this study, and the corrections had no consequential impact on study interpretation.

Dermal toxicity, 21/28-day or 90-day:

342-0343 071391 Calhoun, L. L. and K. A. Johnson, "4-day dermal probe and 21-day dermal toxicity studies in Fischer 344 rats," The Dow Chemical Company, Midland, MI, Sept. 1, 1988. Laboratory Study Nos. K-044793-085, K-044793-086. Chlorpyrifos, purity 100±0.1%, was applied in corn oil vehicle 6 hours/treatment to intact clipped dorsal skin (under gauze, secured by bandages) as indicated. Four female rats/sex/group were dosed by dermal application in corn oil at 0, 1, 10, 100, or 500 mg/kg/day for 4 consecutive days at 6 hours/treatment in a **probe study**. That study found that plasma cholinesterase was inhibited by 45%, 91%, and 97% at 10, 100, and 500 mg/kg/day, respectively. Also, RBC cholinesterase was inhibited by 16%, 49%, and 75% at respective dose levels. There were no other definitive findings in the probe study (which also assessed application site response, clinical signs, and body weight). The **primary** study was a 21-day dermal regimen, with dosing each weekday for a total of 15 exposures at 0, 0.1, 0.5, 1, or 5 mg/kg/day (N = 5/sex). Necropsy followed 2 consecutive treatment days in the final week. Investigators evaluated the parameters of the pilot study, plus a limited FOB, hematology, clinical chemistry, and histopathology. There were no definitive treatment effects in the primary study, hence the highest dose tested of 5 mg/kg/day is the NOEL for both sexes. This study is supplementary and not upgradeable (mainly because the dose range in the primary study was well below what the probe study showed to be supportable). Aldous, June 5, 2015.

CHRONIC STUDIES

Combined (chronic/oncogenicity), rat ** † ("possible adverse effect" based on non-oncogenicity findings in Record No. 153114, rat oncogenicity study)

**342-345 072300 Young, J. T., and M. Grandjean, "Chlorpyrifos: 2-year dietary chronic toxicity-oncogenicity study in Fischer-344 rats". Dow Chemical Co., Freeport TX, 12/23/88. Chlorpyrifos ("AGR 214637"), 98.5%, in diet at 0, 0.05, 0.1, 1, and 10 mg/kg/day. 10/sex/dose designated for 1-year interim sacrifice: 50/sex/dose designated for 2-year duration. Cholinesterase (ChE) inhibition NOEL = 0.05 mg/kg/day (based on slight plasma ChE inhibition at 0.1 mg/kg/day in females). Acetylcholinesterase ChE inhibition NOAEL of 0.1 mg/kg/day is

nevertheless supportable, considering the issues discussed in the review for 354:074494. The NOEL for effects other than ChE inhibition was 0.1 mg/kg/day [based on very slight (≤ 3%) but often statistically significant body weight decrease in 1 mg/kg/day males]. Body weights were statistically significantly reduced in 10 mg/kg/day males (7 to 9% throughout study). The "non-ChE effects" NOAEL was 1 mg/kg/day. Findings at 10 mg/kg/day were frequent perineal yellow staining in females, approximately 50% brain ChE inhibition in males and females, a slight increase in the degree of vacuolation of the adrenal zona fasciculata (males only), and a slight increase in diffuse retinal degeneration in 10 mg/kg/day females. None of these findings indicates possible adverse health effects (see review). ACCEPTABLE**.** C. Aldous, 4/21/89, 11/9/89 (see 354:074494). NOTE: Another rat study (see Record No. 153114 under AOncogenicity, Rat@ similarly identified retinal atrophy and cataracts at the highest dose tested (100 ppm in the latter case).

342-363 087917 (supplemental information to 342-345:072300). "Macroscopic postmortem examination of the eyes and associated structures in albino rats (Dow Method)". (Refers to technique used at Freeport, TX, facility), method description dated 9/11/89. Methodology was presented in accordance with a CDFA request, which was made in the 4/21/89 CDFA review of the cited study. C. Aldous, 3/16/90.

342-250 and -251 036335-036337 McCollister, S. B., R. J. Kociba, P. J. Gehring, and C. G. Humiston, "Results of Two-Year Dietary Feeding Studies on DOWCO 179 in Rats" Dow Chemical, Midland, Michigan, 9/20/71. Chlorpyrifos, (presumed technical); 0, 0.01, 0.03, 0.1, 1.0, and 3.0 mg/kg/day in diet. NOEL cholinesterase enzyme inhibition = 0.1 mg/kg/day. NOEL for other systemic effects = 3.0 mg/kg/day (HDT). No oncogenicity observed. Incomplete, UNACCEPTABLE, and not upgradeable Too few animals, too much attrition due to disease (largely chronic murine pneumonia) & dose levels not justified and apparently below the MTD. C. Aldous, 1/28/86.
EPA 1-liner: [2-year feeding, rat, Dow Chemical Co, 9/20/71] Systemic NOEL 3.0 mg/kg/day (HDT); ChE NOEL = 0.1 mg/kg/day. Carcinogenic potential negative up to 3.0 mg/kg/day (HDT). Core grade, Supplementary.

342-044 031074 Published summary of 250/251:036335-036337.

342-013/053 031070 Summary of 250/251:036335-036337.

EPA 1-liner: [2-year feeding, rat, Dow Chemical Co, 9/20/71] Systemic NOEL 3.0 mg/kg/day (HDT); ChE NOEL = 0.1 mg/kg/day. Carcinogenic potential negative up to 3.0 mg/kg/day (HDT). Core grade, Supplementary.

342-044 031074 Published summary of 250/251:036335-036337.

342-013/053 031070 Summary of 250/251:036335-036337.

Chronic, dog **

**342-0252 036338-036339 McCollister, S. B., R. J. Kociba, P. J. Gehring, and C. G. Humiston, "Results of Two-Year Dietary Feeding Studies on DOWCO® 179 in Beagle Dogs,"

Dow Chemical, Midland, MI, 12/10/71. Chlorpyrifos (97.2% purity) was administered in diets at concentrations adjusted to provide 0, 0.01, 0.03, 0.1, 1.0, and 3.0 mg/kg/day. This study had two phases. In Phase A, there were 3/sex/group treated for 1 year, at which time 1/sex was necropsied. The remaining 2/sex were taken off treatment for 3 months prior to necropsy to evaluate recovery. In Phase B, 4/sex were dosed for 2 years at the above levels. Investigators assessed standard parameters of chronic studies. To assess cholinesterase (ChE) effects, plasma and RBC ChE activities were assayed 3 times pre-treatment and at 6 intervals during Phase A treatment. In Phase B, plasma and RBC ChE activities were assayed twice pre-treatment and at 8 intervals during treatment. Brain ChE was assessed at sacrifices of all dogs in both phases. Plasma ChE inhibition NOEL = 0.01 ppm, based on dose-related inhibition at 0.03 ppm and above. RBC ChE NOEL = 0.1 ppm, based on strong inhibition at 1.0 and 3.0 ppm compared to the same subjects at pre-treatment assessments. (See also Record No. 284915, which is a composite analysis of the RBC data from this study). Brain ChE activity at 3.0 mg/kg/day was reduced by an average of about 18%, with no evident sex difference in magnitude of response. There is a NOEL of 1.0 mg/kg/day for brain ChE. The NOEL for other effects, including behavioral observations, was the highest dose tested of 3.0 mg/kg/day. The study was designated as **acceptable** on 3/16/90, on receipt of details on preparation of treated food. Previous objections of CDFA to this study were (1) concerns that dosage range may not have adequately challenged the dogs, and (2) lack of reporting of ophthalmological examination data in the final report. These were addressed in submissions 306:063996 and 338:070883, respectively. This study was examined by C. Aldous on1/29/86, 4/11/89, 3/16/90 (see also rebuttal response of 6/4/87 and minutes of meeting with Dow Chemical Co. representatives on 6/29/88). A final examination by Aldous on June 3, 2015 updated this summary and noted recent submission of the cited Record No. 284915 data. This study does not indicate an "adverse effect." ChE enzyme responses in this study are well-characterized and consistent with results of other rat dietary studies such as the rat subchronic, developmental toxicity, and reproductive effects studies.

342-363 087918 (Addendum to 342-252:036338, combined dog study). Submission contains mean body weights/sex and average food consumption for a 6-week period. At the end of the 6-week period, it was determined that 100 ppm in diet corresponded closely to 3.0 mg/kg/day in either sex. From that time on, diets were prepared at fixed levels of 100, 33, 3.3, 1.0, and 0.33 ppm by serial dilutions of diets. These data permit an upgrade of the 1971 dog study to ACCEPTABLE status. Aldous, 3/16/90.

342-0969 270309 (Supplementary to Document No. 342-0252, Record Nos. 036338-036339), Authors of the re-analysis are Mattsson, J. L., L. Holden, D. L. Eisenbrandt, and J. E. Gibson. "Reanalysis with optimized power of red blood cell acetylcholinesterase activity from a 1-year dietary treatment of dogs to chlorpyrifos." The date of the re-analysis was 9/22/2000. Study ID: GHC-5127. Chlorpyrifos (97.2% purity) in the dog chronic study was administered in diets at concentrations adjusted to provide 0, 0.01, 0.03, 0.1, 1.0, and 3.0 mg/kg/day. That study had two phases at the above dose levels, which were comparable in design, so that parallel results could properly be considered together. The present analysis was confined to RBC acetylcholinesterase (AChE) inhibition analysis. Four figures show RBC AChE activities by phase and sex consistent with tabular summary data in Record No. 036338. These figures show marked inhibition of RBC AChE activity at 1.0 and 3.0 mg/kg/day, whereas AChE activities of other groups tended to

cluster together at any given time point. Individual pre-treatment AChE activities had more influence on subsequent treatment-phase activities than did possible treatment group effects, except at the two highest dose levels. When investigators normalized the baseline for each group pre-treatment mean, combining data for both sexes in both phases at assay intervals during the first year gave N = 14. A depiction of inter-group differences on this basis found no meaningful differences between control and treatment groups through 0.1 mg/kg/day. When all assays during the first year of treatment were considered together for each group, activity of the 1.0 mg/kg/day group was nearly 50% below baseline, and the 3.0 mg/kg/day group activity was 80% below baseline, whereas all other groups remained within about 4% of baseline. Collectively, these amalgamated data support a NOEL of 0.1 mg/kg/day for RBC AChE. Aldous, June 2, 2015.

342-273 056902 (Tab 3) EPA Office of Pesticide Programs, Toxicology Branch review of study 252:036338-036339. The review was submitted on Oct. 10, 1985 as OPP Toxicology Branch Document #004712. The review classified the study as "Core Minimum Data".

EPA 1-liner: [2-year feeding - dog; Dow Chem. Co.; 12/10/71] Systemic NOEL = > 3.0 mg/kg/day (HDT); Plasma ChE NOEL = 0.01 mg/kg/day; Plasma ChE LEL = 0.10 mg/kg; RBC ChE NOEL = 0.10 mg/kg/day; RBC ChE LEL = 1.0 mg/kg; Brain ChE NOEL = 1.0 mg/kg/day; Brain ChE LEL = 3 mg/kg; Core grade, supplementary [note upgrade to "core minimum" status, indicated in 273:042783].

342-338 070881-070882 are dietary analyses and analytical methods descriptions. These data were evaluated with respect to study 252:036338 in the 4/11/89 CDFA review.

342-338 070883 is a supplement to the original 2-year dog feeding study report. Supplement included ophthalmology data. These data had been submitted to EPA in 1985. These data were evaluated with respect to study 252:036338 in the 4/11/89 CDFA review.

342-044 031073 Published summary of 252:036338.

342-013/053 031070 Summaries of 252:036338-36339.

Oncogenicity, rat (see "Combined, Rat" above)

****342-692 153114** Crown, S., "Pyrinex technical oncogenicity study in the rat", Life Science Research Israel, Ltd., July 12, 1990. Laboratory Study # MAK/095/PYR. Pyrinex (chlorpyrifos), 96.1% purity, was administered in diet to 60 F344 rats/sex/group at 0.2, 5, and 100 ppm. There were two control groups (with and without corn oil mixing supplement), each composed of 60/sex/group. Treatment was for 2 yr, except that 5/sex/group were sacrificed at wk 50 for brain cholinesterase (ChE) assays. ChE enzyme inhibition NOEL = 0.2 ppm (inhibition of plasma ChE at 5 ppm). NOEL for non-ChE-related changes = 5 ppm. No definitive cholinergic signs were evident at any dose level. Findings at 100 ppm included modest body weight decrements and over 50% brain ChE inhibition in both sexes, and an increase over baseline incidences of diffuse retinal atrophy and cataracts in 100 ppm females. The latter findings are **"possible adverse effects**" in an **acceptable** oncogenicity study. Aldous, 8/28/97.

Oncogenicity, mouse **

342-693 153115 Gur, E., "Pyrinex technical oncogenicity study in the mouse", Life Science Research Israel, Ltd.,10/15/92. Laboratory Study # MAK/106/PYR. Fifty-nine CD-1 mice/sex/group were dosed for 79 weeks with Pyrinex technical (chlorpyrifos) in diet at 0, 5, 50, or 250 ppm. An additional 5/sex/group were killed at week 42 for cholinesterase (ChE) evaluation. There was no ChE NOEL in the tested dosage range (dose-related inhibition of plasma ChE in both sexes at weeks 42 and 78). Brain ChE was modestly reduced at 50 ppm and greatly reduced at 250 ppm (residual activity about 20% or less in both sexes and both sampling intervals). RBC ChE was reduced at 250 ppm only. There were no definitive cholinergic signs at any dose. NOEL for other effects was 5 ppm (males displayed excessive lacrimation, opaque eyes, and hair loss around eyes: all plausibly related to contact irritability of test article with resultant scratching). High dose findings, in addition to signs consistent with local irritation, included hepatocyte vacuolation and cystic dilatation of bulbourethral glands (males), and alveolar macrophage accumulation in lungs (females). Male body weights and food consumption were decreased at 250 ppm, and water consumption was sharply reduced in both sexes at that dose level. Survival of high dose males was remarkably higher than other groups. This is an **acceptable oncogenicity study with no adverse chronic effects. Aldous, 8/22/97.

**342-253 036340 Warner, S. D., C. G. Gerbig, R. J. Strebing, and J. A. Molello, "Results of a two-year toxicity and oncogenic study of Chlorpyrifos administered to CD-1 mice in the diet," Dow Chemical Toxicology Laboratory, Indianapolis, Indiana, 3/4/80. Chlorpyrifos, Ref. No. 1-500-2: 99.6% purity at 0, 0.5, 5.0, and 15.0 ppm in diet. NOEL = 15 ppm (no toxicity). No oncogenicity. ACCEPTABLE, based on re-reading of blood smears by S. D. Warner, D.V.M., Ph.D. (data in CDFA record 315:065762) answering a question by CDFA regarding possible effects on lymphocytes, (see 5/29/87 CDFA review). (Other concerns which CDFA had on this report were addressed in the 5/29/87 CDFA review). C. Aldous, 1/31/86, 5/29/87, 4/12/89.

342-273 042782 (Tab #4) Supplemental to 253:36340. Davies, D. B., J. T. Tollett, and L. G. Lomax, "Chlorpyrifos: A Four -Week Dietary Study in CD-1 Mice," Dow Chemical, Midland, MI. Dietary administration of 0 or 15 ppm chlorpyrifos (95.7% purity) to CD-1 mice. 4 week study with body weights slightly reduced and plasma and serum ChE levels statistically significantly reduced (see especially. Table 13). This study supports dose level selection for the oncogenicity study (such as 253:036340, above). After 4 weeks, treated mice had about 10% of control plasma cholinesterase (ChE) activity, and about 50% of RBC ChE activity. Brain AChE activity was statistically reduced in treated females and statistically elevated in treated males: magnitudes were small in both cases and appear to have been incidental. Examined 11/24/86 and again on 6/4/15 by C. Aldous. No written review was required or performed.

EPA 1-liner: [2-Year oncogenic - mice; Dow Chemical Co.; 3/04/80]: Systemic and oncogenic NOEL > 15 ppm (HDT). Core grade, minimum.

342-290:050623 (Rebuttal/Additional data to 253:36340) "Results of a Two-Year Toxicity and Oncogenic Study of Chlorpyrifos Administered to CD-1 Mice in the Diet". Dow Chemical Toxicology Laboratory, 3/4/80. New information consists of individual data for blood smear exams, clinical observation and animal disposition, and gross and histopathology. Reviewer (Aldous) examined previously submitted chemical analyses of test material used in this and in

one other study, and included evaluation in 5/29/87 review. No adverse effects noted. Study not acceptable, but possibly upgradeable. C. Aldous, 5/29/87.

342-013/053 031071 Summary only of 253:036340.

GENOTOXICITY

Bacterial reverse mutation assay ** (see after In vitro mammalian cell assay section for summary statement)

342-255 036348 Simmon, V. F., A. D. Mitchell, and T. A. Jorgenson, "Evaluation of Selected Pesticides as Chemical Mutagens, in Vitro and in Vivo Studies," (brief summary) SRI, 1977; Salmonella and E. coli. UNACCEPTABLE with no adverse effect reported. Salmonella, 4 strains (no TA98), were tested with and without activation at 0, 1, 5, 10, 50, 100, 500 and 1000 µg/plate and with Escherichia coli at the same concentrations. Chlorpyrifos, 98.8%. No evidence of a cytotoxic concentration or rationale for maximum concentration used. No repeat trial, no individual plate counts if more than one was made. Not upgradeable. J. Gee, 2/13/86.

342-273 042784 Bruce, R. J. and J. A. Zempel, "Chlorpyrifos: Evaluation in the Ames' Salmonella/Mammalian-Microsome Mutagenicity Assay," Dow Chemical, Freeport, Texas, 1986; Salmonella. Chlorpyrifos (95.7%) tested in strains TA1535, TA1537, TA98 and TA100 at 0, 1, 3.16, 10, 31.6 and 100 µg/plate; with and without rat liver activation; 30 min pre-incubation before plating, triplicate plates, one trial, no evidence for increased reversion rate. UNACCEPTABLE. Report states that a precipitate formed at 100 µg/plate. The earlier study did not mention this. J. Gee, 7/30/86.

342-419 116728. Supplement to 042784. Contains individual plate counts and a revised table of contents. No change in the study status. No worksheet. Kellner and Gee, 7/9/93.

Mutagenicity: In vitro mammalian cell assay **

**342-255 036351 Mendrala, A. L., "Evaluation of Chlorpyrifos in the Chinese Hamster Ovary Cell-Hypoxanthine (Guanine) Phosphoribosyl Transferase (CHO/HGPRT) Forward Mutation Assay," Dow Chemical, Midland, MI, Sept. 3, 1985. Chlorpyrifos, 95.7% purity, was tested at 0, 10, 20, 25, 30, 40 or 50 µM with and without activation for 4 hours. Positive control was 3 mM EMS. There were 5 dishes per treatment, in a single trial. A precipitate formed at 30 µM and above. Survival percentages (relative to 0 µM control) at chlorpyrifos levels of 10, 20, 25, 30, 40 or 50 were 92, 31, 23, 16, 9, and 7%, respectively. Testing thus bracketed practical limits based on both solubility and cytotoxicity. There was no increase in mutation frequency reported for chlorpyrifos in any single trial. Positive control mutation frequency was about 100x above background. Initially, results were considered to be negative for chlorpyrifos mutagenicity, however study was designated as unacceptable, based on lack of a confirming trial (see original review by J. Gee, 2/13/86). Current guidelines (OPPTS 870.5300, page 7) do not routinely require a repeat this assay after a negative response. Consistent with contemporary guidelines, study should be re-classified as acceptable, with no adverse effects. Aldous, June 5, 2015.

342-291 [No Record No., second "Mutagenicity" tab in volume]. Rebuttal comments ref 255:036351. CDFA conclusion was study still UNACCEPTABLE: major concern remaining is lack of a confirmatory test for a negative result. (J. Gee, 6/5/87).

342-291 057655 A table entitled "Analytical determination of stability of Chlorpyrifos in DMSO" in support of 255:036351, above. (Submitted as part of rebuttal document of 12/1/86).

***SUMMARY: The 1977 SRI study (#036348), using four strains of Salmonella (but not TA98) at 0 to 1000 µg/plate, was negative for increased reversion. Also, the CHO/HGPRT study on file showed negative results. EPA accepted this CHO study (#036351) although CDFA review found it unacceptable because there was no repeat. Considering all of these studies, with no one alone being acceptable, and that #042784 is a repeat of #036348 -- the deficiency for which each was rejected separately -- the 842 data gap is considered filled.

Mutagenicity: In vivo cytogenetics **

342-419 116722 "Evaluation of Chlorpyrifos in an In Vitro Chromosomal Aberration Assay Utilizing Rat Lymphocytes", (Linscombe, V., Mensik D. and Clem, B., Dow Chemical Company, Lab Project Study ID: K-044793-092, 1/29/92). Chlorpyrifos, purity of 98.6%, was evaluated for clastogenic potential using rat lymphocytes treated for 4 hours with concentrations of 0 (DMSO), 5, 16.7, 50, 167.7, 500, 1667.0 or 5000 mg/ml (Assay 1) and 0, 5.0, 16.7, 50.0 and 167.0 mg/ml (Assay 2) with and without S-9 metabolic activation. Cultures were harvested 24 hours after treatment in Assay 1 and 24 and 48 hours after treatment in Assay 2. **No Adverse Effects: No increase in chromosomal aberrations at the highest scorable dose levels of 167 mg/ml (without S-9) and 50 mg/ml (with S-9). ACCEPTABLE. (Kishiyama, Kellner and Gee, 7/1/93).

342-739 161321 Exact duplicate of 342-419 116722 (above). This was submitted in a volume which contained primarily product chemistry data. Aldous, 11/12/98.

342-363 087919 McClintock, M. L., and B. B. Gollapudi, "Evaluation of Chlorpyrifos in the Bone Marrow Micronucleus Test." (Dow, TXT: K-044793-067A, 9/22/89). Chlorpyrifos, lot AGR 214637, 97.9%; tested with CD-1 (ICR) BR mice, with sacrifices of 5/sex/group at 24, 48 or 72 hours after a single oral gavage dosing of 0 (corn oil) or 90 mg/kg b. wt. stated to be 80% of the LD_{50}; cyclophosphamide as positive control; no mortalities but decrease in body weights in the treatment groups; no evidence of micronuclei formation and no clear effect on PCE/NCE. UNACCEPTABLE (only one dose level). (Gee, 3/12/90)

342-255 036350 Gollapudi, B. B., V. A. Linscombe, and J. E. Wilkerson, "Evaluation of Chlorpyrifos in the Mouse Bone Marrow Micronucleus Test," Dow Chemical, Freeport, Texas, 1985; Mouse micronucleus test. UNACCEPTABLE with no adverse effect. Chlorpyrifos, 95.7%, was given by oral gavage to 5/sex/group at 0, 7, 22, or 70 mg/kg with sacrifices at 24 and 48 hours. No statistically significant increase in micronuclei in PCE's is reported; % PCE marginally effected in females only at 48 hours being 63 as compared with 76 for the vehicle control. This is suggestive that a higher dose and/or a longer sampling time should have been included even at the risk of losing some of the animals. In the Appendix data show that survival at 100 mg/kg would be adequate for the assay. Also, no clinical signs were observed. The high

dose reportedly was based on 60% of the LD50 of approximately 111 mg/kg. Guidelines and the meaningfulness of the test call for some signs than a toxic dose was reached, either the MTD for the animal or cytotoxicity to the bone marrow. The only death was in female vehicle control. No data on micronucleated normochromatic erythrocytes are included. Because positive effects have been reported in gene conversion and DNA repair, an adequate test in this test area is needed. Not upgradeable. J. Gee, 2/13/86.
NOTE: EPA considers this study as acceptable, according to the EPA response to CDFA data gap status issues on chlorpyrifos, dated 1/17/89. Aldous, 12/4/89.

342-291 [No Record number, first "Mutagenicity" tab in volume]. Rebuttal comments ref 255:036350. CDFA conclusion was study still UNACCEPTABLE: major concerns remaining are inadequate justification of treatment levels, and lack of a 72 hr sacrifice time. J. Gee, 6/5/87.

Mutagenicity: DNA Damage (not a normally required test category) ** †

342-255 036349 Simmon, V. F., A. D. Mitchell, and T. A. Jorgenson, "Evaluation of Selected Pesticides As Chemical Mutagens, In Vitro and In Vivo Studies," [Segment on mammalian *in vitro* unscheduled DNA synthesis assays] SRI, 1977; UDS in WI-38. UNACCEPTABLE but upgradeable with no adverse effect reported. Chlorpyrifos, 98.8%. WI-38, human embryonic lung fibroblasts, were exposed with and without activation (rat liver) to 0, 10^{-7}, 10^{-6}, 10^{-5}, 10^{-4}, and 10^{-3} with six cultures -S9 and 3 +S9. DPM/µg DNA is reported with no change in the DPM with increasing concentrations. DNA was extracted from the cells by a standard method and an aliquot used to determine the amount of DNA and another portion used to determine the incorporation of tritiated thymidine by liquid scintillation counting as a measure of DNA repair in response to damage by the test article. Missing information on how the CPM were converted to DPM, the quantity of DNA recovered per culture, the passage number of the WI-38, and the rationale for the selection of the concentrations used - whether solubility or cytotoxicity. CDFA review 2-13-86 J. Gee.

342-255 036347 Simmon, V. F., A. D. Mitchell, and T. A. Jorgenson, "Evaluation of Selected Pesticides As Chemical Mutagens, In Vitro and In Vivo Studies --Microbiological Assays" (summary report), SRI, 1977; Saccharomyces cerevisiae D_3. UNACCEPTABLE with a positive effect reported. Mitotic recombination-gene conversion in yeast exposed to a 5% concentration for 4 hours, with and without metabolic activation. The test was repeated. No individual data. Because of the lack of data, the significance of the effect cannot be evaluated but the possible genotoxic effect must be noted. Upgradeable. J. Gee, 2/13/86.

342-255 042609 Simmon, V. F., A. D. Mitchell, and T. A. Jorgenson, "Evaluation of Selected Pesticides As Chemical Mutagens, In Vitro and In Vivo Studies -Microbiological Assays" (summary), SRI, 1977; Escherichia coli and Bacillus subtilis [found under Tab 12, pg. 20]. UNACCEPTABLE with a positive adverse effect reported. Chlorpyrifos, 98.8% purity, at 2.5 µg/disc, was tested with E. coli W3110 and p3478 and with B. subtilis H17 and M45. No activation was included and the test reportedly was repeated 3 times. The comparable zones of inhibition between the strains indicated a larger zone for the repair defective strains. Only one value for each strain is reported. If the full report were submitted, it is possible that the effect could be evaluated for significance. Since no activation was included, the study is not upgradeable. J. Gee, 2/13/86.

**342-273 042785 Mendrala, A. L. and M. D. Dryzga, "Evaluation of Chlorpyrifos in the Rat Hepatocyte Unscheduled DNA Synthesis (UDS) Assay," Dow Chemical, Midland, MI, 1986; Chlorpyrifos (95.7%); primary rat hepatocytes tested for unscheduled DNA synthesis at 10^{-6}, 3.13 x10^{-6}, x 10^{-5}, 3.16 x 10^{-5} and 1 x 10^{-4} M; triplicate cultures in a single trial; no evidence of UDS; toxicity at the highest concentration. Acceptable. J. Gee, 7/30/86.

SUMMARY: The positive findings in the two microbial studies are somewhat related. The B. subtilis test compares the response of rec$^-$ (recombination defective) with wild type organisms. The rec$^-$ strain is not as competent to repair damage and hence shows a greater inhibition of growth from lethality due to DNA damage. The test in Saccharomyces also measures recombination-type events in competent organisms and the increase in these events confirms the DNA damage. The complete versions of these two reports are needed to assess their significance. The two tests in mammalian cells measure a different repair event (excision repair) with repair replication occurring to fill the DNA gap following removal of damaged bases by excision using different enzymes. The positive findings in the microbial tests cannot be dismissed without more information about the bacterial studies.

REPRODUCTIVE TOXICITY, RAT **

**342-399 097570 "Chlorpyrifos: Two-generation dietary reproduction study in Sprague-Dawley rats", (W. J. Breslin, A. B. Liberacki, D. A. Dittenber, K. A. Brzak, and J. F. Quast). The Toxicology Research Laboratory, Health and Environmental Sciences, The Dow Chemical Company, Midland, MI., Study ID: K-044793-088, 6/5/91). Chlorpyrifos, (technical grade Dursban F insecticide, AGR 273801), 98.5% purity, was fed in the diet to 30 Sprague-Dawley rats/sex/group through 2 generations with 1 litter per generation. Concentrations were adjusted as needed to achieve exposures of 0, 0.1, 1.0, and 5.0 mg/kg/day. Treatment began approximately 10 and 12 weeks prior to breeding for the F0 and F1 adults, respectively. Cholinesterase (ChE) inhibition NOEL = 0.1 mg/kg/day (Plasma and RBC ChE inhibition at 1.0 and 5.0 mg/kg/day). Parental NOEL = 1.0 mg/kg/day (increased degree of vacuolation in zona fasciculata, especially in males; altered tinctorial properties in this tissue in females). Reproductive NOEL = 1.0 mg/kg/day (slightly reduced pup weights and slightly reduced pup survival at 5.0 mg/kg/day). There were no clinical signs specifically indicating ChE inhibition. The reproductive findings at 5 mg/kg/day do not warrant a "possible adverse effects" designation, since brain ChE levels were very markedly depressed at that dose level, and all observed reproductive effects appeared to be due to failure of dams to nurture pups which were otherwise normal. ACCEPTABLE. (Green and Aldous, 5/11/92).

342-685 152365 Exact duplicate of 342-399 097570.

342-374 090493 Interim report for Record No. 097570, above.

342-686 152368 Breslin, W. J., A. B. Liberacki, D. A. Dittenber, and J. F. Quast. "Evaluation of the developmental and reproductive toxicity of chlorpyrifos in the rat". *Fundam. Appl. Toxicol*. **29**:119-130 (1996). This is a published summary of major findings of two accepted studies: the reproduction study above (342-399 097570) and the rat teratology study (342-254

036344). Since the abstract was consistent with DPR 1-liner conclusions for the two studies, this publication was not independently reviewed. Aldous, 7/31/97.

342-254 036341 "Three Generation Reproduction and Teratology Study in the Rat Following Prolonged Dietary Exposure to Dursban, O,O-Diethyl O-3,5,6-Trichloro-2-Pyridyl Phosphorothioate," Dow Chemical, Zionsville, Indiana, 8/20/71. Chlorpyrifos, purity and grade not specified. Doses for the main portion of the reproduction study were 0, 0.1, 0.3, and 1.0 mg/kg/day in diet. ChE inhibition NOEL= 0.3 mg/kg/day. General adult toxicity NOEL = 1.0 mg/kg/day (HDT). Reproductive NOEL = 0.3 mg/kg/day (slightly increased pup mortality in first 5 days post-partum) UNACCEPTABLE, incomplete, not upgradeable (more definitive follow-up study is 254:036343). C. Aldous, 1/31/86.

(An additional copy of 036341 is found in Document No. 342-685, Tab 49 (no record #).
EPA 1-liner: [3-Generation reproduction/teratology - rat; Dow Chem. Co.; 8/20/71] Reproduction NOEL>1.0 mg/kg/day (HDT); Teratogenic NOEL = inconclusive. ChE NOEL=0.1 mg/kg Core grade, minimum

342-254 036343 Dietz, F. K., D. C. Mensik, C. A. Hinze, B. L., Rachunek, and H. W. Taylor, "Dursban Insecticide: Assessment of Neonatal Survival In A Two-Generation Reproduction Study In Rats," Dow Chemical, Freeport, Texas, 7/83. Chlorpyrifos, technical; 0, 0.5, 0.8, and 1.2 mg/kg/day (dietary). Parental toxicity NOEL = reproductive toxicity NOEL = highest dose tested = 1.2 mg/kg/day. UNACCEPTABLE, incomplete, upgradeability unlikely (highest dose level not demonstrably toxic, and no justification offered for dosage selection). C. Aldous 2/7/86.
EPA 1-liner: [Two generation repro - rat; Dow Chem.: 7/83] Reproductive NOEL > 1.2 mg/kg/day (HDT); Systemic NOEL = 0.8 mg/kg; Systemic LEL= 1.2 mg/kg (decreased weight gain); Core grade, supplementary.

342-681 152366 Exact duplicate of 254 036343, above.

342-291: [No Record #, Tab = "Reproduction"] Rebuttal comments ref. rat reproduction studies 254:036341 and 254:036343. Registrant noted that CDFA should consider both reproduction studies together, considering additionally rat chronic data. Registrant suggested that plasma and RBC ChE inhibition data support adequacy of dose. CDFA response: Doses are not justified in terms of parental toxicity, notwithstanding enzyme inhibition effects. Chronic studies are imperfect surrogate studies for evaluation of microscopic changes due to test article, since in chronic studies there is no evaluation of effects which carry over the generations. No change in status of studies. C. Aldous, 6/2/87.

342-686 152367 James, P., A. Stubbs, C. A. Parker, J. M. Offer, A. Anderson, "The effect of Pyrinex (chlorpyrifos) on reproductive function of two generations in the rat", Huntingdon Research Centre, Ltd., 4/22/88. HRC Report # MBS 29/881452. Crl:CD®(SD)BR rats received diets containing 0, 2, 10, or 50 ppm chlorpyrifos (95% purity) in diets over 2 generations (1 litter per generation). Parental rats numbered 28/sex/group in the F0 generation, and 24/sex/group in the F1 generation. Protocol was that of a standard reproduction study, with a few pre-weaning developmental evaluations added (surface righting, air righting, and startle responses; and pupil

reflex). There were **no definitive treatment-related effects** (report attributes 3 high dose deaths to treatment, however there were deaths in other groups and no evident unique symptoms in high dose decedents). Study is **not acceptable** as presented (report evidently contains 401 pages, but only pp. 1-228 are present, "confidentiality" stamps cover much of the text, more definitive high dose justification would be needed, and histopathology of parental rats is needed if this study is to be upgraded). Aldous, 8/22/97.

DEVELOPMENTAL TOXICITY

Rat Developmental Toxicity **

**342-254 036344 Ouellette, J. H., D. A. Dittenber, P. M. Kloes, and J. A. John, "Chlorpyrifos: Oral Teratology Study in Fischer 344 Rats," Toxicology Research Lab., Dow Chemical USA, Midland, MI, 7/5/83. Chlorpyrifos, 96.6%. 0, 0.1, 3.0, and 15 mg/kg/day (gavage). Maternal NOEL (excluding cholinesterase (ChE) inhibition) = 3.0 mg/kg/day (cholinergic effects). Maternal ChE inhibition NOEL = 0.1 mg/kg/day (inhibition of plasma and RBC ChE). Developmental toxicity NOEL = 15 mg/kg/day (HDT). ACCEPTABLE due to submission of supplementary information. See CDFA Rebuttal comments, C. Aldous, 6/1/87. (Study had been classified unacceptable in previous review by C. Aldous 2-10-86). C. Aldous, 6/1/87.
EPA 1-liner: [Teratology - rat; Toxicology. Research Lab; 7/5/83] Teratogenic and fetotoxic NOEL> 15 mg/kg/day (HDT); Maternal NOEL= 0.1 mg/kg; Maternal LEL= 3.0 (ChE inhibition) Core grade, minimum.

342-683 152360 (exact duplicate of 342-254 036344, above).

342-291 050624 (Rebuttal by Ouellette *et al*. to primary study 254:036344). Considered in 6/1/87 review of primary study, 254:036344, above.

342-291 050625 (Pilot study to primary study 254:036344). Ouellette, J. H., D. A. Dittenber, R. J. Kociba, and J. A. John, "Chlorpyrifos: Oral teratology probe study in rats". Toxicology Research Lab, Dow, 1/4/83.
Chlorpyrifos, 96.6%. 0, 3, 10, and 30 mg/kg/day by gavage in cottonseed oil. Study demonstrates that 30 mg/kg/day is severely toxic to dams: maternal deaths, typical cholinergic signs, high number of resorptions. Slightly matted haircoat and slight enlargement of adrenals were observed at 15 mg/kg/day. This pilot study clearly substantiates the adequacy of the dosage range selected for the primary study, 254:036344. C. Aldous, 6/1/87.

342-695 153117 Rubin, Y., N. Gal, T. Waner, and A. Nyska, "Pyrinex teratogenicity study in the rat", Makhteshim-Agan of North America Inc., 7/15/87. Laboratory Study #MAK/101/PYR. At least 21 pregnant CD rats/group were dosed with Pyrinex Technical (chlorpyrifos), purity 96.1% by gavage in corn oil on days 6-15 p.c. at 0, 0.5, 2.5, or 15 mg/kg/day. No maternal ChE NOEL was identified (dose-related plasma ChE inhibition at all dose levels at day 15 p.c., with restoration of normal ChE activity in all but high dose dams by p.c. day 20. Maternal functional NOEL = 2.5 mg/kg/day (tremors in 3/21 dams, transient food consumption reduction, modest but consistent body weight decrement). Developmental NOEL = 2.5 mg/kg/day (slight increase in early resorptions). **No adverse reproductive effect at dose levels sufficient to elicit cholinergic responses. Acceptable. Aldous; May 1, 1997.

342-683 152361 Exact duplicate of 342-695 153117, above.

342-681 152354 Muto, M. A., F. Lobelle, J. H. Bidanset, and J. N. D. Wurpel, "Embryotoxicity and neurotoxicity in rats associated with prenatal exposure to Dursban", *Veterinary and Human Toxicology* 34, 498-501 (1992). Investigators from the Department of Pharmaceutical Sciences, St. John's University, Jamaica, NY. Test article was a formulation of 1% chlorpyrifos, 6% xylene, and 93% water. Suspensions were diluted to an unspecified dosing volume with saline. Dosing was ip, either on days 0-7 or on days 7-21 at dose levels of 0, 0.03, 0.1, or 0.3 mg/kg/day of chlorpyrifos. In most cases, there were 8 pregnant rats (strain unspecified) per dose for each treatment time period. Dams were allowed to litter, then pups were evaluated for "general viability, body weight and physical characteristics". Selected pups were evaluated for "neurotoxicity" on a rotarod on day 16. The same day, pups were evaluated for motor behavior (subjective open field observation) and for righting behavior on an inclined screen. An additional study evaluated the neurotoxicity and behavioral tests following exposures of 0.1 or 0.3 mg (presumably ip) as single doses on day 3, 10, or 12 postpartum, or as multiple doses on days 6-10 postpartum. Investigators claimed that treatment caused increased embryolethality following dosing on gestation days 0-7 and gestation days 7-21. Since the highest embryolethality was in the lowest dose group treated on gestation days 0-7 (77% lethality), these data are of questionable value. Incidences of "physical abnormalities" were reportedly highest in 0.1 and 0.3 mg/kg/day groups (66 and 55%, respectively), among litters treated on gestation days 0-7. No corresponding control data were presented. Rotarod performance was reported to be impaired in pups dosed at 0.3 mg/kg on days 3, 10, and 12, and in offspring of dams dosed with 0.3 mg/kg on days 7-21, and in offspring of dams dosed with 0.03, 0.1, or 0.3 mg/kg on days 0-7. These data are suspect because differences between mean values at any treatment time dwarfed differences between dose groups at individual treatment times, even though all pups were evaluated at day 16. The study is unacceptable (in addition to deficiencies noted above, test article does not represent either the a.i. or any end use product; the route (ip) is not a plausible route of human exposure; the conclusions are speculative, evidenced by discussion of possible delayed distal neuropathy, while ignoring a valid 1986 subchronic hen neurotoxicity study, which would have been available through "freedom of information" provisions long before the time of this publication; and the presentation of the article shows that it could not have gone through a meaningful review, indicated by the above deficiencies, and by misspellings (the term "access" when "assess" was meant) and by failures to provide control data in figures or to provide numerical counts for types of purported treatment-caused malformations. No more information is requested of this paper. Aldous, 9/3/97.

342-681 152355 Nimphius, M. J. (M.S. dissertation under direction of graduate advisor J. H. Bidanset at St. John's University College of Pharmacy and Allied Health Professions, New York). "The effects of chlorpyrifos and xylene on embryonal and fetal development in the rat" (approval date: 9/13/95). Sprague-Dawley rats were dosed subcutaneously with 0, 0.3, 3, or 10 mg/kg/day chlorpyrifos (analytical grade, 99% purity) on days 1-7 of gestation (typically 8/dose/group), then sacrificed on gestation day 19 or 20. Other rats received xylene or chlorpyrifos/xylene s.c. on the same schedule. Parameters examined were resorptions, weights and lengths of fetuses, and external malformations. None of these showed biologically meaningful changes. This study is unacceptable (it does not conform to any FIFRA study

design: route is not relevant to plausible human exposure, timing of dosing is not useful for evaluation of malformations, fetal examinations were only for grossly evident changes, group sizes were too small, and sacrifices were not done on a fixed gestation day). The study does not make a significant contribution to chlorpyrifos hazard assessment. Aldous, 9/3/97.

[Rat Developmental Toxicity Studies: Chlorpyrifos Metabolites]

342-684 152362 Hanley, T. R., G. J. Zielke, and L. G. Lomax, "3,5,6-Trichloro-2-pyridinol: oral teratology study in Fischer 344 rats", The Dow Chemical Co., Midland, MI, 7/23/87. Laboratory Study #: K-038278-011. Groups of 32-34 mated Fischer 344 rats were dosed with 0, 50, 100, or 150 mg/kg/day 3,5,6-trichloro-2-pyridinol (TCP, 99.7% purity) by gavage in 4 ml/kg Methocel on days 6-15 of gestation in a standard teratology study. Maternal NOEL = 50 mg/kg/day (minor body weight gain decrements). Developmental NOEL = 150 mg/kg/day (HDT). An acceptable study of a major metabolite of chlorpyrifos, with no adverse effect indicated. Aldous, 7/31/97.

Rabbit Developmental Toxicity ** (No adverse effects for technical chlorpyrifos, however high doses of a metabolite caused developmental toxicity)

342-694 153116 Rubin, Y., A. Nyska, and T. Waner, "Pyrinex teratogenicity study in the rabbit", Life Science Research Israel Ltd., 7/15/87. Laboratory Study # MAK/103/PYR. At least 14 HY/CR (a NZW variety) rabbits per group were dosed by gavage in corn oil with chlorpyrifos (Pyrinex Technical, purity 96.1%) on days 7-19 p.c. at 0, 1, 9, 81, or 140 mg/kg/day. Maternal NOEL = 81 mg/kg/day (body weight gain decrement during treatment period). Developmental NOEL = 81 mg/kg/day [reduced crown/rump length, reduced fetal weight, ossification delays (indicated by non-ossification of fifth sternebra and/or xiphisternum)]. No adverse effects are indicated. For comparison, the pilot study had found 100% lethality in does at 270 mg/kg/day. **Acceptable. Aldous, 4/29/97.

342-685 152364 Exact duplicate of 342-694 153116, above.

[Rabbit Developmental Toxicity Studies: Chlorpyrifos Metabolites]

342-684 152363 Hanley, T. R., G. J. Zielke, and L. G. Lomax, "3,5,6-Trichloro-2-pyridinol: oral teratology study in New Zealand White rabbits", The Dow Chemical Co., Midland, MI, 7/23/87. Laboratory Study #: K-038278-015. Sixteen does/group were dosed with 0, 25, 100, or 250 mg/kg/day 3,5,6-trichloro-2-pyridinol (TCP, purity 99.7%) by gavage in aqueous 0.5% Methocel on gestation days 7-19 in a teratology study. Maternal NOEL = 100 mg/kg/day (minor maternal body weight decrement during treatment). Developmental NOEL = 25 mg/kg/day (hydrocephaly and dilated cerebral ventricles). The latter observations were not statistically significantly increased in either of the two higher dose groups compared to concurrent controls, however historical background incidences were very low (compare hydrocephaly litter incidences of 2/13 and 3/13 at 100 and 250 mg/kg/day, respectively, to a historical incidence of 1/839 litters). These findings indicate a **possible adverse effect**. For perspective, 100 mg/kg/day of TCP is the molar equivalent to 66% of a chlorpyrifos dose which caused 100%

mortality in LSRI Report MAK/102/PYR (cited in the accepted chlorpyrifos rabbit teratology study under DPR Record No. 153166). **Acceptable** metabolite study. Aldous, 7/31/97.

Mouse Developmental Toxicity **

**342-254 036345 Deacon, M. M., J. S. Murray, M. K. Pilny, D. A. Dittenber, T. R. Hanley, Jr., and J. A. John, "The Effects of Orally Administered Chlorpyrifos on Embryonal and Fetal Development in Mice," Dow Chemical, Toxicology Research Lab., Midland, MI, 7/24/79; Chlorpyrifos, presumed technical; 0, 0.1, 1, 10, and 25 mg/kg/day by gavage; NOEL for maternal functional toxicity = 1 mg/kg/day [cholinesterase (ChE) effects as salivation, tremors, etc.]. ChE enzyme NOEL = 0.1 mg/kg/day (significant inhibition of maternal plasma ChE at 1 mg/kg/day). Developmental toxicity NOEL = 10 mg/kg/day (decreased fetal length and weight, delayed ossification in skull, sternebrae). ACCEPTABLE, in consideration of additional information in 291:050626 (See one-liner below). Report was previously not accepted (CDFA review 2/13/86, C. Aldous). C. Aldous, 6/1/87.

342-291 050626 (Addendum to 254:036345, primary mouse teratology study). Dow Chemical, Midland, MI, 7/24/79. New information provides grade of test article, dates of preparation of dose solutions, individual necropsy sheets for dams dying prior to term, and rationale for selection of mouse as test animal. C. Aldous, 6/1/87.

EPA 1-liner: Teratology - mice; Toxicology. Research Lab.; 7/24/74 [sic: presumed this is the 7/24/79 study]; Teratogenic NOEL > 25 mg/kg/day (HDT); fetotoxic NOEL = 10 mg/kg fetotoxic LEL = 25 mg/kg (decreased fetal length, increased skeletal variants); Plasma and RBC ChE NOEL = 0.1 mg/kg/day.

342-013/053 031072 Summary of 254:036345 (see above).

342-682 152359 (Tab 43). Deacon, M. M., J. S. Murray, M. K. Pilny, K. S. Rao, D. A. Dittenber, T. R. Hanley, Jr., and J. A. John, "Embryotoxicity and Fetotoxicity of Orally Administered Chlorpyrifos in Mice", *Toxicol. Appl. Pharmacol.* 54:31-40 (1980). This is the published report corresponding to 342-254 036345, above.

Developmental Toxicity: Allegations of Effects on Humans

The following critical review by Dr. J. E. Gibson and associated support documents were submitted in response to allegations that chlorpyrifos elicited human malformations.

342-680 152356 Gibson, J. E., "Critical review of allegations associating Dursban with human teratogenicity", 12/23/96 (analysis was given DowElanco Study ID JEG122396). Dr. Gibson was responding to allegations by Dr. J. Sherman that chlorpyrifos was the causative agent for several human birth defects. The most detailed version of Dr. Sherman's report was in Int. J. Occup. Med. Toxicol., 4:417-431 (1995). Dr. Gibson's primary objections to the article were (1) Dr. Sherman does not have the training and experience to properly perform such an analysis, (2) the four cases described do not present a coherent pattern of effects, (3) the possibilities of genetic causation were ignored, even though in most cases one or more physicians experienced in evaluation of birth defects attributed findings to genetic defects (4) none of the cases offered measures of exposure, (5) statistical analysis in the article was unsound, (6) outcomes of cited

animal studies were misunderstood or misrepresented, and (7) the article did not state the author's role as paid consultant in lawsuits filed by the three affected families, which disclosure is an ethical responsibility of authorship. All lawsuits involving the four children have been dismissed. Neither the Sherman report (DPR Record No. 152349) nor Dr. Gibson's review are primary sources of new data, hence do not have independent worksheets. **Supporting data, including some complete studies, follow in Document Nos. 342-681 to 342-686. "One-liners" describing these submissions are found in this worksheet.** Aldous, 8/22/97.

Records submitted in support of 342-680 152356 above, included: Document No. 342-681: Record Nos. 152349, 152350, 152351, 152352, 152353 152354,152355; and Document No. 342-682: Record Nos. 152357, 152358, 152359.

NEUROTOXICITY

Acute neurotoxicity, rat **

342-448 126408 Wilmer, J., et. al. "Chlorpyrifos: Acute Neurotoxicity Study in Fischer 344 Rats", (Dow Chemical Company, Study ID: K-044793-093B, 9/11/92). Chlorpyrifos (purity 98.1%, lot #MM-890115-616) was administered in a single oral gavage to 10 Fischer 344 rats/sex/group at levels of 0, 10, 50 or 100 mg/kg. Body weights of mid- and high-dose rats were significantly reduced on day 2 but not on day 8 or 15. Clinical signs (increased perineal soiling) in mid- and high-dose rats and FOB observations (incoordination, decreased muscle tone, tremor, increased lacrimation and salivation) in high-dose females were seen soon after dosing (day 1). Motor activity was reduced in mid- and high dose rats on day 1; some reductions persisted to day 8 in high-dose females. NOEL (Body wt., Clinical signs, FOB and motor activity) = 10 mg/kg. No histopathologic changes. NOEL (histopathology) = 100 mg/kg. **No Adverse Effects. Original DPR review had requested additional purity, stability and homogeneity data on the dosing material, justification for dose level selection, and clarification of the statistical methods used, as criteria for "acceptable" status. These data were provided (see review for Record No. 132457, below) and report is now **acceptable**. Kellner and Gee, 7/5/94; Aldous, 4/9/97.

342-492 132457 [Cover letter referencing supplementary data was by Blewett, T. C. The acute range-finding study in this record supporting dose selection for the acute neurotoxicity study was by Wilmer, J. W. *et al.* (Study ID K-044793-093A)]. Addendum to Document # 342-448, Record # 126408 (rat acute neurotoxicity). Cover letter date: 10/4/94. The three primary acceptability concerns expressed in the original DPR review have been adequately addressed: characterization of technical and treated diets for content, stability, and homogeneity; range finding study clinical signs data as evidence that selected dose levels were appropriate; and evaluation of statistical significance for major parameters of this study. In the range-finding study, two F344 rats/sex/group were dosed once by corn oil gavage at 50, 100, 150, and 200 mg/kg. Clinical signs consistent with ChE inhibition peaked at about 6 hr after dosing. Major signs were decreased activity, incoordination, lacrimation, muscle twitches, perineal soiling, salivation, and tremors. These signs were well established at 100 mg/kg and above, especially in females. Range finding study data are sufficient to justify dose levels used in the neurotoxicity study. Additional statistical data are consistent with interpretations in the original DPR review.

The study is re-classified as **acceptable**, with **no adverse effects** other than expected ChE inhibition-associated changes. Aldous, 4/9/97.

90-day neurotoxicity, rat **

342-445 126304, "Chlorpyrifos: 13-Week Neurotoxicity Study in Fischer Rats", (Shankar, M., Bond, D. and Crissman, J., Dow Chemical Company, Laboratory Project K-044793-094, 9/16/93). Chlorpyrifos, purity 98.1%, was administered in the feed at concentrations of 0, 0.1, 1, 5 or 15 mg/kg to 10 Fischer 344 rats/sex/group for 13 weeks. High-dose males and females had reduced motor activity at week 4. Perineal soiling (low incidence) was observed for 5 and 15 mg/kg/day groups; NOEL (for clinical signs, FOB, motor activity) = 1 mg/kg/day. No histopathologic findings. Neuropathological NOEL = 15 mg/kg/day. **No Adverse Effects. Report was originally classified as unacceptable, but upgradeable. Data provided in Record No. 132458 (see below) allowed an upgrade to **acceptable** status. This study type is considered "supplemental" under SB 950 at this time. Kishiyama, Kellner and Gee, 7/6/94; Aldous, 4/8/97.

342-493 132458 (Addendum to Document # 342-445, Record # 126304). Cover letter dated 10/4/94. The three primary acceptability concerns expressed in the original DPR review have been adequately addressed: characterization of technical and treated diets for content, stability, and homogeneity; ChE inhibition data as evidence that selected dose levels were appropriate; and evaluation of statistical significance for major parameters of this study. Data obtained from a 1988 subchronic feeding study found ChE enzyme inhibition NOEL = 0.1 mg/kg/day (inhibition of plasma ChE in both sexes and of RBC ChE in females at 1 mg/kg/day). ChE-related clinical effects NOEL = 1 mg/kg/day (perineal staining in occasional females at 5 and 15 mg/kg/day). Motor activity reduction, at 15 mg/kg/day during the week 4 evaluation only, was confirmed statistically. NOEL for findings other than probable acute ChE effects = 15 mg/kg/day (HDT). The study is re-classified as **acceptable**, with **no adverse effects** other than expected ChE inhibition and associated changes. Aldous, 4/8/97.

342-448 126409 Spencer, P. *et. al*. "Positive Control Exercises: Motor Activity, Functional Observational Battery and Neuropathology". Dow Chemical Co. submitted this report in support of -445:126304 and -448:126408; it contains validation studies of motor activity tests, functional observational battery (FOB) assays and neuropathological examinations using rats that were administered compounds with well-documented neurotoxic potential. This document was found to be ACCEPTABLE to satisfy the FIFRA guidelines for positive controls. An evaluation of these studies is included in the background sections of the acute and 13-week rat neurotoxicity studies mentioned above. No Worksheet. Kellner and Gee, 7/18/94.

4-week rat oral gavage cognitive study **

**342-747 162522 Maurissen, J. P., M. R. Shankar, and J. L. Mattsson, "Chlorpyrifos: cognitive study in adult Long-Evans rats", The Dow Chemical Co., Midland, MI, 4/29/96, Laboratory Project ID: K-044793-096. Female Long-Evans rats were dosed by gavage in corn oil with 0, 1, 3, or 10 mg/kg/day chlorpyrifos (98.1% purity) for 4 weeks. The cognitive study was a "delayed matching to position task" design. Cognitive testing was done during each of the treatment weeks and for 4 weeks thereafter, by methods described below. Rats were placed on modest food restriction to provide incentive to seek the "food reward" in the study. Rats were trained and selected for the study, based on positional memory performance. In a given test, a rat

was presented with one of two retractable levers. The rat was to press the lever offered, cross the cage and interrupt a beam at the food cup within 10 seconds, and then return to the side of the cage with the levers. At this time, both levers would be presented. The rat was expected to select and press the correct lever (i.e., the one just presented a few seconds earlier) within 10 seconds after leaving the food cup station. A correct choice made a food reward available at the food cup. In addition to the above test, the task was made more difficult by involving progressively longer delays (up to 15 seconds) between the first lever press and the time in which a nose-poke in the food cup would extend the levers (called the delayed matching-to-position or "DMPT" paradigm). These rats were also examined twice daily on treatment days during the 4-wk dosing period: observations were about 3 hr and 21 hr after the most recent treatment. Satellite groups of 6/dose/interval were used for ChE assays and brain NTE assays on the day following the last treatment, and 1 month after the last treatment. The 1998 DPR review placed the NOEL for memory retention at 3 mg/kg/day (considering a small apparent memory retention change at 10 mg/kg/day to be a "possible adverse effect"). **This determination was subsequently changed** (see review for Document No. 342-789, immediately below). NOEL for clinical observations is 1 mg/kg/day (miosis). There is no NOEL for ChE inhibition (marked inhibition of plasma and RBC ChE and modest (8%) inhibition of brain ChE at 1 mg/kg/day). Some high dose observations associated with the DMPT tests were appropriately considered by investigators to have been attributable to motor slowing and/or decreased motivation (increased "actual total delay", increased "void trials", and decreased numbers of nose-pokes per trial). None of these were noted after the end of the treatment period. Report was originally classified as not acceptable (requiring dosing solution analysis). Such data were subsequently provided (see immediately below). Study is **acceptable**. Aldous, 11/6/98, 10/12/99.

342-789 168961, 168962, and 168963. **Supplemental information to the above cognitive study (Record 342-747 162522)**. Additional data and explanatory text were provided. Essential responses summarized below are detailed in review "W162522 s01.wpd". New data supplied dosing solution analyses, and additional tables showing mean correct responses for individual animals and for treatment groups, including methodology used to obtain memory retention slope values. **These data allow an upgrade of Record No. 162522 to acceptable status.** In addition, investigators provided a statistical analysis of slopes of the memory retention curves for the various treatment groups. Data show that there were no statistically significant responses, hence data **do not demonstrate a possible adverse effect** (a change from the previous review). The variability of the data is sufficiently large that only a very substantial decrease of memory retention would have been detectable, thus the present study conditions **did not provide a sensitive test**. Aldous, 10/12/99.

Developmental neurotoxicity, rat **

**342-746 162521, Hoberman, A. M., "Developmental neurotoxicity study of chlorpyrifos administered orally via gavage to Crl:CD®(SD)BR VAF/Plus® presumed pregnant rats", Argus Research Laboratories, Inc., 5/1/98. Sponsor Protocol No. K-044793-109; Argus Study ID 304-001. Crl:CD®(SD)BR VAF/Plus® presumed pregnant rats were gavaged on gestation day 6 through lactation day 11 with chlorpyrifos (99.8%) in corn oil at 0, 0.3, 1, and 5 mg/kg/day. Initially there were 25 dams/group on treatment. On lactation day 5, twenty litters/treatment were continued on study. Four subsets of 20 pups/sex/group were selected on lactation day 5, each consisting of 1/sex/litter. Primary investigations for the subsets were: (Subset 1):

morphometric evaluations and histopathology of brains after postpartum day 12 sacrifice, (Subset 2): spatial delayed alternation studies at postpartum days 23-25 and 62-91, (Subset 3): motor activity testing on postpartum days 14, 18, 22, and 61: auditory startle on postpartum days 23 and 62, (Subset 4): evaluation of developmental landmarks (pinna unfolding, eye opening, preputial separation or vaginal opening); brain weight evaluation in 10/sex/group sacrificed during lactation days 66-71, and neurohistopathology following *in situ* perfusion of 6/sex/litter. Maternal NOEL = 0.3 mg/kg/day (brain ChE inhibition). Clinical signs of ChE inhibition were observed in 5 mg/kg/day dams. Developmental NOEL = 1 mg/kg/day (decreased neonatal survival; decreased pup growth, with 11% reduction in body weight at 66 days postpartum in males; maturational delays of pinna unfolding, preputial separation in males, and vaginal patency in females; reduced morphometric dimensions of cerebellum and hippocampal gyrus at day 12 postpartum compared to concurrent and historical controls, reduced morphometric dimensions of parietal cortex and hippocampal gyrus at day 66 postpartum compared to concurrent and historical controls in high dose females, reduced motor activity at day 14 postpartum, reduced auditory startle habituation peak response and increased latency to response at day 23 postpartum). This study was classified as "not acceptable but upgradeable" in the initial review, with the primary concern being appropriateness of the validation studies for evaluation of spatial delayed alternation. The response in Record No. 168955 (below) addressed the advantages of the using memory retention as a function of time for validation of technique, as compared with memory reduction due to exogenous chemicals. The investigators' response gave examples of many confounding effects of exogenous chemicals on parameters other than on memory. Study findings are not of sufficient magnitude or persistence to be considered as "adverse". Report is now **acceptable**. Aldous, 11/13/98 and 9/17/99.

342-769 164347 Submission of morphometry and histopathology data on F1 rats sacrificed after day 66 in Record No. 162521, above. Data were incorporated into the review for the main study under that Record Number. Aldous, 11/12/98.

342-789 168955, 168959, and 168960. Supplemental information to developmental neurotoxicity study 342-746 162521. Final report date of update: 5/7/99. Additional data and explanatory text were provided, **allowing an upgrade of Record No. 162521 to acceptable status**. Essential responses summarized below are detailed in review "s162521 s01.wpd". The validation studies for evaluation of spatial delayed alternation, which were based on temporal patterns of memory performance over sufficient duration to show a consistent linear change over time, were shown to be satisfactory. Representative micrographs prepared by the pathologist were presented, demonstrating several of the commonly encountered lesions following insult to the several areas of the CNS, dorsal root ganglia, and peripheral nerves. Additional brain morphometric data requested by U.S. EPA were provided, plus selected published articles. One article showed that poor nutrition reduces pup brain weight increases, although to a much lesser extent than the decrement of body weight gain. Another article determined that the reductions of dimensions in brain regions appear to affect all brain morphometric measurements proportionately. A third article showed that poor nutrition leads to locomotion delays which are quite remarkable during lactation days 14-16, whereas some components of coordinated movement and altered posture remain affected for a longer time. Aldous, 9/17/99.

342-832 (suppl. to 342-746) 182481 (suppl. to 162521) Hoberman, A. M., Report Supplement 3 to: "Developmental neurotoxicity study of chlorpyrifos administered orally via gavage to Crl:CD®(SD)BR VAF/Plus® presumed pregnant rats, "Argus Research Laboratories, Inc., dated 5/1/98 (of original study), this supplement dated Oct. 9, 2000. Protocol No. of this supplement: 304-001. Brain morphometric data from the original report were re-tabulated alongside historical control data from 4 or 5 studies per parameter. Only one measurement having a high dose value statistically significantly different from concurrent controls was outside the range of the historical controls: the cerebellar anterior/posterior dimension in 5 mg/kg/day male 12-day pups was significantly below concurrent control dimension, and also outside the range of the available historical controls. Females did not suggest such a relationship at 12 days, and neither sex showed altered cerebellar anterior/posterior distance after 66 days. In the context of the demonstrated high maternal and neonatal toxicity of this dose, the supplemental data reinforce the lack of demonstrated special toxicity of the test article toward the developing nervous system. Supplemental to a previously acceptable study with no adverse effects. Aldous, 9/26/01.

342-824 178362 [Same report as 342-746 162521, above].

Delayed neurotoxicity, hen **

**342-291 051119 Barna-Lloyd, T., J. R. Szabo, and J. T. Young, "Chlorpyrifos: Subchronic Organophosphate-Induced Delayed-Neurotoxicity (OPIDN) Study In Laying Chicken Hens," (Report No. TXT:K-044793-064), Health & Environmental Sciences, Dow Chemical, Freeport, Texas, 4/86. Chlorpyrifos, tech. (approx. 96% purity). 0, 1, 5, and 10 mg/kg/day. No evidence of delayed distal neuropathy. 10 mg/kg/day chlorpyrifos caused weight loss, diminished egg laying capacity, and transient abnormal gait (fully reversible between dosing periods, and not persistent throughout study). Study fills neurotoxicity data requirement. C. Aldous, 6/3/87.

342-255 036346 Rowe, L. D., S. D. Warner, and R. V. Johnston, "Acute Delayed Neurotoxicologic Evaluation of Chlorpyrifos in White Leghorn Hens," Dow Chemical, Lake Jackson, Texas, 5/22/78; Chlorpyrifos, tech; 0, 50, and 100 mg/kg (gelatin capsule); NOEL = 100 mg/kg for behavioral or microscopically evident delayed neuropathy (Highest dose tested) NOT ACCEPTABLE, not complete, not upgradeable (no repeat dosage at day 21 when no effects were observed, not all currently required tissues examined.) C. Aldous, 2/13/86.

EPA 1-liner: [Acute delayed neurotoxicity - hen; Dow; 5/22/78] LD50 in hens= 50 mg/kg Negative @ 50 & 100 mg/kg. Core grade, minimum.

342-496 132855 Abou-Donia, M. B., and K. R. Wilmarth, "DowElanco chlorpyrifos joint neurotoxic action of chlorpyrifos and safrotin in hens (Duke Univ. Medical Center Dept. of Physiology and Pharmacology, Durham, NC). Assigned to Worker Health and Safety Branch for review. (Aldous, 8/8/97).

342-745 162520 (No Author) "Preliminary Report: Assessment of neurotoxicity associated with co-exposure to the organophosphorus insecticides chlorpyrifos and diazinon". White leghorn hens were dosed with maximal levels of chlorpyrifos and/or diazinon and kept alive with atropine and 2-PAM for 96 hours prior to sacrifice and assays of ChE (plasma and brain), and

brain NTE. There were apparently cumulative effects for brain and plasma ChE. Although diazinon by itself did not affect NTE activity, diazinon potentiated the NTE inhibition of chlorpyrifos from 35% to 65% of normal. There is insufficient information in this preliminary report to warrant a Medical Toxicology Branch worksheet. Aldous, 11/09/98.

IMMUNOTOXICITY **

** 342-0907; 258212; Chlorpyrifos: Assessment of Immunotoxic Potential Using the Sheep Red Blood Cell Assay after 28-Day Dietary Exposure to Rats@; (D.R. Boverhof, J.A. Murray, R. Sura; Toxicology & Environmental Research and Consulting, The Dow Chemical Company, Midland, MI; Study ID No. 101023; 6/28/10); Ten female Sprague-Dawley rats/group received 0, 0.4, 2.0 and 10.0 mg/kg/day of Chlorpyrifos technical (lot no. KC28161419; purity: 99.8%) in the diet for 28 days. Another 10 females were dosed by intraperitioneal injection with 20 mg/kg/day of cyclophosphamid from day 24 through day 28 as the positive control group. No deaths occurred during the treatment period. There was no treatment-related effect upon the mean body weights or food consumption. The hematology parameters were not affected by the treatment. Red blood cell cholinesterase (ChE) activity was reduced in a dose-related manner for all treatment groups. Brain ChE activity was significantly less than that of the controls at the 2 and 10 mg/kg treatment levels. The mean absolute and relative weights of the spleen and thymus were not affected by the treatment. The anti-SRBC IgM serum titers were less for the 2 and 10 mg/kg treatment groups. However, the effect was not manifested in a dose-related manner (i.e., the titers for 2 and 10 mg/kg groups were 36 and 59% of the control group, respectively). These results were judged to be equivocal based on the range of variability demonstrated in the control group values and the lack of a clear dose-response. Other parameters (spleen and thymus weights, white blood cell differential counts) did not indicate any suppression of immunopotency. The positive control was functional. **Study acceptable.** (Moore, 5/3/11)

ENDOCRINE DISRUPTOR STUDIES

SUPPLEMENTAL STUDIES

Human Epidemiological Studies Related to Neurotoxicity

342-543 138174 Nolan, R. J. (Study Director) "Critical analysis of the allegations of neuropathy due to chlorpyrifos submitted to the United States Environmental Protection Agency on November 7, 1994". DowElanco had identified 31 individuals for whom physicians had made at least tentative diagnoses of neuropathy having possible association with chlorpyrifos. Although several cases of massive chlorpyrifos exposure had previously been documented, only one appeared to have caused organophosphate-type delayed neuropathy (OPIDN): this was an attempted suicide in which heroic treatments were required to address severe cholinergic symptoms (investigators citing Lotti *et al.*, 1986). The primary focus of the present investigation was on OPIDN symptoms, however other neurological findings were noted where found. None of the exposures (or worst plausible estimates of exposures) were judged to have been "biologically significant" [i.e., exposures were likely to have been too low to have measurably depressed plasma ChE, or (for inhalation route) were less than the NAS guideline of 10 µg/m^3].

Studies to date have indicated that it is critical to achieve at least 50% inhibition of neurotoxic esterase in order obtain OPIDN symptoms: this is unlikely to happen except at dose sufficient to elicit major cholinergic crises. Onsets of acute symptoms in this study were compared with plausible response times for acute ChE inhibitory signs (usually within 4 hr, in any case within 24 hr). The majority of cases presented no cholinergic signs, and none presented signs which were unambiguously due to ChE inhibition. Only three persons had documented neuropathy which became evident within one month of alleged exposure (a plausible time frame for OPIDN), without a demonstrated alternate cause. Of these, no two of them had consistent symptoms. DowElanco therefore determined that the alleged neuropathologies could not reasonably be attributed to chlorpyrifos. No SB-950 worksheet is appropriate, since this is not a relevant study type, and data do not support a treatment effect. Aldous, 8/11/97.

342-707 154147 "Critical assessment of reported entitled 'Review of chlorpyrifos poisoning data'". This report was directed to Worker Health and Safety Branch for review, since the commonly expected poisoning incidents would be acute cholinergic events. No Medical Toxicology Branch review has been requested. Aldous, 8/11/97.

NON-GUIDELINE STUDIES RELATING TO CHOLINESTERASE AND METABOLISM

Human acute oral, evaluating clinical signs, metabolism, and/or cholinesterase

342-788; 168932; "A Rising Dose Toxicology Study to Determine the No-Observable-Effect-Levels (NOEL) for erythrocyte Acetylcholinesterase (AChE) Inhibition and Cholinergic Signs and Symptoms of Chlorpyrifos at Three Dose Levels"; (Kisicki, J.C. *et. al.*; MDS Harris, Lincoln, Nebraska; Study ID. DR K-044793-284; 4/19/99); Six male and six female human volunteers/treatment group were fasted overnight prior to being dosed orally once with 0 (placebo: lactose monohydrate), 0.5 or 1.0 mg/kg of chlorpyrifos powder (purity: 99.8%) in capsules (phase 1) or 0 or 2.0 mg/kg (phase 2) in a double blind, randomized study. The health status of each subject was monitored for up to 7 days. Vital signs (blood pressure, pulse rate, respiration rate, and body temperature) were recorded prior to dosing and at 1, 2, 4, 8, 12, 24, 48 and 168 hours after dosing. Blood samples for erythrocyte acetylcholinesterase (AChE) analysis were drawn 10 hours prior to dosing, at the time of dosing and at 2, 4, 8, 12, 24, 36, 48, 72, 96, 120, 144 and 168 hours post-dose for erythrocyte AChE activity and chlorpyrifos and metabolite analyses. A blood sample was drawn prior to dosing for paraoxonase activity determination. Urine samples were collected at 12 hour intervals starting 48 hours prior to dosing and at 0 to 6 and 6 to 12 hours post-dose and 12 hour intervals thereafter up to 168 hours after dosing. Although clinical symptoms such as anorexia, diarrhea, nausea, vomiting, dizziness, dyspnea, and headache were reported, none of these signs occurred in a dose-related manner. There was no apparent treatment-related effect upon any of the vital signs. Mean erythrocyte AChE activities were not significantly affected in a dose-related manner. One subject in the 2.0 mg/kg treatment group demonstrated a maximal 30% inhibition between AChE activity reported at 0 time and at 12 hours post-dose. Otherwise, no other subject in the high dose group had a

reduction in erythrocyte AChE activity greater than 12% based on the higher of the two baseline values. The blood and urine levels of chlorpyrifos and its metabolites and the paraoxonase activity analysis for individual subjects were not included in this initial report and thus could not be evaluated. **No adverse effects indicated. NOEL:** 1.0 mg/kg (based upon the 30% inhibition of erythrocyte AChE demonstrated by one of the subjects in the 2.0 mg/kg treatment group). **Supplemental Study.** (Moore, 5/18/99).

342-823 178361 This is a copy of study 342-788; 168932, above.

342-822 178360; Brzak, K. A., "A Rising Dose Toxicology Study to Determine the No-Observable-Effect- Levels (NOEL) for erythrocyte Acetylcholinesterase (AChE) Inhibition and Cholinergic Signs and Symptoms of Chlorpyrifos at Three Dose Levels – Part B" Acetylcholinesterase (AChE) Inhibition Study; Human; The Dow Chemical Company, Midland, MI; Laboratory I.D. No. 981176; 6/5/00; Chlorpyrifos; Human volunteers (6/sex/dose) received a single oral dose of 0.0, 0.5, 1.0 or 2.0 mg/kg (capsule form) in a double-blind clinical trial; blood and urine specimens were collected and analyzed for chlorpyrifos and its metabolites (chlorpyrifos oxon and 3,5,6-trichloro-2-pyridinol (TCP)) using GC-MS; pretreatment Chlorpyrifos Oxonase (CPOase), paraoxonase and diazoxonase were determined spectrophotometrically; blood and urine specimens were generally below the limit of quantitation (LOQ) for chlorpyrifos; average AUC for TCP in blood (by increasing dose) was 14.0, 25.2 and 51.2 µg/g, respectively and amount TCP excreted in the urine was 4.1, 8.7 and 15.9 mg, respectively during the first 168 hr following ingestion; blood and urinary TCP levels increased rapidly, remained constant over first 48 hr post-treatment, and then declined with an average half-life of 29 to 36 hr; administration by capsule probably reduced absorption (average of 34.7%, 30.8% and 29.5% absorbed in 0.5, 1.0 or 2.0 mg/kg dose group, respectively); serum CPOase activity was within the range of activity reported in previous studies and there were no extreme values; RBC ChE depression was seen in only one individual, a 2.0 mg/kg female that showed unusually high absorption of chlorpyrifos (87.9% versus 29.5%). Supplementary Data. Kellner, 2/23/01. [NOTE by C. Aldous: This study is "Part B" of 342-788; 168932, above].

342-834 183264 This is a copy of 342-822 178360, above.

Human repeat dosing, oral, evaluating clinical signs, metabolism, and/or cholinesterase

342-0343 071392 Coulston, F., T. Griffin, and L. Golberg, "Safety evaluation of Dowco 179 in human volunteers," Institute of Experimental Pathology and Toxicology, Albany Medical College, Albany, NY, March 1972. Four male volunteers/group were dosed by tablet with Dowco 179 (chlorpyrifos) at 0 mg/kg/day (placebo) for 48 days, 0.014 mg/kg/day for 27 days, 0.03 mg/kg/day for 20 days, or 0.10 mg/kg/day for 9 days. Investigators assessed hematology and clinical chemistry weekly, and plasma cholinesterase (ChE) and RBC ChE twice weekly. These assessments continued as needed post-treatment to determine recovery. No treatments affected hematology or clinical chemistry or RBC ChE. Plasma ChE inhibition was marked and progressive over time at 0.10 mg/kg/day, with inhibition of 10% on days 1 to 3, 46% inhibition on day 6, and 66% inhibition on day 9, when dosing of that group was stopped. Recovery of this group progressed after cessation of dosing, with plasma ChE reaching twice the treatment day 9 activity at recovery day 11, and complete recovery to pre-treatment activity at recovery day 25.

Plasma ChE activity in the 0.03 mg/kg/day group was reduced by about 30% during days 16-20. Complete recovery from this lesser effect was complete by 20 days off treatment. Study gives useful supplementary information. Aldous, June 5, 2015.
342-0607 145821 is an exact copy of 342-0343 071392, above.

Human dermal (or dermal/oral comparison), evaluating clinical signs, metabolism, and/or cholinesterase

342-122 948115 Nolan, R. J., D. L. Rick, N. L. Freshour, and J. H. Saunders, "Chlorpyrifos: pharmacokinetics in human volunteers following single oral and dermal doses," Dow Chemical, Midland, MI, Aug. 1982. Healthy male volunteers were dosed with chlorpyrifos (analytical grade, 99.8% purity) to assess kinetics of chlorpyrifos and of its major metabolite (3,5,6-trichloro-2-pyridinol), and to follow changes in plasma and RBC cholinesterase (ChE) over time. N = 5 for major parameters. Exposures were a 0.5 mg/kg single oral dose, followed 4 weeks later (ample time for clearance from the oral exposure) by a single 5 mg/kg dermal dose. None of these doses elicited clinical signs. Following 0.5 mg/kg oral dosing, plasma ChE was inhibited to about 15% of baseline, with greatest inhibition at 0.5 to 2 hrs after dosing. By 8 hours, plasma ChE levels were 3-4 fold higher than the lowest activity. By 27 to 30 hours, plasma ChE activity had returned to baseline. Dermal dosing with 5 mg/kg chlorpyrifos had no definitive effect on plasma ChE at any time post-dose. RBC ChE activity was inherently more variable than plasma ChE. RBC ChE activity was not measurably affected by these oral or dermal exposure levels. Blood chlorpyrifos levels following 0.5 mg/kg oral dosing was either non-detectable, or was in the range of 5-30 ng/ml blood. The highest blood chlorpyrifos levels did not appear at consistent times post-dosing, and clearly would not represent a reliable measure of exposure. Blood concentrations of chlorpyrifos following 5 mg/kg dermal exposure were either non-detectable or did not exceed 10 ng/ml. Blood levels of 3,5,6-trichloro-2-pyridinol following 0.5 mg/kg oral dosing showed quite variable kinetics between subjects, but tended to peak at 2-8 hours at about 1 µg/ml blood, with levels at 24 hours being no less than 50% of peak concentrations. This confirms that this metabolite would be a good indicator of exposure. Dermal exposure of 5 mg/kg yielded 3,5,6-trichloro-2-pyridinol blood levels which occasionally exceeded 0.1 µg/ml. There was about a 4-fold range of peak 3,5,6-trichloro-2-pyridinol blood between dermal exposure subjects. Investigators estimated the half-life of 3,5,6-trichloro-2-pyridinol to be about 27 hours by either route. Urinary peak excretion rates of 3,5,6-trichloro-2-pyridinol were at about 9 hours for oral route, and about 42 hours for the dermal route. Time to decrease to about 50% of maximum urinary 3,5,6-trichloro-2-pyridinol levels were roughly 30 hours for oral exposure and 84 hours for dermal route. Thus this study shows that chlorpyrifos is only moderately absorbed through the skin, that plasma ChE is a good marker of systemic load for several hours after exposure, whereas urinary 3,5,6-trichloro-2-pyridinol assays would be useful for qualitative exposure assessment for 2-3 days for oral route, and slightly longer for dermal exposure. Useful supplementary data. Aldous, 4/16/15.

342-0197 001367, also 342-0627 149353 These are exact copies of 342-122 948115, above.

342-0343 071383 Nolan, R. J., D. L. Rick, N. L. Freshour, and J. H. Saunders, "Chlorpyrifos: pharmacokinetics in human volunteers," *Toxicology and Applied Pharmacology* **73**, 8-15 (1984). This is a published version of Record No. 948115.

342-763 165484 Griffin, P., H. Mason, K. Heywood, and J. Crocker, "Oral and dermal absorption of chlorpyrifos: A human volunteer study", cover letter dated 11/23/98. (This was a manuscript accepted for publication in Occupational & Environmental Medicine). Data were reviewed by T. Thongsinthusak of DPR Worker Health and Safety Branch: that review is bound with the volume. Dermal applications led to 1% absorption (evidenced as dialkylphosphate urinary metabolites), and 53% unaltered chlorpyrifos was recovered by washing the application site. Investigators did not account for the balance for the remainder of residues. Aldous, 10/13/99.

Primate Studies

342-384 091999 Coulston, F., L. Golberg, R. Abraham, K. F. Benitz, T. B. Griffin, and M. Norvell, "Final Report on Safety Evaluation and Metabolic Studies on DOWCO 179 (IN 151)," Institute of Experimental Pathology and Toxicology, Albany Medical College, Albany, NY, 3/18/71 (unpublished study). This early study included rat and monkey data. Only the 6-month monkey study is summarized here. Fourteen rhesus macaque monkeys (Macaca mulatta) were placed on study (8 males and 6 females), with 3-4 animals per group at doses of 0, 0.08, 0.40, or 2.00 mg/kg/day of DOWCO 179 (chlorpyrifos, purity unspecified). Test article was administered by gavage as aqueous suspensions in 1% gum tragacanth. Four males (1/group) were sacrificed at 3 months. Nine of the remaining 10 monkeys survived to 6 month termination. There were no effects on body weight, clinical signs, hematology, or clinical chemistry. Plasma cholinesterase (ChE) inhibition was observed at all dose levels (65%, 28%, and 24% of pre-treatment activities for 0.08, 0.40, or 2.00 mg/kg/day monkeys (sexes combined), respectively. RBC ChE was only inhibited at the top 2 dose levels (79% and 34% of pre-treatment activities for 0.40, or 2.00 mg/kg/day monkeys, respectively. Midbrain ChE (the only CNS tissue evaluated) showed no evidence of treatment effect at 0.4 mg/kg/day or below. Only 2 monkeys were evaluated for midbrain ChE at 2.00 mg/kg/day: a male sacrificed at 3 months which showed no difference from the control, and a female sacrificed at 6 months which had a lower activity than concurrent controls, but within the range of variability indicated for other animals on study. If the one case indicating a treatment effect were indeed dose-related, it would indicate comparable response to whole-brain values previously obtained for repeat-dose studies in species such as rat and dog. Urine was collected for 24 hours during week 16 to see whether 3,5,6-trichloro-2-pyridinol (TCP) in urine could be used to estimate chlorpyrifos exposure. Results were highly variable for the 7 subjects evaluated, but show promise for urinary TCP as a rough estimator of exposure. Investigators evaluated possible induction of biphenyl-4-hydroxylase or biphenyl-2-hydroxylase activity in liver homogenate 9000 x g fractions, and found no induction of these activities. This is a supplementary study, performed before modern guidelines were formulated, and is not a candidate to fill a FIFRA data requirement. Data are too scant to assess possible adverse effects. Aldous, 3/19/18.

Rat acute oral, evaluating clinical signs, metabolism, and/or cholinesterase

342-763 164102 Mendrala, A. L. and K. A. Brzak, "Chlorpyrifos: Part A - Concentration - time course of chlorpyrifos and chlorpyrifos-oxon in blood," The Dow Chemical Co., Midland, 8/31/98, Laboratory Project Study ID 971187A. This study had two segments. [Segment 1]: Chlorpyrifos was administered by gavage in corn oil to male F344 rats at dose levels of 0.5 to

100 mg/kg. Four rats/group were killed at intervals ranging from 10 min to 12 hr to determine time course of (a) concentrations of chlorpyrifos and chlorpyrifos-oxon, and (b) plasma and brain cholinesterase (ChE) activities. Chlorpyrifos concentrations peaked at 3 hr, with levels dropping substantially at 6 to 12 hr. Chlorpyrifos-oxon was only about 1% as abundant as chlorpyrifos, and was typically detectable at 1 hr and 3 hr intervals only. Plasma ChE inhibition was evident at all dose levels, with plasma ChE inhibition peaking in the range of 3 to 6 hours. The 3-hour plasma response (as % of control ChE activity) was 84%, 72%, 42%, 33%, 18%, and 18 % in 0.5, 1, 5, 10, 50, and 100 mg/kg groups, respectively. Brain ChE inhibition was evident at 10 mg/kg and above, with brain ChE activity (as % of control) at 6-hour peak response being 88%, 30%, and 28% in 10, 50, and 100 mg/kg groups, respectively. Estimated half-life for chlorpyrifos in blood was 2.7, 1.5, 2.1, or 7.3 hours for 5, 10, 50, or 100 mg/kg chlorpyrifos dose levels, respectively. [Segment 2]: Four rats/group were dosed by gavage in corn oil with achieved levels of 3 and 63 mg/kg of ring-labeled ^{14}C-chlorpyrifos, administered 3 hours prior to sacrifice. Blood was collected for measurements of circulating chlorpyrifos, chlorpyrifos-oxon, and the trichloropyridinol (TCP) hydrolysis product. TCP was by far the most abundant residue in blood (about 99% of chlorpyrifos-equivalents at either dose level). Remaining dose-equivalents were approximately 1% chlorpyrifos, and less than 0.1% was chlorpyrifos oxon. Report provides useful supplementary data. Findings of brain ChE are designated as "possible adverse effects." Aldous, 10/13/99; re-examined with a worksheet by Aldous on April 9, 2018.

Rat chlorpyrifos acute vapor inhalation, evaluating clinical signs, metabolism, and/or cholinesterase

NOTE: The two rat acute vapor inhalation studies below assess acute responses to **parent chlorpyrifos** and to **chlorpyrifos oxon**, respectively.

342-0937; 271252; Hotchkiss, J. A., S. M. Krieger, K. M. Mahoney, K. A. Brzak, N. A. Malowinski, and D. L. Rick, "Nose-Only Inhalation of Chlorpyrifos Vapor: Limited Toxicokinetics and Determination of Time-Dependent Effects on Plasma, Red Blood Cell, Brain and Lung Cholinesterase Activity in Female CD(SD): Crl Rats"; (Toxicology & Environmental Research and Consulting, The Dow Chemical Company, Midland, MI; Study ID No. 131040; 5/2/13); Forty female Crl:CD(SD) rats/group were exposed nose-only to either 0 (filtered air) or 17.7 ppb (0.254 µg/l) of a saturated vapor of chlorpyrifos technical (lot no. 7299412; purity: 97.6%) for 6 hours. Eight animals/group/time point were euthanized at 0, 2, 4, 6 and 12 hours post-exposure. Blood, brain and lung tissue were procured from each animal. Cholinesterase activity was assayed in the plasma, blood, brain and lungs. Blood levels of chlorpyrifos and its primary metabolite, trichloropyridinol were determined as well. The animals demonstrated no signs of toxicity during the exposure or for the 12-hour post-exposure period. The peak level of chlorpyrifos in the blood was immediately after the completion of the exposure, diminishing to a non-detectable level by 6 hours post-exposure. The trichloropyridinol peak levels were noted up to 2 hours post-exposure and gradually diminished over the 12-hour post-exposure observation period. Chlorpyrifos-oxon was not detectable in any of the samples. None of the tissues which were assayed from the exposed group demonstrated a significant reduction in cholinesterase activity in comparison to the control activity levels. Activity in the blood and plasma of the exposed animals was 93 and 86%, respectively, of the control values at 4 hours post-exposure, the maximal reduction. The ChE activity in the lungs of the exposed animals was 89% of the

control group at that time point. There was no apparent effect upon ChE activity in the brain. **No adverse effect indicated. Study supplemental.** (Moore, 6/4/13)

342-0950 274123; "Nose-Only Inhalation of Chlorpyrifos-Oxon Vapor: Limited Toxicokinetics and Determination of Time-Dependent Effects on Plasma, Red Blood Cell, Brain and Lung Cholinesterase Activity in Female CD(SD):Crl Rats"; (J.A. Hotchkiss, S.M. Krieger, K.M. Mahoney, K.A. Brzak, N.A. Malowinski, D.L. Rick; Toxicology & Environmental Research and Consulting, The Dow Chemical Company, Midland, MI; Study ID. 131067; 8/30/13); In Phase 1, the highest attainable saturated vapor concentration of chlorpyrifos-oxon (oxon) under standard laboratory conditions typical of an acute nose-only inhalation exposure study was determined and selected for Phase 2 of this study. In Phase 2, eight female CD(SD):Crl rats/group/sacrifice time were exposed for 6 consecutive hours to filtered air (control) or a time weighted average concentration of 35.3 $\mu g/m^3$ (2.58 ppb) oxon vapors using a flow-past nose-only inhalation exposure system. Rats were sacrificed immediately (0 hr) and at 1, 2, 4, 8 and 24 hours after the end of exposure. Blood and tissues were isolated and processed to determine cholinesterase (ChE) activity in red blood cells (RBC), plasma, and lung and brain tissues. Whole blood samples from n=4 rats in each group/sacrifice time were analyzed to determine the concentrations of oxon and 3,5,6-trichloro-2-pyridinol (TCP). No clinical signs of toxicity were noted in oxon-exposed rats at any time during or after exposure. No oxon was detected in the blood at any time after exposure (lower limit of quantification (LLQ), 0.118 ng/g blood), however, blood TCP levels > LLQ (2.44 ng/g blood) were detected in all assayed blood samples collected at 0 through 4 hours after exposure and in 1/4 assayed blood specimens collected 8 hours post-exposure. By contrast, blood TCP levels were below LLQ in 3/4 and 4/4 animals sacrificed at 8 and 24 hours after exposure, respectively. No oxon-induced inhibition of ChE activity was detected in RBC, plasma, lung or brain at any time after exposure. The presence of TCP in the blood of oxon-exposed rats confirms that oxon vapor is absorbed through the respiratory tract, however, the inhaled oxon is rapidly metabolized and not systemically bioavailable, given that all the assayed blood levels were below LLQ (0.118 ng/g or 3.53×10^{-4} nmol/g blood). Based on the absence of cholinesterase inhibition in RBC, plasma, brain or lung (the portal-of-entry tissue), the 6-hour No Observed Effect Concentration (NOEC) for inhaled oxon vapor is > 35 μg oxon/m^3 air. The results of this study suggest that there is no biologically relevant hazard from inhalation of a saturated vapor concentration (35.3 $\mu g/m^3$) of chlorpyrifos oxon. **Study Supplemental**. (Guo, 11/13/13)

Rat chlorpyrifos repeat-dose vapor inhalation, evaluating clinical signs, metabolism, and/or cholinesterase

342-0343 071388 Landry, T. D., D. A. Dittenber, L. L. Calhoun, L. G. Lomax, and P. Morabito, "Chlorpyrifos: 2-week nose-only vapor inhalation exposure study in Fischer 344 rats," The Dow Chemical Company, Midland, MI, 6/10/86. This study exposed female rats (N = 6) to 0 or 12 ppb chlorpyrifos vapor (99.7% purity) 6 hours/day, 5 days/week, with sacrifice one day after the last exposure (with 3 consecutive days of exposure before the day of sacrifice). Investigators evaluated cholinesterase (plasma, RBC, and brain), clinical signs, body weights, hematology, and gross pathology. There were no treatment responses. The tested concentration was noted to be about 50% of the maximum theoretical maximum vapor level for chlorpyrifos. Although individual data were provided, there is no DPR worksheet for this report, since it does not address a data requirement, and because it was negative. Aldous, 5/15/15.

342-0343 071389 Corley, R. A., T. D. Landry, L. L. Calhoun, D. A. Dittenber, and L. G. Lomax, "Chlorpyrifos: 13-week nose-only vapor inhalation exposure study in Fischer 344 rats," The Dow Chemical Company, Midland, MI, 11/13/86. This study exposed both sexes (N = 10) to 0, 5.2, 10.3, or 20.6 ppb chlorpyrifos vapor (100% purity, reporting mean assayed chamber concentrations) 6 hours/day, 5 days/week, with sacrifice one day after the last exposure (with at least 4 consecutive days of exposure before the day of sacrifice, following overnight fasting). Investigators evaluated cholinesterase (plasma, RBC, and brain), clinical signs (shortly after each exposure period), body weights, organ weights, hematology, clinical chemistry, urinalysis, and gross pathology. Protocol tissues of both sexes were subject to histopathology examination in control and high dose groups. There were no treatment responses. The maximum vapor level for chlorpyrifos was noted to be about 25 ppb. This is a valid supplementary study. Although individual data were provided, there is no DPR worksheet for this report, since it does not address a standard data requirement, and because responses were negative. Aldous, 5/15/15.

Rat chlorpyrifos acute aerosol inhalation, evaluating clinical signs, metabolism, and/or cholinesterase

342-0908; 258214; AAcute Inhalation Exposure of Adult Crl:CD(SD) Rats to Particulate Chlorpyrifos Aerosols: Kinetics of Concentration-Dependent Cholinesterase (ChE) Inhibition in Red Blood Cells, Plasma, Brain and Lung@; (J.A. Hotchkiss, S.M. Krieger, K.A. Brzak, D.L. Rick; Toxicology & Environmental Research and Consulting, The Dow Chemical Company, Midland, MI; Study ID. 091133; 6/29/10); In Phase I, six Sprague-Dawley rats/sex/group were exposed nose-only to 0, 13.3 or 66.7 mg/m^3 (analytical) of Chlorpyrifos technical (lot no. KC28161419; purity: 99.8%) for six hours. Blood was drawn from an indwelling jugular catheter at 2, 4, 6 hours of exposure and at 0.5, 1, 2, 4, 6, 12, and 24 hours post-exposure. Red blood cell and plasma cholinesterase (ChE) activities were assayed for each time point. In Phase II, 54 female rats/group were exposed nose-only to 0, 3.7, 12.9, 22.1 or 53.5 mg/m^3 of the test material for up to 6 hours. Six animals/group/time point were euthanized at 2, 4, and 6 hours of exposure and at 2, 6, 12, 24, 48 and 72 hours post-exposure. Cholinesterase activities in the red blood cells, plasma, lungs and brain were assayed and the blood concentrations of chlorpyrifos (CPF), chlorpyrifos-oxon (CPO) and trichloropyridinol (TCP) were measured. Urine was collected from 6 animals/group at 0 to 12, 12 to 24, 24 to 48 and 48 to 72 hours and trichloropyridinol concentrations were determined. In Phase I, significant inhibition of red blood cell and plasma ChE activities was evident at 13.3 mg/m^3 For RCE ChE activity, maximal inhibition of 65% for males and 80% for the females was noted at 2 hours post-exposure. For plasma ChE activity, maximal inhibition of 66% for males and 87% for females was evident from 6 hours of exposure to 1 hour post-exposure. Based on these results, females were deemed to be more sensitive to the effects of CPF on ChE activity and thus were selected for testing in Phase II. ChE inhibition in the plasma achieved a maximal level of 48% at 6 hours of exposure in the 3.7 mg/m^3 group. In the lungs, a maximal level of ChE inhibition was noted at 47% in the 3.7 mg/m^3 at 6 hours of exposure. ChE activity in the brain was significantly reduced for the 12.9, 22.1 and 53.5 mg/m^3 groups with maximal inhibitions of 19, 21 and 22%, respectively, which were noted at 6, 6 and 2 hours post-exposure, respectively. For RBC ChE activity, the results were inconsistent at the 3.7 mg/m^3 exposure level possibly due to the variability of the control values. Maximal reduction in activity was not evident until 24 to 48 hours post-

exposure. The blood levels of CPF were highest at 4 to 6 hours of exposure for all of the exposure levels with a peak value of 65 ng/g noted for the 53.5 mg/m^3 group. CPO was recovered in the blood at peak levels of 0.22 ng/g during the exposure at the 53.5 mg/m^3 exposure level. Peak levels of 2400 ng/g of TCP for the highest exposure group were noted at 12 hours post-exposure. The plasma half-life of CPF ranged from 0.463 to 3.34 hours over the exposure concentration range. The ratio of the areas under the curve for TCP/CPF ranged from 545 to 1057. The inhaled dose of the test material was calculated to be 1.04, 3.62, 6.21 and 15.0 mg/kg. Excretion of TCP in the urine demonstrated a half-life ranging from 10.6 to 11.6 hours. Using these excretion data the percentage of inhaled CPF which was absorbed was calculated and ranged from 36 to 79%. **Study supplemental.** (Moore, 5/2/11)

Rat chlorpyrifos life stage comparisons (as neonate vs. young adult), evaluating clinical signs, metabolism, and/or cholinesterase

342-0906; 257044; AComparison of Cholinesterase (ChE) Inhibition in Young Adult and Pre-weanling CD Rats after Acute and Repeated Chlorpyrifos or Chlorpyrifos-Oxon Exposures@; (M.S. Marty, A.K. Andrus; Toxicology & Environmental Research and Consulting, The Dow Chemical Company, Midland, MI; Study ID. 091107; 6/29/10); Pre-weanling (11 days post-natal) and young adult female Sprague-Dawley rats were dosed orally by gavage, using vehicles of corn oil or rat=s milk or in the diet (adult rats only) with concentrations of Chlorpyrifos technical (CPF) (lot no. KC28161419, purity 99.8%) ranging from 0.05 to 10 mg/kg, in a single dose regimen or at concentrations ranging from 0.05 to 3.5 mg/kg/day of CPF in corn oil in a 10-day multiple dosing regimen (pre-weanling: days 11 to 21 post-natal, young adult: 70 to 80 days old). Other groups of pre-weanling and young adult female rats were dosed orally by gavage in a single dose regimen with Chlorpyrifos-oxon (CPO) in corn oil (lot no. 199902031-66, purity: 94.9%) at concentrations ranging from 0.005 to 1.0 mg/kg. In a 10-day multiple dosing regimen, both pre-weanling and young adult females were dosed orally by gavage with 0.01 and 0.5 mg/kg/day of CPO in the same manner as the CPF-treated animals. Eight animals/sex were included in the pre-weanling groups and 8 females/group were dosed in the young adult cohort. Preliminary studies were performed in order to establish the time-to-peak inhibition profile for plasma, red blood cell and brain cholinesterase (ChE) inhibition. In the dose-response studies, animals were euthanized at the time-to-peak ChE inhibition. The concentrations of CPF, CPO and trichloropyridinol (TCP) in the blood of some of the study animals were determined. A functional observational battery was performed on the study animals in the multiple-dosing regimen after 9 days of dosing. The times-to-peak effect were as follows: PND 11 pups: 1. CPF in corn oil (6 hours), 2. CP0 in corn oil (4 hours), 3. CPF in rat=s milk (8 hours); young adult females: 1. CPF in corn oil (8 hours), 2. CPO in corn oil (4 hours), 3. CPF in diet (after conclusion of the 12-hour exposure period) (8 hours). Based upon the results of the dose response studies, no effect levels were established for plasma, red blood cell and brain ChE inhibition under the different dosing scenarios. In the **single dose regimen**, NOELs for the plasma and red blood cell ChE inhibition were 0.5 mg/kg for both sexes of the pre-weanlings after treatment with CPF, using either corn oil or rat=s milk as the vehicle, and for the young adult females treated by gavage, using a corn oil vehicle, or in the diet. The NOEL values for the brain ChE inhibition were 2 mg/kg for the male pre-weanlings treated with CPF, using either corn oil or rat=s milk as the vehicle, for the female pre-weanlings, using corn oil as the vehicle and for the adult females treated by gavage or in the diet. For the pre-weanling females dosed with CPF in rat=s milk, the brain ChE inhibition NOEL was 0.5 mg/kg. The NOELs for

treatment with a single dose regimen of CPO were as follows: for both male and female pre-weanlings, the NOELs for plasma ChE inhibition: 0.05 mg/kg, for red blood cell ChE inhibition: 0.1 mg/kg and for brain ChE inhibition: 0.5 mg/kg. For the young adult females, the NOEL for plasma, red blood cell and brain ChE inhibition were 0.1, 0.1 and 0.5 mg/kg, respectively. In the **multiple dose regimen** in which the pre-weanlings and young adults were treated with CPF in corn oil by gavage, the NOEL values for ChE inhibition were as follows: male and female pre-weanlings, plasma and RBC: 0.1 mg/kg, brain: 0.5 mg/kg; young adult females, plasma: 0.1 mg/kg/day, red blood cell: 0.5 mg/kg/day, brain: 0.5 mg/kg/day. The NOELs for ChE inhibition after multiple treatments with CPO in corn oil were as follows: male and female pre-weanlings and young adult females, plasma and red blood cell: 0.01 mg/kg/day, brain: 0.5 mg/kg/day. The NOEL values were reduced from 0.5 mg/kg to 0.1 mg/kg/day for plasma and red blood cell ChE inhibition in the pre-weanlings after multiple treatments with CPF in corn oil. The brain ChE inhibition for these animals was lowered from 2 mg/kg to 0.5 mg/kg/day. In the young adult females, the NOELs for plasma and brain ChE inhibition were lowered from 0.5 mg/kg to 0.1 mg/kg/day and from 2 mg/kg to 0.5 mg/kg/day, respectively. The concentrations of CPF and TCP in the blood at the NOEL and/or LOEL treatment levels for the various treatment scenarios were examined. Treatment with CPF in corn oil or rat=s milk to pre-weanling rats in either a single dose or multiple dose regimen resulted in TCP/CPF concentration ratios (based on ng/g of blood) ranging from 70 to 209. For the young female rats, in certain instances, the CPF concentration was below the limits of detection and the ratio could not be calculated. Otherwise, the ratios were 935 and 449 (0.5 and 2.0 mg/kg, by gavage, respectively), 7243 (2.0 mg/kg in the diet) in the single dose regimen and 2450 (0.5 mg/kg/day) and 651 (1.0 mg/kg/day) after multiple doses by gavage. These data indicate a possible difference in the metabolic disposition of CPF between the pre-weanling pups and the young adult animals. No treatment-related effects were identified in the FOB. **Supplemental Study.** (Moore, 2/23/11)

342-0897 253051 This is an interim report of 342-0906; 257044, above.

342-0997 293277 M.S. Marty, A.K. Andrus, M.P. Bell, J.K. Passage, A. W, Perala, K. A. Brzak, M. J. Bartels, and D.R. Juberg, "Cholinesterase inhibition and toxicokinetics in immature and adult rats after acute or repeated exposures to chlorpyrifos or chlorpyrifos–oxon," Regulatory Toxicology and Pharmacology | Vol 63, 209-224 (2012). This is a published version of Record No. 257044, above.

342-764 164103 Mattsson, J. L., J. P. Maurissen, P. J. Spencer, K. A. Brzak, and C. L. Zablotny, "Effects of chlorpyrifos administered via gavage to CD rats during gestation and lactation on plasma, erythrocyte, heart and brain cholinesterase, and analytical determination of chlorpyrifos and metabolites", The Dow Chemical Co., Midland, 08/98. This study was not reviewed under SB-950, but has been examined extensively by R. Cochran for the chlorpyrifos risk assessment. Aldous 10/13/99.

Dog chlorpyrifos subchronic or subacute, dietary, evaluating clinical signs, metabolism, and/or cholinesterase †

342-836; 183362; "Chlorpyrifos Technical: 6-Week Dietary Study of Acetylcholinesterase Inhibition in Beagle Dogs"; (B.R. Marable, P.C. Baker, K.E. Stebbins and J.P. Maurissen; Toxicology & Environmental Research and Consulting, The Dow Chemical Company, Midland,

MI; Study ID: 011036; 7/27/01); Four beagle dogs/sex/group received 0, 0.5, 1.0 or 2.0 mg/kg/day of Dursban FM (Chlorpyrifos Technical) (lot no. 7299412, TSN100759, purity: 97.6%) in the diet for 6 weeks. The animals were fed twice per day and the content of the a.i. in the diet was adjusted in a manner such that the daily intake per body weight was maintained. No deaths resulted from the treatment. There was no apparent dose-related effect upon the mean body weights. No clinical signs were noted during the treatment period. The mean red blood cell cholinesterase (ChE) activity was reduced in a dose-related manner with maximal levels of inhibition achieved after 6 weeks (% of baseline, males, 0.5: 44.5%, 1.0: 27.6%, 2.0: 14.4%; females, 0.5: 56.9%, 1.0: 32.8%, 2.0: 18.9%). There was no dose-related effect upon the brain, diaphragm, muscle or nodose ganglion acetylcholinesterase (AChE) activity for either sex after 6 weeks of treatment. The AChE activity in the left atrium of the heart of the males was reduced in a dose-related manner (% of control, 0.5: 99.3, 1.0: 84.5%, 2.0: 74.5%). This effect was not noted for the females. **Possible adverse effect**: significant inhibition of AChE in the heart. **NOEL:** (M/F) < 0.5 mg/kg/day (based upon the reduced red blood cell ChE activity for both the males and females in the 0.5 mg/kg treatment group); **Supplemental Study** (non-guideline study) (Moore, 11/4/02)

342-833 182482 Baker, P. C. *et al.*, "Communication: Preliminary evaluation of acetylcholinesterase (AChE) in brain, peripheral tissues, and RBC in beagle dogs," The Dow Chemical Company, Midland, MI, 5/11/01. Report ID CPF0501. [Report begins on p. 38 of this volume]. Three males/group were dosed in diet with 0, 0.3, 0.6, or 1.2 mg/kg/day chlorpyrifos for 28 days. Parameters evaluated at termination focused on acetylcholinesterase measurements in RBC's, brain, nodose ganglion, left atrium, left ventricle, diaphragm muscle, and thigh muscle. In-life RBC acetylcholinesterase activity was measured weekly. All dogs survived the treatment, and there were no characteristic clinical signs. Body weight was unaffected by treatment. RBC acetylcholinesterase activity was reduced in dose-related fashion. Despite high variability in control activities, reductions in the higher two dose levels were clearly treatment-related (about 50% reduction at 1.2 mg/kg/day). These changes appeared to be progressive over time. No other tissues showed statistically significant reductions in AChE activity. Some of the assayed AChE activity values were so variable that the small numbers of dogs available could only have indicated major treatment responses. This is a useful pilot study, but data are unsuitable for quantitative analysis. Aldous, 9/27/01.

Dog chlorpyrifos subchronic or subacute, pet collar exposure, evaluating clinical signs, metabolism, and/or cholinesterase

342-244; 34080; Boyd, J. P., Cholinesterase Inhibition Study; 855; Dog; P.A.C.E. International, Dallas, TX; Project No. 20-208-1184; 5/14/85; pet collar, 8.0% A.I.; 6 treated animals, 4 untreated control animals; 1 collar/animal, 91 day treatment period; No mortality; Observations: no treatment-related effects, no irritation evident at the collar site; Cholinesterase (ChE) Inhibition: significant inhibition of plasma ChE from day 3 to end of study (maximal inhibition-83.7%, day 69), no apparent treatment effect on RBC ChE activity; no adverse effect; NOEL cannot be determined (significant inhibition of plasma ChE activity exhibited by treated animals); Study supplemental. (Moore, 5/12/93)

In vitro tissue studies of cholinesterase inhibition and metabolism

342-0951 274124; "*In vitro* Sensitivity of Cholinesterase to Inhibition by Chlorpyrifos-oxon in Several Tissues of the Rat"; (J.E. Chambers, E.C. Meek, H.W. Chambers; Center for

Environmental Health Sciences, College of Veterinary Medicine, Mississippi State University, Mississippi State, MS; Study ID. NS000128; 9/16/13); to compare the inherent sensitivity of cholinesterase in several tissues to inhibition by chlorpyrifos-oxon (CPFO) through determination of inhibitory concentrations (IC_{50} values), young adult male rats were euthanized; brain, blood, lung, heart, diaphragm, esophagus, stomach (flushed) and duodenum were removed from the animals and flash frozen in liquid nitrogen. In some animals, the heart and lungs were perfused with saline through the aorta to remove residual blood and the contents of the esophagus and duodenum were flushed out of the tissues, followed by flash freeze. Red blood cells (RBCs) collected were used intact, and also lysed and centrifuged to prepare a RBC ghost. All tissues were homogenized (except plasma and RBC ghosts) in 0.05 M Tris-HCl buffer, pH 7.4 at 37 °C, with a motorized glass-Teflon homogenizer, and plasma was diluted and RBCs and RBC ghosts were re-suspended in this buffer. A modified Ellman (spectrophotometric) method for measurement of cholinesterase activity was used with acetylthiocholine or butyrylthiocholine (only for some of the plasma duodenum samples) as substrate and 5,5'-dithiobis-(2-nitrobenzoic acid) (DTNB) as the chromogen. Tissue preparations were diluted in the above buffer to yield an activity level that produced about 1.2-2.0 Absorbance Units (AU) following the substrate incubation period (15 min. at 37 °C for all tissues except RBCs which was 1 hr at 37 °C) in the control samples. Five concentrations of CPFO in ethanol were used to provide an inhibition range of 20-80%; protein was quantified by the Lowry method. IC_{50} values were calculated for each of 3 replications (3 separate rats) by log-legit regression, and 95% confidence intervals were calculated for the IC_{50} means. The mean IC_{50} values (for assays conducted with acetylthiocholine as substrate, AChE) were: brain, 3.77 nM; duodenum – flushed, 3.72 nM vs. not flushed, 4.17 nM; esophagus – flushed, 3.13 nM vs. not flushed, 3.28 nM; stomach-flushed, 4.08 nM; lung – perfused, 7.21 nM vs. not perfused, 8.57 nM; heart – perfused, 3.06 nM vs. not perfused, 3.91 nM; diaphragm, 6.64 nM; RBCs, 4.19 nM vs. RBC ghosts, 5.08 nM; plasma, 55.36 nM. The assays conducted with butyrylthiocholine showed IC_{50} values very similar to those by AChE: duodenum – flushed, 3.72 nM vs. not flushed, 5.05 nM; plasma, 50.05 nM. There is no difference in the inherent sensitivity of the acetylcholinesterase in the several solid tissues studied (brain, esophagus, stomach, duodenum, heart, diaphragm, lung and red blood cells) to inhibition by chlorpyrifos-oxon, as indicated by IC_{50} values all within the same order of magnitude. The higher IC_{50} values in plasma logically result from the presence within plasma of other proteins that can be readily inhibited by CPFO (e.g., carboxylesterases) or that can absorb CPFO (e.g., albumin), thus reducing the levels of CPFO that were available to inhibit plasma cholinesterase; lower CPFO bioavailability resulted in a higher IC_{50} value, but it does not necessarily indicate lower inherent sensitivity of plasma cholinesterase. **Study Supplemental**. (Guo, 1/02/14)

342-774 165918 "Standard operating protocol for analysis of the effects of chlorpyrifos, diazinon, and sulfotep on neurite length in differentiating neuroblastoma cells in vitro." This volume is currently in evaluation by another division of DPR, and appears unlikely to be pivotal to Medical Toxicology Branch, based on its title. There are, however, studies in the public literature relating to chlorpyrifos effects on differentiating cells in culture, hence this protocol may be supportive of such a study. C. Aldous, 10/13/99.

Registrant rebuttal responses or commentaries on cholinesterase effects and inter-species extrapolations

342-790 168952 Chen, W. L., R. J. Nolan, and J. L. Mattsson, "Dow AgroSciences' response to the report of the Hazard Identification Assessment Review Committee (HIARC) entitled 'Chlorpyrifos - Hazard Identification Based on Animal Studies'". This record was an evaluation of existing data, and not a report of new data, except for an abstract of a recent human study by Kisicki *et al.* (reviewed as DPR Record No. 168932, see 1-liner below). "Laboratory Study ID" # GH-C 4904. This record was provided to call to question key U.S. EPA conclusions regarding hazard evaluation of chlorpyrifos. **Human clinical sign evaluation:** The cited abstract concluded that the NOEL for RBC AChE was 1 mg/kg, based on 1/12 volunteers having over a 17% decrease in this enzyme at 2 mg/kg. None of the 12 volunteers at the highest dose of 2 mg/kg experienced clinical symptoms. This result suggest that a single subject presenting signs of "blurred vision, feeling of faintness, and runny nose" in an earlier study at 0.1 mg/kg/day was unlikely to have been responding to chlorpyrifos treatment. **Relevance of RBC AChE vs. BuChE:** Registrants observed that the latter has no known physiological function and no apparent relevance to human hazard assessment. In contrast, RBC AChE is evidently identical to the AChE associated with neuromuscular transmission, hence relevant in human hazard assessment. **Comparative inhibition of AChE from different sources:** Rat studies over the dose range of 10 to 100 mg/kg indicated that RBC AChE had a 12-fold lower ED_{50} than whole brain, hence regulation on blood AChE would protect against cholinergic toxicity. AChE in other tissues was less sensitive to inhibition (i.e. had a higher ED_{50}) than whole brain (p. 22). **Primary conclusions of investigators:** Investigators determined (1) that human data are valid and preferable to animal data in assessing human hazard, (2) that human RBC AChE rather than BuChE should be used to set RfD's, (3) and that the laboratory animal data base (if agencies are determined to use such for human safety assessment) is sufficiently complete that (a) there is no justification for an additional ten-fold safety factor for uncertainties regarding possible special toxicity to infants and children and (b) the comparative blood ChE responses of humans and laboratory animals (for RBC AChE and BuChE) are sufficiently well-characterized that a 10-fold interspecies uncertainty factor is not appropriate. Supportive published articles were included: (1) Chen *et al.* "Human red blood cell acetylcholinesterase inhibition as the appropriate and conservative surrogate endpoint for establishing chlorpyrifos reference dose", **Regulatory Toxicology and Pharmacology 29**, 15-22 (1999), (2) Schardein and Scialli, "The legislation of toxicologic safety factors: The Food Quality Protection Act with chlorpyrifos as a test case", **Reproductive Toxicology 13**, 1-14, 1999, and (3) Gibson, J. E. *et al.*, "How to determine if an additional 10x safety factor is needed for chemicals: A test case with chlorpyrifos", **Toxicological Sciences 48**, 117-122 (1999). No worksheet (no reviewable data). Aldous, 9/14/99.

342-756 162540 Albers, J. W. *et al.*, "Determination of the reference dose for chlorpyrifos: Expert panel report." No date was given for report: cover letter date for volume was 6/19/98. Dow AgroSciences convened a panel of experts, who determined in this 85-page record that (1) multiple studies support an RfD for repeated oral dose exposure of 0.01 mg/kg/day, and (2) the RfD for single oral exposure was determined to be 0.05 mg/kg. There are no new studies, hence no DPR worksheet. Aldous, 10/13/99.

Mechanistic Studies on Serine Hydrolases that Degrade Endocannabinoids

The following studies by R. L. Carr *et al*. explored effects of chlorpyrifos on two serine hydrolase enzymes involved in degradation of endocannabinoid degradation: [monoacylglycerol lipase (MAGL), and fatty acid amide hydrolase (FAAH)]. The associated endocannabinoids were 2-arachidonoylglycerol (2-AG) and anandamide (AEA). The latter are essential in neurodevelopment, but their levels in CNS are controlled by the above enzymes to keep ligand concentrations at optimal levels. Test animals were male and female Sprague-Dawley rat pups, dosed with chlorpyrifos daily by gavage from PND 10 through 16 at up to 5 mg/kg/day. Tissues tested included forebrain, and sometimes midbrain and plasma. Generally cholinesterase (ChE) was assayed in parallel.

(No DPR Record or Document Number) Carr, R. L., A. L. Adams, D. R. Kepler, A. B. Ward, and M. K. Ross, "Induction of endocannabinoid levels in juvenile rat brain following developmental chlorpyrifos exposure," *Toxicological Sciences* **135**(1), 193-201, 2013. Ten-day old Sprague-Dawley rat pups were dosed with chlorpyrifos (99% purity) daily by gavage in corn oil from PND 10 through 16 at 0, 1, 2.5, or 5 mg/kg/day, with groups of 6-8 (blocked by sex and litter) sacrificed at 4, 12, 24, or 48 hours after the last dose. Forebrain ChE, MAGL, and FAAH activities were assayed at these intervals, in addition to forebrain levels of the two endocannabinoids which are primarily degraded respectively by MAGL and FAAH: (2-AG and AEA). Forebrain ChE response was strongest at 12 hours after the last dose, with inhibition of 24%, 55%, and 68% at respective dose levels. ChE inhibition at 48 hours was 9%, 36%, and 46% respectively. MAGL response was strongest at 4 hours, with inhibition of 14%, 24%, and 41% at respective dose levels. MAGL inhibition at 48 hours was 7%, 16%, and 33% respectively. FAAH was more strongly inhibited: inhibition was greatest at 4 to 12 hours after the last dose. Inhibition at 12 hours was 52%, 90%, and 93% at respective dose levels. FAAH inhibition at 48 hours was 16%, 38%, and 48% respectively. Levels of 2-AG were most notably increased at 12 hours, at which time respective treated groups had elevations of 30%, 52%, and 63% over controls (all statistically significant). By 48 hours, there were no significant differences from control, however the 5 mg/kg/day group mean was 19% over control. Levels of AEA were also most notably increased at 12 hours, at which time respective treated groups had elevations of 65%, 128%, and 190% over controls (all statistically significant). By 48 hours, the only significant difference from control was at 5 mg/kg/day group (81% over control). Investigators indicated in their discussion that FAAH is the dominant degradation enzyme for AEA, evidenced by other studies showing nearly complete mitigation of AEA effects when a specific FAAH inhibitor is employed. Investigators noted further that other studies had found that 2-AG is subject to appreciable degradation by enzymes not included in the present study. Investigators concluded that particularly alteration of FAAH activity due to chlorpyrifos may alter neuronal system development at critical stages of growth. There is no DPR worksheet, as only summary data were provided. This is a valid supplementary study. Aldous, 5/13/15.

(No DPR Record or Document Number) Carr, R. L., C. A. Graves, L. C. Mangum, C. A. Nail, and M. K. Ross, "Low level chlorpyrifos exposure increases anandamide accumulation in juvenile rat brain in the absence of brain cholinesterase inhibition," *Neurotoxicology* **43**:82-89 (2014). This work is basically an extension of that described in *Toxicological Sciences* **135**(1), above, assessing the lower dose of 0.5 mg/kg/day from PND 10-16, with sacrifice at 4 and 12 hours. Serum carboxylesterase was inhibited by 94% and 74% at 4 and 12 hours after the last

dose, respectively. Serum cholinesterase was inhibited by 36% and 25% at 4 and 12 hours after the last dose, respectively. Forebrain cholinesterase and forebrain MAGL activities were not altered at this dose. Forebrain FAAH was reduced by 14% at 4 hours (not significant) and by 25% at 12 hours (significant, $p < 0.05$). There was no significant difference in 2-AG in forebrain at 0.5 mg/kg/day, but forebrain AEA levels were increased by 18% at 4 hours and by 37% (significant, $p < 0.05$) at 12 hours. There is no DPR worksheet, as only summary data were provided. This is a valid supplementary study. Aldous, 5/13/15.

(No Document or Record Numbers) Carr, R. L., A. Borazjani, and M. K. Ross, "Effect of developmental chlorpyrifos exposure, on endocannabinoid metabolizing enzymes, in the brain of juvenile rats," Toxicological Sciences 122(1): 112-120 (2011). Male and female Sprague-Dawley rats were exposed to 0, 1, 2.5, or 5 mg/kg/day chlorpyrifos. Most tests were performed in pups dosed on PND 10-16, with sacrifice 4 hours after the PND 16 treatment. Body weight gains were reduced (dose-related) in 2.5 to 5 mg/kg/day pups. ChE activity (as percent of control) was reduced in respective dose groups of pups by tissue as follows: forebrain (18, 41, and 52%), medulla-pons (18, 38, and 55%), and serum (32, 50, and 55%). Pup forebrain MAGL activity was reduced by 14, 22, and 37% in respective groups. Pup forebrain FAAH activity was reduced by 40, 93, and 96% in respective groups. Investigators used a fluororphosphonate-biotin (FP-biotin) probe to mark serine hydrolase enzymes in PND 16 pups and performed an SDS-PAGE separation, ultimately visualizing the marked enzymes with a chemiluminescent reagent and capturing images on x-ray film. FP-biotin probe analyses found a strong reduction of marked FAAH at 1 mg/kg/day, with no visible presence remaining at higher dose levels. MAGL staining was quite faint, even in controls, but suggested a treatment-related reduction in female pups. Another serine hydrolase enzyme, KIAA 1363, described elsewhere as highly responsive to chlorpyrifos oxon, showed a marked dose-related reduction in this treatment range. Possible importance of the latter was outside of the scope of this article, however other abstracts by Cassidy et al. indicate that spontaneous recovery of KIAA 1363 may be rapid enough to not warrant major concern. MAGL was detectible in membrane fractions but not in cytosolic fractions, when evaluated in pup brain extracts. A specific MAGL inhibitor, JZL184, reduced 2-AG hydrolysis activity to about 55% of control activity at 10 µM, with no additional inhibition at higher dose levels. This suggests that chlorpyrifos effects on MAGL are less likely to elicit profound effects on its substrate levels than effects on FAAH. Investigators concluded that chlorpyrifos inhibition of AEA hydrolysis may be the principal concern for juvenile development, with reduced FAAH enzyme activity as the most plausible cause. There is no DPR worksheet, as data are limited to summary tables and figures. Aldous, 5/14/15.

ADDITIONAL NON-GUIDELINE REPORTS: NOT REVIEWED FOR THIS SUMMARY

342-0976 286275 Miguel A. Sogorb and Eugenio Vilanova, "Serum albumins and detoxication of anti-cholinesterase agents," Chemico-Biological Interactions 187, Issues 1–3, 6 September 2010, Pages 325-329. This published article is of possible general interest in understanding the role that serum albumin plays in hydrolyzing certain cholinergic compounds. The summary data are too brief to review. The abstract follows (Aldous, 4/10/18). Serum albumin displays an esterase activity that is capable of hydrolysing the anti-cholinesterase compounds carbaryl, paraoxon, chlorpyrifos-oxon, diazoxon and O-hexyl, O-2,5-dichlorphenyl phosphoramidate. The

detoxication of all these anti-cholinesterase compounds takes place at significant rates with substrate concentrations in the same order of magnitude as expected during in vivo exposures, even when these substrate concentrations are between 15 and 1300 times lower than the recorded Km constants. Our data suggest that the efficacy of this detoxication system is based on the high concentration of albumin in plasma (and in the rest of the body), and not on the catalytic efficacy itself, which is low for albumin. We conclude the need for a structure–activity relationship study into the albumin-associated esterase activities because this protein is universally present in vertebrates and could compensate for reduced levels of other esterases, i.e., lipoprotein paraoxonase, in some species. It is also remarkable that the biotransformation of xenobiotics can be reliably studied in vitro, although conditions as similar as possible to in vivo situations are necessary.

Record Number 275321 Epidemiology studies pertaining to chlorpyrifos exposures: considerations of reliability and utility
DPR Received Date: 12/13/2013
Study Date:
Document Number: 342-0952

Record Number 279907 Development of chemical specific adjustment factors for chlorpyrifos and chlorpyrifos oxon
DPR Received Date: 09/04/2014
Source: The Dow Chemical Company Midland, Michigan
Study Date: 10/31/2013
Document Number: 342-0960

Record Number 282730 In vitro age-dependent enzymatic metabolism of chlorpyrifos and chlorpyrifos-oxon in human hepatic microsomes and chlorpyrifos-oxon in plasma (journal article)
DPR Received Date: 01/20/2015
Document Number: 342-0965

Record Number 281309 Chlorpyrifos reevaluation in California toxicology research in support of chlorpyrifos (pt.1-2)
DPR Received Date: 11/18/2014
Source: Dow AgroSciences Indianapolis, IN
Study Date: 11/17/2014
Document Number: 342-0964

Record Number 282735 In vitro rat hepatic and intestinal metabolism of the organophosphate pesticides chlorpyrifos and diazinon (journal article)
DPR Received Date: 01/20/2015
Document Number: 342-0965

Record Number 282734 Age-dependent pharmacokinetic and pharmacodynamic response in preweanling rats following oral exposure to the organophosphorus insecticide chlorpyrifos (journal article)

DPR Received Date: 01/20/2015
Document Number: 342-0965

Record Number 282731 The effects of plasma lipids on the pharmacokinetics of chlorpyrifos and the impact on interpretation of blood biomonitoring data (journal article)
DPR Received Date: 01/20/2015
Study Date: 02/17/2009
Document Number: 342-0965

Record Number 282729 A human life-stage physiologically based pharmacokinetic and pharmacodynamic modeling for chlorpyrifos: development and validation (journal article)
DPR Received Date: 01/20/2015
Document Number: 342-0965

Record Number 282486 Using PBPK/PD modeling for assessing the toxicity of chlorpyrifos and the risks from current and historical exposures
DPR Received Date: 01/20/2015
Study Date: 12/08/2014
Document Number: 342-0965

Record Number 282559 Chlorpyrifos PBPK/PD modeling for multiple routes of exposure
DPR Received Date: 01/20/2015
Source: Summit Toxicology, L.L.P. Allenspark, CO
Study Date: 11/08/2013
Document Number: 342-0965

Record Number 282740 Serum albumin is as efficient as paraoxonase in the detoxication of paraoxon at toxicologically relevant concentrations (journal article)
DPR Received Date: 01/20/2015
Document Number: 342-0965

Record Number 282741 Cytochrome P450-specific human PBPK/PD models for the organophosphorus pesticides: chlorpyrifos and parathion (journal article)
DPR Received Date: 01/20/2015
Document Number: 342-0965

Record Number 282653 Application of a source-to-outcome model for the assessment of health impacts from dietary exposures to insecticide residues (journal article)
DPR Received Date: 01/20/2015
Document Number: 342-0965

Record Number 282557 Physiologically based pharmacokinetic/pharmacodynamic (PBPK/PD) modeling of dermal exposure to chlorpyrifos: validation and application to mixed oral and dermal exposures
DPR Received Date: 01/20/2015
Source: Battelle Pacific Northwest Laboratories Richland, WA

Study Date: 03/05/2013
Document Number: 342-0965

Record Number 279905 A human life-stage physiologically based pharmacokinetic and pharmacodynamic model for chlorpyrifos: development and validation (journal article)
DPR Received Date: 09/04/2014
Document Number: 342-0960

Record Number 282736 A physiologically based pharmacokinetic and pharmacodynamic (PBPK/PD) model for the organophosphate insecticide chlorpyrifos in rats and humans (journal article)
DPR Received Date: 01/20/2015
Document Number: 342-0965

Record Number 282558 Physiologically based pharmacokinetic/pharmacodynamic (PBPK/PD) modeling of oral exposure to chlorpyrifos: impact on toxicity adjustment factors
DPR Received Date: 01/20/2015
Source: Battelle Pacific Northwest Laboratories Richland, WA
Study Date: 01/25/2013
Document Number: 342-0965

Record Number 282737 Physiologically based pharmacokinetic and pharmacodynamic model for the inhibition of acetylcholinesterase by diisopropylfluorophosphate (journal article)
DPR Received Date: 01/20/2015
Document Number: 342-0965

Record Number 282728 Chlorpyrifos PBPK/PD model for multiple routes of exposure (journal article)
DPR Received Date: 01/20/2015
Document Number: 342-0965

Record Number 282727 Development of a source-to-outcome model for dietary exposures to insecticide residues: an example using chlorpyrifos (journal article)
DPR Received Date: 01/20/2015
Document Number: 342-0965

Record Number 274124 In vitro sensitivity of cholinesterase to inhibition by chlorpyrifos-oxon in several tissues of the rat
DPR Received Date: 10/03/2013
Document Number: 342-0951

Record Number 279906 Chlorpyrifos PBPK/PD model for multiple routes of exposure (journal article)
DPR Received Date: 09/04/2014
Document Number: 342-0960

Record Number 282738 Reduced birth weight in relation to pesticide mixtures detected in cord blood of full-term infants (journal article)
DPR Received Date: 01/20/2015
Document Number: 342-0965

Record Number 282739 Human paraoxonase 1 hydrolysis of nanomolar chlorpyrifos-oxon concentrations is unaffected by phenotype or q192r genotype (journal article)
DPR Received Date: 01/20/2015
Document Number: 342-0965

Record Number 948107) Clinical toxicity of Dursban in dog after multiple applications of aerosol formulation (18P.)
DPR Received Date:
Source: Dow Chemical U.S.A. Midland, MI
Study Date: 12/01/1968
Document Number: 342-0119

Record Number 948135) Comparison of cholinesterase depression in humans and rabbits following exposure to Chlorpyrifos (22 pp.)
DPR Received Date:
Source: Dow Chemical U.S.A. Midland, MI
Study Date: 08/01/1971
Document Number: 342-0032

APPENDIX 2.

EXPOSURE ESTIMATES AND MARGINS OF EXPOSURE FOR DEVELOPMENTAL NEUROTOXICITY

Appendix 2a - Drift Exposure for Infants with Aerial Application of Chlorpyrifos

EAS EXPOSURE ESTIMATES												
Drift-Modeling - AGDISP				Dermal Dose		Incidental Oral Dose				1-hr TWA air conc.* (mg/m3)	Inhalation Dose (mg/kg/day)	Drift ADD (mg/kg/day)
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	External PBPK (mg/kg/day)	9.6% Absorption (mg/kg/day)	Hand to-Mouth (mg/kg/day)	Oral-to-Mouth (mg/kg/day)	Soil Ingestion (mg/kg/day)	Combined (mg/kg/day)			
AT 802A	2	1	25	0.0517238	0.0049655	0.0010761	0.0000330	0.0000080	0.0011171	0.0292	0.0007178	0.0068005
AT 802A	2	1	50	0.0407100	0.0039082	0.0008469	0.0000260	0.0000063	0.0008793	0.0264	0.0006490	0.0054364
AT 802A	2	1	100	0.0274241	0.0026327	0.0005705	0.0000175	0.0000043	0.0005923	0.0220	0.0005408	0.0037658
AT 802A	2	1	250	0.0142959	0.0013724	0.0002974	0.0000091	0.0000022	0.0003088	0.0161	0.0003958	0.0020770
AT 802A	2	1	500	0.0085207	0.0008180	0.0001773	0.0000054	0.0000013	0.0001840	0.0117	0.0002876	0.0012896
AT 802A	2	1	1000	0.0045444	0.0004363	0.0000945	0.0000029	0.0000007	0.0000981	0.0065	0.0001598	0.0006942
AT 802A	2	1	1320	0.0029665	0.0002848	0.0000617	0.0000019	0.0000005	0.0000641	0.0046	0.0001128	0.0004617
AT 802A	2	1	2608	0.0005365	0.0000515	0.0000112	0.0000003	0.0000001	0.0000116	0.0016	0.0000396	0.0001027
Bell 205 Helicopter	2	1	25	0.0490098	0.0047049	0.0010196	0.0000313	0.0000076	0.0010585	0.0336	0.0008260	0.0065895
Bell 205 Helicopter	2	1	50	0.0300118	0.0028811	0.0006244	0.0000192	0.0000047	0.0006482	0.0274	0.0006736	0.0042029
Bell 205 Helicopter	2	1	100	0.0182406	0.0017511	0.0003795	0.0000116	0.0000028	0.0003940	0.0219	0.0005384	0.0026834
Bell 205 Helicopter	2	1	250	0.0116450	0.0011179	0.0002423	0.0000074	0.0000018	0.0002515	0.0153	0.0003761	0.0017455
Bell 205 Helicopter	2	1	500	0.0069112	0.0006635	0.0001438	0.0000044	0.0000011	0.0001493	0.0102	0.0002508	0.0010635
Bell 205 Helicopter	2	1	1000	0.0033767	0.0003242	0.0000702	0.0000022	0.0000005	0.0000729	0.0058	0.0001426	0.0005397
Bell 205 Helicopter	2	1	1320	0.0023669	0.0002272	0.0000492	0.0000015	0.0000004	0.0000511	0.0045	0.0001101	0.0003885
Bell 205 Helicopter	2	1	2608	0.0003787	0.0000364	0.0000079	0.0000002	0.0000001	0.0000082	0.0020	0.0000502	0.0000947
AT 802A	2	2	25	0.1035108	0.0099370	0.0021535	0.0000661	0.0000161	0.0022356	0.0493	0.0012120	0.0133846
AT 802A	2	2	50	0.0811676	0.0077921	0.0016886	0.0000518	0.0000126	0.0017531	0.0437	0.0010743	0.0106194
AT 802A	2	2	100	0.0542169	0.0052048	0.0011279	0.0000346	0.0000084	0.0011710	0.0350	0.0008604	0.0072362
AT 802A	2	2	250	0.0271400	0.0026054	0.0005646	0.0000173	0.0000042	0.0005862	0.0237	0.0005826	0.0037742
AT 802A	2	2	500	0.0147692	0.0014178	0.0003073	0.0000094	0.0000023	0.0003190	0.0153	0.0003761	0.0021130
AT 802A	2	2	1000	0.0058067	0.0005574	0.0001208	0.0000037	0.0000009	0.0001254	0.0072	0.0001770	0.0008599
AT 802A	2	2	1320	0.0034083	0.0003272	0.0000709	0.0000022	0.0000005	0.0000736	0.0049	0.0001210	0.0005218
AT 802A	2	2	2608	0.0006312	0.0000606	0.0000131	0.0000004	0.0000001	0.0000136	0.0016	0.0000401	0.0001143
Bell 205 Helicopter	2	2	25	0.0993451	0.0095371	0.0020668	0.0000634	0.0000154	0.0021457	0.0580	0.0014258	0.0131086
Bell 205 Helicopter	2	2	50	0.0611597	0.0058713	0.0012724	0.0000391	0.0000095	0.0013209	0.0458	0.0011259	0.0083182
Bell 205 Helicopter	2	2	100	0.0380592	0.0036537	0.0007918	0.0000243	0.0000059	0.0008220	0.0345	0.0008481	0.0053238
Bell 205 Helicopter	2	2	250	0.0210809	0.0020238	0.0004386	0.0000135	0.0000033	0.0004553	0.0215	0.0005285	0.0030076
Bell 205 Helicopter	2	2	500	0.0107929	0.0010361	0.0002245	0.0000069	0.0000017	0.0002331	0.0130	0.0003196	0.0015888
Bell 205 Helicopter	2	2	1000	0.0047337	0.0004544	0.0000985	0.0000030	0.0000007	0.0001022	0.0068	0.0001672	0.0007238
Bell 205 Helicopter	2	2	1320	0.0030296	0.0002908	0.0000630	0.0000019	0.0000005	0.0000654	0.0050	0.0001227	0.0004789
Bell 205 Helicopter	2	2	2608	0.0005049	0.0000485	0.0000105	0.0000003	0.0000001	0.0000109	0.0022	0.0000538	0.0001132
AT 802A	2	2.3	25	0.1189648	0.0114206	0.0024750	0.0000760	0.0000185	0.0025694	0.0526	0.0012926	0.0152826
AT 802A	2	2.3	50	0.0931976	0.0089470	0.0019389	0.0000595	0.0000145	0.0020129	0.0464	0.0011417	0.0121015
AT 802A	2	2.3	100	0.0621317	0.0059646	0.0012926	0.0000397	0.0000096	0.0013419	0.0371	0.0009130	0.0082196
AT 802A	2	2.3	250	0.0310659	0.0029823	0.0006463	0.0000198	0.0000048	0.0006710	0.0250	0.0006138	0.0042671
AT 802A	2	2.3	500	0.0164765	0.0015817	0.0003428	0.0000105	0.0000026	0.0003559	0.0159	0.0003899	0.0023275
AT 802A	2	2.3	1000	0.0063874	0.0006132	0.0001329	0.0000041	0.0000010	0.0001380	0.0075	0.0001834	0.0009345
AT 802A	2	2.3	1320	0.0036292	0.0003484	0.0000755	0.0000023	0.0000006	0.0000784	0.0051	0.0001254	0.0005522
AT 802A	2	2.3	2608	0.0007984	0.0000766	0.0000166	0.0000005	0.0000001	0.0000172	0.0017	0.0000413	0.0001352
Bell 205 Helicopter	2	2.3	25	0.1143195	0.0109747	0.0023783	0.0000730	0.0000177	0.0024691	0.0611	0.0015020	0.0149458
Bell 205 Helicopter	2	2.3	50	0.0704063	0.0067590	0.0014647	0.0000450	0.0000109	0.0015206	0.0482	0.0011854	0.0094650
Bell 205 Helicopter	2	2.3	100	0.0439132	0.0042157	0.0009136	0.0000280	0.0000068	0.0009484	0.0362	0.0008902	0.0060543
Bell 205 Helicopter	2	2.3	250	0.0238075	0.0022855	0.0004953	0.0000152	0.0000037	0.0005142	0.0222	0.0005453	0.0033450
Bell 205 Helicopter	2	2.3	500	0.0119763	0.0011497	0.0002492	0.0000076	0.0000019	0.0002587	0.0133	0.0003267	0.0017351
Bell 205 Helicopter	2	2.3	1000	0.0051534	0.0004947	0.0001072	0.0000033	0.0000008	0.0001113	0.0069	0.0001689	0.0007749
Bell 205 Helicopter	2	2.3	1320	0.0032663	0.0003136	0.0000680	0.0000021	0.0000005	0.0000705	0.0050	0.0001239	0.0005080
Bell 205 Helicopter	2	2.3	2608	0.0006533	0.0000627	0.0000136	0.0000004	0.0000001	0.0000141	0.0023	0.0000553	0.0001321

*Breathing height was assumed to be 1.7 ft.

Abbreviations: TWA = Time Weighted Average, ADD = Absorbed Daily Dose.

Appendix 2a - Drift Exposure for Infants with Aerial Application of Chlorpyrifos

EAS EXPOSURE ESTIMATES												
Drift-Modeling - AGDISP				Dermal Dose		Incidental Oral Dose				1-hr TWA air conc.* (mg/m3)	Inhalation Dose (mg/kg/day)	Drift ADD (mg/kg/day)
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	external PBPK (mg/kg/day)	9.6% absorption (mg/kg/day)	Hand to-Mouth (mg/kg/day)	Oral-to-Mouth (mg/kg/day)	Soil Ingestion (mg/kg/day)	Combined (mg/kg/day)			
AT 802A	15	1	25	0.0444655	0.0042687	0.0009251	0.0000284	0.0000069	0.0009604	0.0413	0.0010155	0.0062446
AT 802A	15	1	50	0.0355661	0.0034143	0.0007399	0.0000227	0.0000055	0.0007682	0.0391	0.0009607	0.0051432
AT 802A	15	1	100	0.0237949	0.0022843	0.0004950	0.0000152	0.0000037	0.0005139	0.0348	0.0008557	0.0036540
AT 802A	15	1	250	0.0122130	0.0011724	0.0002541	0.0000078	0.0000019	0.0002638	0.0289	0.0007110	0.0021472
AT 802A	15	1	500	0.0075740	0.0007271	0.0001576	0.0000048	0.0000012	0.0001636	0.0243	0.0005971	0.0014878
AT 802A	15	1	1000	0.0056489	0.0005423	0.0001175	0.0000036	0.0000009	0.0001220	0.0190	0.0004661	0.0011304
AT 802A	15	1	1320	0.0051124	0.0004908	0.0001064	0.0000033	0.0000008	0.0001104	0.0164	0.0004034	0.0010046
AT 802A	15	1	2608	0.0015148	0.0001454	0.0000315	0.0000010	0.0000002	0.0000327	0.0090	0.0002208	0.0003989
Bell 205 Helicopter	15	1	25	0.0442761	0.0042505	0.0009211	0.0000283	0.0000069	0.0009563	0.0592	0.0014558	0.0066626
Bell 205 Helicopter	15	1	50	0.0256884	0.0024661	0.0005344	0.0000164	0.0000040	0.0005548	0.0517	0.0012705	0.0042914
Bell 205 Helicopter	15	1	100	0.0148955	0.0014300	0.0003099	0.0000095	0.0000023	0.0003217	0.0448	0.0011023	0.0028540
Bell 205 Helicopter	15	1	250	0.0103511	0.0009937	0.0002153	0.0000066	0.0000016	0.0002236	0.0367	0.0009012	0.0021185
Bell 205 Helicopter	15	1	500	0.0077633	0.0007453	0.0001615	0.0000050	0.0000012	0.0001677	0.0288	0.0007090	0.0016219
Bell 205 Helicopter	15	1	1000	0.0050809	0.0004878	0.0001057	0.0000032	0.0000008	0.0001097	0.0202	0.0004973	0.0010948
Bell 205 Helicopter	15	1	1320	0.0040710	0.0003908	0.0000847	0.0000026	0.0000006	0.0000879	0.0150	0.0003675	0.0008463
Bell 205 Helicopter	15	1	2608	0.0006627	0.0000636	0.0000138	0.0000004	0.0000001	0.0000143	0.0080	0.0001969	0.0002748
AT 802A	15	2	25	0.0929073	0.0089191	0.0019329	0.0000593	0.0000144	0.0020066	0.0703	0.0017277	0.0126534
AT 802A	15	2	50	0.0748560	0.0071862	0.0015573	0.0000478	0.0000116	0.0016167	0.0660	0.0016220	0.0104249
AT 802A	15	2	100	0.0509980	0.0048958	0.0010610	0.0000326	0.0000079	0.0011015	0.0579	0.0014224	0.0074197
AT 802A	15	2	250	0.0268244	0.0025751	0.0005581	0.0000171	0.0000042	0.0005794	0.0468	0.0011500	0.0043045
AT 802A	15	2	500	0.0171045	0.0016420	0.0003558	0.0000109	0.0000027	0.0003694	0.0381	0.0009369	0.0029483
AT 802A	15	2	1000	0.0124339	0.0011937	0.0002587	0.0000079	0.0000019	0.0002685	0.0279	0.0006849	0.0021471
AT 802A	15	2	1320	0.0107929	0.0010361	0.0002245	0.0000069	0.0000017	0.0002331	0.0227	0.0005585	0.0018278
AT 802A	15	2	2608	0.0025878	0.0002484	0.0000538	0.0000017	0.0000004	0.0000559	0.0103	0.0002535	0.0005578
Bell 205 Helicopter	15	2	25	0.0922130	0.0088524	0.0019184	0.0000589	0.0000143	0.0019916	0.0828	0.0020360	0.0128801
Bell 205 Helicopter	15	2	50	0.0549112	0.0052715	0.0011424	0.0000351	0.0000085	0.0011860	0.0715	0.0017575	0.0082149
Bell 205 Helicopter	15	2	100	0.0325049	0.0031205	0.0006762	0.0000208	0.0000050	0.0007020	0.0612	0.0015038	0.0053263
Bell 205 Helicopter	15	2	250	0.0227219	0.0021813	0.0004727	0.0000145	0.0000035	0.0004907	0.0488	0.0011997	0.0038717
Bell 205 Helicopter	15	2	500	0.0161578	0.0015511	0.0003361	0.0000103	0.0000025	0.0003490	0.0373	0.0009167	0.0028168
Bell 205 Helicopter	15	2	1000	0.0097830	0.0009392	0.0002035	0.0000062	0.0000015	0.0002113	0.0252	0.0006200	0.0017705
Bell 205 Helicopter	15	2	1320	0.0074477	0.0007150	0.0001549	0.0000048	0.0000012	0.0001609	0.0207	0.0005079	0.0013837
Bell 205 Helicopter	15	2	2608	0.0013254	0.0001272	0.0000276	0.0000008	0.0000002	0.0000286	0.0115	0.0002822	0.0004381
AT 802A	15	2.3	25	0.1074240	0.0103127	0.0022349	0.0000686	0.0000167	0.0023201	0.0779	0.0019143	0.0145472
AT 802A	15	2.3	50	0.0866651	0.0083198	0.0018030	0.0000553	0.0000135	0.0018718	0.0730	0.0017941	0.0119857
AT 802A	15	2.3	100	0.0590106	0.0056650	0.0012277	0.0000377	0.0000092	0.0012745	0.0637	0.0015652	0.0085048
AT 802A	15	2.3	250	0.0311384	0.0029893	0.0006478	0.0000199	0.0000048	0.0006725	0.0513	0.0012609	0.0049227
AT 802A	15	2.3	500	0.0198154	0.0019023	0.0004122	0.0000127	0.0000031	0.0004280	0.0415	0.0010200	0.0033502
AT 802A	15	2.3	1000	0.0143716	0.0013797	0.0002990	0.0000092	0.0000022	0.0003104	0.0299	0.0007341	0.0024241
AT 802A	15	2.3	1320	0.0121215	0.0011637	0.0002522	0.0000077	0.0000019	0.0002618	0.0241	0.0005920	0.0020174
AT 802A	15	2.3	2608	0.0029759	0.0002857	0.0000619	0.0000019	0.0000005	0.0000643	0.0106	0.0002613	0.0006113
Bell 205 Helicopter	15	2.3	25	0.1068433	0.0102570	0.0022228	0.0000682	0.0000166	0.0023076	0.0917	0.0022540	0.0148186
Bell 205 Helicopter	15	2.3	50	0.0638012	0.0061249	0.0013273	0.0000407	0.0000099	0.0013780	0.0789	0.0019396	0.0094425
Bell 205 Helicopter	15	2.3	100	0.0378887	0.0036373	0.0007882	0.0000242	0.0000059	0.0008183	0.0671	0.0016486	0.0061042
Bell 205 Helicopter	15	2.3	250	0.0262753	0.0025224	0.0005466	0.0000168	0.0000041	0.0005675	0.0532	0.0013071	0.0043970
Bell 205 Helicopter	15	2.3	500	0.0184363	0.0017699	0.0003836	0.0000118	0.0000029	0.0003982	0.0402	0.0009887	0.0031568
Bell 205 Helicopter	15	2.3	1000	0.0111779	0.0010731	0.0002325	0.0000071	0.0000017	0.0002414	0.0269	0.0006606	0.0019751
Bell 205 Helicopter	15	2.3	1320	0.0084923	0.0008153	0.0001767	0.0000054	0.0000013	0.0001834	0.0220	0.0005401	0.0015388
Bell 205 Helicopter	15	2.3	2608	0.0015243	0.0001463	0.0000317	0.0000010	0.0000002	0.0000329	0.0127	0.0003115	0.0004907

*Breathing height was assumed to be 1.7 ft.

Abbreviations: TWA = Time Weighted Average, ADD = Absorbed Daily Dose.

Appendix 2a - Drift Exposure for Infants with Aerial Application of Chlorpyrifos

RAS RISK CALCULATIONS								
Drift-Modeling - AGDISP				Margins of Exposure[a]				
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	Dermal	Combined Incidental Oral	Inhalation	Combined Drift	Combined Drift, Diet & Drinking Water[b]
AT 802A	2	1	25	2	9	14	1	1
AT 802A	2	1	50	3	11	15	2	2
AT 802A	2	1	100	4	17	18	3	2
AT 802A	2	1	250	7	32	25	5	4
AT 802A	2	1	500	12	54	35	8	5
AT 802A	2	1	1000	23	102	63	14	7
AT 802A	2	1	1320	35	156	89	22	9
AT 802A	2	1	2608	194	863	253	97	12
Bell 205 Helicopter	2	1	25	2	9	12	2	1
Bell 205 Helicopter	2	1	50	3	15	15	2	2
Bell 205 Helicopter	2	1	100	6	25	19	4	3
Bell 205 Helicopter	2	1	250	9	40	27	6	4
Bell 205 Helicopter	2	1	500	15	67	40	9	6
Bell 205 Helicopter	2	1	1000	31	137	70	19	8
Bell 205 Helicopter	2	1	1320	44	196	91	26	9
Bell 205 Helicopter	2	1	2608	275	1223	199	106	12
AT 802A	2	2	25	1	4	8	<1	<1
AT 802A	2	2	50	1	6	9	<1	<1
AT 802A	2	2	100	2	9	12	1	1
AT 802A	2	2	250	4	17	17	3	2
AT 802A	2	2	500	7	31	27	5	4
AT 802A	2	2	1000	18	80	56	12	6
AT 802A	2	2	1320	31	136	83	19	8
AT 802A	2	2	2608	165	734	250	87	12
Bell 205 Helicopter	2	2	25	1	5	7	<1	<1
Bell 205 Helicopter	2	2	50	2	8	9	1	1
Bell 205 Helicopter	2	2	100	3	12	12	2	2
Bell 205 Helicopter	2	2	250	5	22	19	3	3
Bell 205 Helicopter	2	2	500	10	43	31	6	4
Bell 205 Helicopter	2	2	1000	22	98	60	14	7
Bell 205 Helicopter	2	2	1320	34	153	82	21	8
Bell 205 Helicopter	2	2	2608	206	917	186	88	12
AT 802A	2	2.3	25	<1	4	8	<1	<1
AT 802A	2	2.3	50	1	5	9	<1	<1
AT 802A	2	2.3	100	2	7	11	1	1
AT 802A	2	2.3	250	3	15	16	2	2
AT 802A	2	2.3	500	6	28	26	4	3
AT 802A	2	2.3	1000	16	72	55	11	6
AT 802A	2	2.3	1320	29	128	80	18	8
AT 802A	2	2.3	2608	130	580	242	74	12
Bell 205 Helicopter	2	2.3	25	<1	4	7	<1	<1
Bell 205 Helicopter	2	2.3	50	1	7	8	1	<1
Bell 205 Helicopter	2	2.3	100	2	11	11	2	1
Bell 205 Helicopter	2	2.3	250	4	19	18	3	2
Bell 205 Helicopter	2	2.3	500	9	39	31	6	4
Bell 205 Helicopter	2	2.3	1000	20	90	59	13	7
Bell 205 Helicopter	2	2.3	1320	32	142	81	20	8
Bell 205 Helicopter	2	2.3	2608	159	709	181	76	12

a/ Margin of Exposure = NOEL / Exposure. NOEL = 0.01 mg/kg based on ↑ anxiety and locomotor activity in PND21 male rats (Silva et al 2017).
b/Acute dietary exposure estimate for infants was 0.00027 mg/kg/day at the 99.9th percentile consumption rate. Acute drinking water exposure estimated for infants was 0.000439 mg/kg/day at the 99.9th percentile consumption rate for DPR's surface water monitoring data.

Appendix 2a - Drift Exposure for Infants with Aerial Application of Chlorpyrifos

RAS RISK CALCULATIONS								
Drift-Modeling - AGDISP				Margins of Exposure[a]				
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	Dermal	Combined Incidental Oral	Inhalation	Combined Drift	Combined Drift, Diet & Drinking Water[b]
AT 802A	15	1	25	2	10	10	2	1
AT 802A	15	1	50	3	13	10	2	2
AT 802A	15	1	100	4	19	12	3	2
AT 802A	15	1	250	9	38	14	5	4
AT 802A	15	1	500	14	61	17	7	5
AT 802A	15	1	1000	18	82	21	9	5
AT 802A	15	1	1320	20	91	25	10	6
AT 802A	15	1	2608	69	306	45	25	9
Bell 205 Helicopter	15	1	25	2	10	7	2	1
Bell 205 Helicopter	15	1	50	4	18	8	2	2
Bell 205 Helicopter	15	1	100	7	31	9	4	3
Bell 205 Helicopter	15	1	250	10	45	11	5	4
Bell 205 Helicopter	15	1	500	13	60	14	6	4
Bell 205 Helicopter	15	1	1000	21	91	20	9	6
Bell 205 Helicopter	15	1	1320	26	114	27	12	6
Bell 205 Helicopter	15	1	2608	157	699	51	36	10
AT 802A	15	2	25	1	5	6	<1	<1
AT 802A	15	2	50	1	6	6	<1	<1
AT 802A	15	2	100	2	9	7	1	1
AT 802A	15	2	250	4	17	9	2	2
AT 802A	15	2	500	6	27	11	3	3
AT 802A	15	2	1000	8	37	15	5	4
AT 802A	15	2	1320	10	43	18	5	4
AT 802A	15	2	2608	40	179	39	18	8
Bell 205 Helicopter	15	2	25	1	5	5	<1	<1
Bell 205 Helicopter	15	2	50	2	8	6	1	1
Bell 205 Helicopter	15	2	100	3	14	7	2	2
Bell 205 Helicopter	15	2	250	5	20	8	3	2
Bell 205 Helicopter	15	2	500	6	29	11	4	3
Bell 205 Helicopter	15	2	1000	11	47	16	6	4
Bell 205 Helicopter	15	2	1320	14	62	20	7	5
Bell 205 Helicopter	15	2	2608	79	349	35	23	9
AT 802A	15	2.3	25	<1	4	5	<1	<1
AT 802A	15	2.3	50	1	5	6	<1	<1
AT 802A	15	2.3	100	2	8	6	1	1
AT 802A	15	2.3	250	3	15	8	2	2
AT 802A	15	2.3	500	5	23	10	3	2
AT 802A	15	2.3	1000	7	32	14	4	3
AT 802A	15	2.3	1320	9	38	17	5	4
AT 802A	15	2.3	2608	35	156	38	16	8
Bell 205 Helicopter	15	2.3	25	<1	4	4	<1	<1
Bell 205 Helicopter	15	2.3	50	2	7	5	1	<1
Bell 205 Helicopter	15	2.3	100	3	12	6	2	1
Bell 205 Helicopter	15	2.3	250	4	18	8	2	2
Bell 205 Helicopter	15	2.3	500	6	25	10	3	3
Bell 205 Helicopter	15	2.3	1000	9	41	15	5	4
Bell 205 Helicopter	15	2.3	1320	12	55	19	6	4
Bell 205 Helicopter	15	2.3	2608	68	304	32	20	8

a/ Margin of Exposure = NOEL / Exposure. NOEL = 0.01 mg/kg based on ↑ anxiety and locomotor activity in PND21 male rats (Silva et al 2017).
b/Acute dietary exposure estimate for infants was 0.00027 mg/kg/day at the 99.9th percentile consumption rate. Acute drinking water exposure estimated for infants was 0.000439 mg/kg/day at the 99.9th percentile consumption rate for DPR's surface water monitoring data.

Appendix 2b - Drift Exposure for Infants with Airblast Application of Chlorpyrifos

EAS EXPOSURE ESTIMATES												
Orchard Airblast - Dormant Apple - 60 Swath												
Drift Modeling - AgDRIFT				Dermal Dose		Incidental Oral Dose						
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	external PBPK (mg/kg/day)	9.6% absorption (mg/kg/day)	Hand-to-Mouth (mg/kg/day)	Object-to-Mouth (mg/kg/day)	Soil Ingestion (mg/kg/day)	Combined (mg/kg/day)	1-hr TWA air conc.* (mg/m3)	Inhalation Dose (mg/kg/day)	Drift ADD (mg/kg/day)
AT 802A	2	1	25	0.0174674	0.0016769	0.0003634	0.0000112	0.0000027	0.0003773	0.0292	0.0007178	0.0027720
AT 802A	2	1	50	0.0066462	0.0006380	0.0001383	0.0000042	0.0000010	0.0001435	0.0264	0.0006490	0.0014306
AT 802A	2	1	75	0.0032600	0.0003130	0.0000678	0.0000021	0.0000005	0.0000704	0.0239	0.0005870	0.0009703
AT 802A	2	1	100	0.0018525	0.0001778	0.0000385	0.0000012	0.0000003	0.0000400	0.0220	0.0005408	0.0007587
AT 802A	2	1	150	0.0007826	0.0000751	0.0000163	0.0000005	0.0000001	0.0000169	0.0194	0.0004759	0.0005679
AT 802A	2	1	200	0.0004134	0.0000397	0.0000086	0.0000003	0.0000001	0.0000089	0.0175	0.0004306	0.0004792
AT 802A	2	1	250	0.0002493	0.0000239	0.0000052	0.0000002	0.0000000	0.0000054	0.0161	0.0003958	0.0004251
AT 802A	2	1	300	0.0001609	0.0000155	0.0000033	0.0000001	0.0000000	0.0000035	0.0149	0.0003675	0.0003864
AT 802A	2	1	500	0.0000442	0.0000042	0.0000009	0.0000000	0.0000000	0.0000010	0.0117	0.0002876	0.0002928
AT 802A	2	1	1000	0.0000081	0.0000008	0.0000002	0.0000000	0.0000000	0.0000002	0.0065	0.0001598	0.0001607
AT 802A	2	1	1320	0.0000041	0.0000004	0.0000001	0.0000000	0.0000000	0.0000001	0.0046	0.0001131	0.0001136
AT 802A	2	1	2608	0.0000007	0.0000001	0.0000000	0.0000000	0.0000000	0.0000000	0.0016	0.0000393	0.0000394
AT 802A	2	2	25	0.0349349	0.0033538	0.0007268	0.0000223	0.0000054	0.0007545	0.0493	0.0012120	0.0053202
AT 802A	2	2	50	0.0132923	0.0012761	0.0002765	0.0000085	0.0000021	0.0002871	0.0437	0.0010743	0.0026374
AT 802A	2	2	75	0.0065199	0.0006259	0.0001356	0.0000042	0.0000010	0.0001408	0.0386	0.0009488	0.0017155
AT 802A	2	2	100	0.0037049	0.0003557	0.0000771	0.0000024	0.0000006	0.0000800	0.0350000	0.0008604	0.0012961
AT 802A	2	2	150	0.0015653	0.0001503	0.0000326	0.0000010	0.0000002	0.0000338	0.0300	0.0007368	0.0009209
AT 802A	2	2	200	0.0008268	0.0000794	0.0000172	0.0000005	0.0000001	0.0000179	0.0264	0.0006498	0.0007470
AT 802A	2	2	250	0.0004986	0.0000479	0.0000104	0.0000003	0.0000001	0.0000108	0.0237	0.0005826	0.0006413
AT 802A	2	2	300	0.0003219	0.0000309	0.0000067	0.0000002	0.0000000	0.0000070	0.0215	0.0005280	0.0005658
AT 802A	2	2	500	0.0000884	0.0000085	0.0000018	0.0000001	0.0000000	0.0000019	0.0153	0.0003761	0.0003865
AT 802A	2	2	1000	0.0000162	0.0000016	0.0000003	0.0000000	0.0000000	0.0000004	0.0072	0.0001770	0.0001789
AT 802A	2	2	1320	0.0000081	0.0000008	0.0000002	0.0000000	0.0000000	0.0000002	0.0049	0.0001205	0.0001214
AT 802A	2	2	2608	0.0000015	0.0000001	0.0000000	0.0000000	0.0000000	0.0000000	0.0016	0.0000393	0.0000395
AT 802A	2	4	25	0.0698698	0.0067075	0.0014536	0.0000446	0.0000108	0.0015091	0.0795	0.0019539	0.0101704
AT 802A	2	4	50	0.0265846	0.0025521	0.0005531	0.0000170	0.0000041	0.0005742	0.0688	0.0016918	0.0048181
AT 802A	2	4	75	0.0130398	0.0012518	0.0002713	0.0000083	0.0000020	0.0002816	0.0594	0.0014610	0.0029944
AT 802A	2	4	100	0.0074099	0.0007113	0.0001542	0.0000047	0.0000012	0.0001600	0.0526	0.0012923	0.0021637
AT 802A	2	4	150	0.0031306	0.0003005	0.0000651	0.0000020	0.0000005	0.0000676	0.0431	0.0010603	0.0014284
AT 802A	2	4	200	0.0016536	0.0001588	0.0000344	0.0000011	0.0000003	0.0000357	0.0367	0.0009025	0.0010969
AT 802A	2	4	250	0.0009972	0.0000957	0.0000207	0.0000006	0.0000002	0.0000215	0.0315	0.0007741	0.0008914
AT 802A	2	4	300	0.0006438	0.0000618	0.0000134	0.0000004	0.0000001	0.0000139	0.0274	0.0006738	0.0007495
AT 802A	2	4	500	0.0001767	0.0000170	0.0000037	0.0000001	0.0000000	0.0000038	0.0176	0.0004322	0.0004530
AT 802A	2	4	1000	0.0000325	0.0000031	0.0000007	0.0000000	0.0000000	0.0000007	0.0076	0.0001878	0.0001916
AT 802A	2	4	1320	0.0000162	0.0000016	0.0000003	0.0000000	0.0000000	0.0000004	0.0051	0.0001259	0.0001278
AT 802A	2	4	2608	0.0000030	0.0000003	0.0000001	0.0000000	0.0000000	0.0000001	0.0019	0.0000460	0.0000463
AT 802A	2	6	25	0.1048047	0.0100613	0.0021804	0.0000669	0.0000163	0.0022636	0.1042	0.0025616	0.0148864
AT 802A	2	6	50	0.0398769	0.0038282	0.0008296	0.0000255	0.0000062	0.0008613	0.0884	0.0021732	0.0068626
AT 802A	2	6	75	0.0195598	0.0018777	0.0004069	0.0000125	0.0000030	0.0004225	0.0752	0.0018488	0.0041490
AT 802A	2	6	100	0.0111148	0.0010670	0.0002312	0.0000071	0.0000017	0.0002401	0.0650	0.0015979	0.0029050
AT 802A	2	6	150	0.0046959	0.0004508	0.0000977	0.0000030	0.0000007	0.0001014	0.0508	0.0012490	0.0018012
AT 802A	2	6	200	0.0024805	0.0002381	0.0000516	0.0000016	0.0000004	0.0000536	0.0414	0.0010190	0.0013107
AT 802A	2	6	250	0.0014959	0.0001436	0.0000311	0.0000010	0.0000002	0.0000323	0.0348	0.0008555	0.0010314
AT 802A	2	6	300	0.0009657	0.0000927	0.0000201	0.0000006	0.0000001	0.0000209	0.0298	0.0007322	0.0008458
AT 802A	2	6	500	0.0002651	0.0000254	0.0000055	0.0000002	0.0000000	0.0000057	0.0179	0.0004400	0.0004712
AT 802A	2	6	1000	0.0000487	0.0000047	0.0000010	0.0000000	0.0000000	0.0000011	0.0077	0.0001893	0.0001950
AT 802A	2	6	1320	0.0000243	0.0000023	0.0000005	0.0000000	0.0000000	0.0000005	0.0052	0.0001278	0.0001307
AT 802A	2	6	2608	0.0000044	0.0000004	0.0000001	0.0000000	0.0000000	0.0000001	0.0020	0.0000492	0.0000497

* AGDISP modeling for AT802A 2GPA with various application rates was used for inhalation surrogates. Therefore, the air concentrations will be the same for airblast and ground boom at the same application rates. Breathing height was assumed to be 1.7 ft.

Abbreviations: TWA = Time Weighted Average, ADD = Absorbed Daily Dose.

Appendix 2b - Drift Exposure for Infants with Airblast Application of Chlorpyrifos

EAS EXPOSURE ESTIMATES												
Orchard Airblast - Sparse Orchard - 60 Swath												
Drift Modeling - AgDRIFT				Dermal Dose		Incidental Oral Dose				1-hr TWA air conc.* (mg/m3)	Inhalation Dose (mg/kg/day)	Drift ADD (mg/kg/day)
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	external PBPK (mg/kg/day)	9.6% absorption (mg/kg/day)	Hand-to-Mouth (mg/kg/day)	Object-to-Mouth (mg/kg/day)	Soil Ingestion (mg/kg/day)	Combined (mg/kg/day)			
AT 802A	2	1	25	0.0141633	0.0013597	0.0002947	0.0000090	0.0000022	0.0003059	0.0292	0.0007178	0.0023834
AT 802A	2	1	50	0.0064505	0.0006192	0.0001342	0.0000041	0.0000010	0.0001393	0.0264	0.0006490	0.0014076
AT 802A	2	1	75	0.0036229	0.0003478	0.0000754	0.0000023	0.0000006	0.0000782	0.0239	0.0005870	0.0010130
AT 802A	2	1	100	0.0023132	0.0002221	0.0000481	0.0000015	0.0000004	0.0000500	0.0220	0.0005408	0.0008129
AT 802A	2	1	150	0.0011771	0.0001130	0.0000245	0.0000008	0.0000002	0.0000254	0.0194	0.0004759	0.0006143
AT 802A	2	1	200	0.0007101	0.0000682	0.0000148	0.0000005	0.0000001	0.0000153	0.0175	0.0004306	0.0005141
AT 802A	2	1	250	0.0004765	0.0000457	0.0000099	0.0000003	0.0000001	0.0000103	0.0161	0.0003958	0.0004518
AT 802A	2	1	300	0.0003408	0.0000327	0.0000071	0.0000002	0.0000001	0.0000074	0.0149	0.0003675	0.0004076
AT 802A	2	1	500	0.0001250	0.0000120	0.0000026	0.0000001	0.0000000	0.0000027	0.0117	0.0002876	0.0003023
AT 802A	2	1	1000	0.0000259	0.0000025	0.0000005	0.0000000	0.0000000	0.0000006	0.0065	0.0001598	0.0001628
AT 802A	2	1	1320	0.0000121	0.0000012	0.0000003	0.0000000	0.0000000	0.0000003	0.0046	0.0001131	0.0001145
AT 802A	2	1	2608	0.0000006	0.0000001	0.0000000	0.0000000	0.0000000	0.0000000	0.0016	0.0000393	0.0000394
AT 802A	2	2	25	0.0283266	0.0027194	0.0005893	0.0000181	0.0000044	0.0006118	0.0493	0.0012120	0.0045431
AT 802A	2	2	50	0.0129010	0.0012385	0.0002684	0.0000082	0.0000020	0.0002786	0.0437	0.0010743	0.0025914
AT 802A	2	2	75	0.0072458	0.0006956	0.0001507	0.0000046	0.0000011	0.0001565	0.0386	0.0009488	0.0018009
AT 802A	2	2	100	0.0046264	0.0004441	0.0000962	0.0000030	0.0000007	0.0000999	0.0350	0.0008604	0.0014045
AT 802A	2	2	150	0.0023542	0.0002260	0.0000490	0.0000015	0.0000004	0.0000508	0.0300	0.0007368	0.0010137
AT 802A	2	2	200	0.0014201	0.0001363	0.0000295	0.0000009	0.0000002	0.0000307	0.0264	0.0006498	0.0008168
AT 802A	2	2	250	0.0009531	0.0000915	0.0000198	0.0000006	0.0000001	0.0000206	0.0237	0.0005826	0.0006947
AT 802A	2	2	300	0.0006817	0.0000654	0.0000142	0.0000004	0.0000001	0.0000147	0.0215	0.0005280	0.0006082
AT 802A	2	2	500	0.0002499	0.0000240	0.0000052	0.0000002	0.0000000	0.0000054	0.0153	0.0003761	0.0004055
AT 802A	2	2	1000	0.0000519	0.0000050	0.0000011	0.0000000	0.0000000	0.0000011	0.0072	0.0001770	0.0001831
AT 802A	2	2	1320	0.0000242	0.0000023	0.0000005	0.0000000	0.0000000	0.0000005	0.0049	0.0001205	0.0001233
AT 802A	2	2	2608	0.0000013	0.0000001	0.0000000	0.0000000	0.0000000	0.0000000	0.0016	0.0000393	0.0000395
AT 802A	2	4	25	0.0566532	0.0054387	0.0011786	0.0000362	0.0000088	0.0012236	0.0795	0.0019539	0.0086162
AT 802A	2	4	50	0.0258020	0.0024770	0.0005368	0.0000165	0.0000040	0.0005573	0.0688	0.0016918	0.0047261
AT 802A	2	4	75	0.0144915	0.0013912	0.0003015	0.0000093	0.0000022	0.0003130	0.0594	0.0014610	0.0031652
AT 802A	2	4	100	0.0092529	0.0008883	0.0001925	0.0000059	0.0000014	0.0001998	0.0526	0.0012923	0.0023805
AT 802A	2	4	150	0.0047085	0.0004520	0.0000980	0.0000030	0.0000007	0.0001017	0.0431	0.0010603	0.0016140
AT 802A	2	4	200	0.0028402	0.0002727	0.0000591	0.0000018	0.0000004	0.0000613	0.0367	0.0009025	0.0012365
AT 802A	2	4	250	0.0019061	0.0001830	0.0000397	0.0000012	0.0000003	0.0000412	0.0315	0.0007741	0.0009983
AT 802A	2	4	300	0.0013633	0.0001309	0.0000284	0.0000009	0.0000002	0.0000294	0.0274	0.0006738	0.0008342
AT 802A	2	4	500	0.0004999	0.0000480	0.0000104	0.0000003	0.0000001	0.0000108	0.0176	0.0004322	0.0004910
AT 802A	2	4	1000	0.0001037	0.0000100	0.0000022	0.0000001	0.0000000	0.0000022	0.0076	0.0001878	0.0002000
AT 802A	2	4	1320	0.0000484	0.0000046	0.0000010	0.0000000	0.0000000	0.0000010	0.0051	0.0001259	0.0001316
AT 802A	2	4	2608	0.0000026	0.0000002	0.0000001	0.0000000	0.0000000	0.0000001	0.0019	0.0000460	0.0000463
AT 802A	2	6	25	0.0849798	0.0081581	0.0017679	0.0000543	0.0000132	0.0018354	0.1042	0.0025616	0.0125550
AT 802A	2	6	50	0.0387029	0.0037155	0.0008052	0.0000247	0.0000060	0.0008359	0.0884	0.0021732	0.0067246
AT 802A	2	6	75	0.0217373	0.0020868	0.0004522	0.0000139	0.0000034	0.0004695	0.0752	0.0018488	0.0044050
AT 802A	2	6	100	0.0138793	0.0013324	0.0002887	0.0000089	0.0000022	0.0002998	0.0650	0.0015979	0.0032301
AT 802A	2	6	150	0.0070627	0.0006780	0.0001469	0.0000045	0.0000011	0.0001525	0.0508	0.0012490	0.0020796
AT 802A	2	6	200	0.0042604	0.0004090	0.0000886	0.0000027	0.0000007	0.0000920	0.0414	0.0010190	0.0015200
AT 802A	2	6	250	0.0028592	0.0002745	0.0000595	0.0000018	0.0000004	0.0000618	0.0348	0.0008555	0.0011917
AT 802A	2	6	300	0.0020450	0.0001963	0.0000425	0.0000013	0.0000003	0.0000442	0.0298	0.0007322	0.0009727
AT 802A	2	6	500	0.0007498	0.0000720	0.0000156	0.0000005	0.0000001	0.0000162	0.0179	0.0004400	0.0005282
AT 802A	2	6	1000	0.0001556	0.0000149	0.0000032	0.0000001	0.0000000	0.0000034	0.0077	0.0001893	0.0002076
AT 802A	2	6	1320	0.0000726	0.0000070	0.0000015	0.0000000	0.0000000	0.0000016	0.0052	0.0001278	0.0001364
AT 802A	2	6	2608	0.0000039	0.0000004	0.0000001	0.0000000	0.0000000	0.0000001	0.0020	0.0000492	0.0000496

* AGDISP modeling for AT802A 2GPA with various application rates was used for inhalation surrogates. Therefore, the air concentrations will be the same for airblast and ground boom at the same application rates. Breathing height was assumed to be 1.7 ft.

Abbreviations: TWA = Time Weighted Average, ADD = Absorbed Daily Dose.

Appendix 2b - Drift Exposure for Infants with Airblast Application of Chlorpyrifos

RAS RISK CALCULATIONS								
Orchard Airblast - Dormant Apple - 60 Swath								
Drift Modeling - AgDRIFT				Margins of Exposure[a]				
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	Dermal	Combined Incidental Oral	Inhalation	Combined Drift	Combined Drift, Diet & Drinking Water[b]
AT 802A	2	1	25	6	27	14	4	3
AT 802A	2	1	50	16	70	15	7	5
AT 802A	2	1	75	32	142	17	10	6
AT 802A	2	1	100	56	250	18	13	7
AT 802A	2	1	150	133	592	21	18	8
AT 802A	2	1	200	252	1120	23	21	8
AT 802A	2	1	250	418	1857	25	24	9
AT 802A	2	1	300	647	2877	27	26	9
AT 802A	2	1	500	2358	10480	35	34	10
AT 802A	2	1	1000	12835	57048	63	62	11
AT 802A	2	1	1320	25672	114106	88	88	12
AT 802A	2	1	2608	140763	625668	254	254	13
AT 802A	2	2	25	3	13	8	2	2
AT 802A	2	2	50	8	35	9	4	3
AT 802A	2	2	75	16	71	11	6	4
AT 802A	2	2	100	28	125	12	8	5
AT 802A	2	2	150	67	296	14	11	6
AT 802A	2	2	200	126	560	15	13	7
AT 802A	2	2	250	209	929	17	16	7
AT 802A	2	2	300	324	1438	19	18	8
AT 802A	2	2	500	1179	5240	27	26	9
AT 802A	2	2	1000	6417	28524	56	56	11
AT 802A	2	2	1320	12836	57053	83	82	12
AT 802A	2	2	2608	70381	312835	254	253	13
AT 802A	2	4	25	1	7	5	<1	<1
AT 802A	2	4	50	4	17	6	2	2
AT 802A	2	4	75	8	36	7	3	3
AT 802A	2	4	100	14	62	8	5	3
AT 802A	2	4	150	33	148	9	7	5
AT 802A	2	4	200	63	280	11	9	6
AT 802A	2	4	250	104	464	13	11	6
AT 802A	2	4	300	162	719	15	13	7
AT 802A	2	4	500	589	2620	23	22	9
AT 802A	2	4	1000	3209	14262	53	52	11
AT 802A	2	4	1320	6418	28527	79	78	12
AT 802A	2	4	2608	35191	156418	218	216	13
AT 802A	2	6	25	<1	4	4	<1	<1
AT 802A	2	6	50	3	12	5	1	1
AT 802A	2	6	75	5	24	5	2	2
AT 802A	2	6	100	9	42	6	3	3
AT 802A	2	6	150	22	99	8	6	4
AT 802A	2	6	200	42	187	10	8	5
AT 802A	2	6	250	70	310	12	10	6
AT 802A	2	6	300	108	479	14	12	6
AT 802A	2	6	500	393	1747	23	21	8
AT 802A	2	6	1000	2139	9508	53	51	11
AT 802A	2	6	1320	4279	19018	78	77	12
AT 802A	2	6	2608	23460	104278	203	201	13

a/ Margin of Exposure = NOEL / Exposure. NOEL = 0.01 mg/kg based on ↑ anxiety and locomotor activity in PND21 male rats (Silva et al 2017).
b/Acute dietary exposure estimate for infants was 0.00027 mg/kg/day at the 99.9th percentile consumption rate. Acute drinking water exposure estimated for infants was 0.000439 mg/kg/day at the 99.9th percentile consumption rate for DPR's surface water monitoring data.

Appendix 2b - Drift Exposure for Infants with Airblast Application of Chlorpyrifos

RAS RISK CALCULATIONS								
Orchard Airblast - Sparse Orchard - 60 Swath								
Drift Modeling - AgDRIFT				Margins of Exposure[a]				
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	Dermal	Combined Incidental Oral	Inhalation	Combined Drift	Combined Drift, Diet & Drinking Water[b]
AT 802A	2	1	25	7	33	14	4	3
AT 802A	2	1	50	16	72	15	7	5
AT 802A	2	1	75	29	128	17	10	6
AT 802A	2	1	100	45	200	18	12	7
AT 802A	2	1	150	88	393	21	16	8
AT 802A	2	1	200	147	652	23	19	8
AT 802A	2	1	250	219	972	25	22	9
AT 802A	2	1	300	306	1358	27	25	9
AT 802A	2	1	500	834	3705	35	33	10
AT 802A	2	1	1000	4017	17853	63	61	11
AT 802A	2	1	1320	8609	38265	88	87	12
AT 802A	2	1	2608	161568	718145	254	254	13
AT 802A	2	2	25	4	16	8	2	2
AT 802A	2	2	50	8	36	9	4	3
AT 802A	2	2	75	14	64	11	6	4
AT 802A	2	2	100	23	100	12	7	5
AT 802A	2	2	150	44	197	14	10	6
AT 802A	2	2	200	73	326	15	12	7
AT 802A	2	2	250	109	486	17	14	7
AT 802A	2	2	300	153	679	19	16	8
AT 802A	2	2	500	417	1853	27	25	9
AT 802A	2	2	1000	2008	8927	56	55	11
AT 802A	2	2	1320	4304	19133	83	81	12
AT 802A	2	2	2608	80784	359071	254	253	13
AT 802A	2	4	25	2	8	5	1	1
AT 802A	2	4	50	4	18	6	2	2
AT 802A	2	4	75	7	32	7	3	3
AT 802A	2	4	100	11	50	8	4	3
AT 802A	2	4	150	22	98	9	6	4
AT 802A	2	4	200	37	163	11	8	5
AT 802A	2	4	250	55	243	13	10	6
AT 802A	2	4	300	76	340	15	12	6
AT 802A	2	4	500	208	926	23	20	8
AT 802A	2	4	1000	1004	4463	53	50	11
AT 802A	2	4	1320	2152	9566	79	76	12
AT 802A	2	4	2608	40392	179536	218	216	13
AT 802A	2	6	25	1	5	4	<1	<1
AT 802A	2	6	50	3	12	5	1	1
AT 802A	2	6	75	5	21	5	2	2
AT 802A	2	6	100	8	33	6	3	3
AT 802A	2	6	150	15	66	8	5	4
AT 802A	2	6	200	24	109	10	7	4
AT 802A	2	6	250	36	162	12	8	5
AT 802A	2	6	300	51	226	14	10	6
AT 802A	2	6	500	139	618	23	19	8
AT 802A	2	6	1000	669	2976	53	48	11
AT 802A	2	6	1320	1435	6378	78	73	12
AT 802A	2	6	2608	26928	119691	203	202	13

a/ Margin of Exposure = NOEL / Exposure. NOEL = 0.01 mg/kg based on ↑ anxiety and locomotor activity in PND21 male rats (Silva et al 2017).
b/Acute dietary exposure estimate for infants was 0.00027 mg/kg/day at the 99.9th percentile consumption rate. Acute drinking water exposure estimated for infants was 0.000439 mg/kg/day at the 99.9th percentile consumption rate for DPR's surface water monitoring data.

Appendix 2c - Drift Exposure for Infants with Ground Boom Application of Chlorpyrifos

EAS EXPOSURE ESTIMATES												
Ground Boom - High Boom 40 swath/50th Percentile												
Drift Modeling - AgDRIFT				Dermal Dose		Incidental Oral Dose				1-hr TWA air conc.* (mg/m3)	Inhalation Dose (mg/kg/day)	Drift ADD (mg/kg/day)
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	external PBPK (mg/kg/day)	9.6% absorption (mg/kg/day)	Hand-to-Mouth (mg/kg/day)	Object-to-Mouth (mg/kg/day)	Soil Ingestion (mg/kg/day)	Combined (mg/kg/day)			
AT 802A	2	1	25	0.0029980	0.0002878	0.0000624	0.0000019	0.0000005	0.0000648	0.0292	0.0007178	0.0010704
AT 802A	2	1	50	0.0019882	0.0001909	0.0000414	0.0000013	0.0000003	0.0000429	0.0264	0.0006490	0.0008828
AT 802A	2	1	75	0.0014832	0.0001424	0.0000309	0.0000009	0.0000002	0.0000320	0.0239	0.0005870	0.0007614
AT 802A	2	1	100	0.0011677	0.0001121	0.0000243	0.0000007	0.0000002	0.0000252	0.0220	0.0005408	0.0006781
AT 802A	2	1	150	0.0008521	0.0000818	0.0000177	0.0000005	0.0000001	0.0000184	0.0194	0.0004759	0.0005761
AT 802A	2	1	200	0.0006627	0.0000636	0.0000138	0.0000004	0.0000001	0.0000143	0.0175	0.0004306	0.0005085
AT 802A	2	1	250	0.0005365	0.0000515	0.0000112	0.0000003	0.0000001	0.0000116	0.0161	0.0003958	0.0004589
AT 802A	2	1	300	0.0004418	0.0000424	0.0000092	0.0000003	0.0000001	0.0000095	0.0149	0.0003675	0.0004195
AT 802A	2	1	500	0.0002293	0.0000220	0.0000048	0.0000001	0.0000000	0.0000050	0.0117	0.0002876	0.0003146
AT 802A	2	1	1000	0.0000690	0.0000066	0.0000014	0.0000000	0.0000000	0.0000015	0.0065	0.0001598	0.0001679
AT 802A	2	1	1320	0.0000375	0.0000036	0.0000008	0.0000000	0.0000000	0.0000008	0.0046	0.0001131	0.0001175
AT 802A	2	1	2608	0.0000055	0.0000005	0.0000001	0.0000000	0.0000000	0.0000001	0.0016	0.0000393	0.0000400
AT 802A	2	2	25	0.0059961	0.0005756	0.0001247	0.0000038	0.0000009	0.0001295	0.0493	0.0012120	0.0019171
AT 802A	2	2	50	0.0039763	0.0003817	0.0000827	0.0000025	0.0000006	0.0000859	0.0437	0.0010743	0.0015419
AT 802A	2	2	75	0.0029665	0.0002848	0.0000617	0.0000019	0.0000005	0.0000641	0.0386	0.0009488	0.0012977
AT 802A	2	2	100	0.0023353	0.0002242	0.0000486	0.0000015	0.0000004	0.0000504	0.0350	0.0008604	0.0011350
AT 802A	2	2	150	0.0017041	0.0001636	0.0000355	0.0000011	0.0000003	0.0000368	0.0300	0.0007368	0.0009372
AT 802A	2	2	200	0.0013254	0.0001272	0.0000276	0.0000008	0.0000002	0.0000286	0.0264	0.0006498	0.0008056
AT 802A	2	2	250	0.0010730	0.0001030	0.0000223	0.0000007	0.0000002	0.0000232	0.0237	0.0005826	0.0007088
AT 802A	2	2	300	0.0008836	0.0000848	0.0000184	0.0000006	0.0000001	0.0000191	0.0215	0.0005280	0.0006319
AT 802A	2	2	500	0.0004585	0.0000440	0.0000095	0.0000003	0.0000001	0.0000099	0.0153	0.0003761	0.0004300
AT 802A	2	2	1000	0.0001380	0.0000132	0.0000029	0.0000001	0.0000000	0.0000030	0.0072	0.0001770	0.0001932
AT 802A	2	2	1320	0.0000749	0.0000072	0.0000016	0.0000000	0.0000000	0.0000016	0.0049	0.0001205	0.0001293
AT 802A	2	2	2608	0.0000111	0.0000011	0.0000002	0.0000000	0.0000000	0.0000002	0.0016	0.0000393	0.0000406
AT 802A	2	4	25	0.0119921	0.0011512	0.0002495	0.0000077	0.0000019	0.0002590	0.0795	0.0019539	0.0033641
AT 802A	2	4	50	0.0079527	0.0007635	0.0001654	0.0000051	0.0000012	0.0001718	0.0688	0.0016918	0.0026270
AT 802A	2	4	75	0.0059329	0.0005696	0.0001234	0.0000038	0.0000009	0.0001281	0.0594	0.0014610	0.0021587
AT 802A	2	4	100	0.0046706	0.0004484	0.0000972	0.0000030	0.0000007	0.0001009	0.0526	0.0012923	0.0018416
AT 802A	2	4	150	0.0034083	0.0003272	0.0000709	0.0000022	0.0000005	0.0000736	0.0431	0.0010603	0.0014611
AT 802A	2	4	200	0.0026509	0.0002545	0.0000551	0.0000017	0.0000004	0.0000573	0.0367	0.0009025	0.0012142
AT 802A	2	4	250	0.0021460	0.0002060	0.0000446	0.0000014	0.0000003	0.0000463	0.0315	0.0007741	0.0010265
AT 802A	2	4	300	0.0017673	0.0001697	0.0000368	0.0000011	0.0000003	0.0000382	0.0274	0.0006738	0.0008817
AT 802A	2	4	500	0.0009170	0.0000880	0.0000191	0.0000006	0.0000001	0.0000198	0.0176	0.0004322	0.0005400
AT 802A	2	4	1000	0.0002759	0.0000265	0.0000057	0.0000002	0.0000000	0.0000060	0.0076	0.0001878	0.0002203
AT 802A	2	4	1320	0.0001498	0.0000144	0.0000031	0.0000001	0.0000000	0.0000032	0.0051	0.0001259	0.0001435
AT 802A	2	4	2608	0.0000222	0.0000021	0.0000005	0.0000000	0.0000000	0.0000005	0.0019	0.0000460	0.0000486
AT 802A	2	6	25	0.0179882	0.0017269	0.0003742	0.0000115	0.0000028	0.0003885	0.1042	0.0025622	0.0046775
AT 802A	2	6	50	0.0119290	0.0011452	0.0002482	0.0000076	0.0000019	0.0002576	0.0884	0.0021732	0.0035760
AT 802A	2	6	75	0.0088994	0.0008543	0.0001851	0.0000057	0.0000014	0.0001922	0.0884	0.0021732	0.0032197
AT 802A	2	6	100	0.0070059	0.0006726	0.0001458	0.0000045	0.0000011	0.0001513	0.0650	0.0015968	0.0024206
AT 802A	2	6	150	0.0051124	0.0004908	0.0001064	0.0000033	0.0000008	0.0001104	0.0884	0.0021732	0.0027744
AT 802A	2	6	200	0.0039763	0.0003817	0.0000827	0.0000025	0.0000006	0.0000859	0.0884	0.0021732	0.0026408
AT 802A	2	6	250	0.0032189	0.0003090	0.0000670	0.0000021	0.0000005	0.0000695	0.0348	0.0008557	0.0012342
AT 802A	2	6	300	0.0026509	0.0002545	0.0000551	0.0000017	0.0000004	0.0000573	0.0884	0.0021732	0.0024849
AT 802A	2	6	500	0.0013755	0.0001321	0.0000286	0.0000009	0.0000002	0.0000297	0.0179	0.0004404	0.0006021
AT 802A	2	6	1000	0.0004139	0.0000397	0.0000086	0.0000003	0.0000001	0.0000089	0.0077	0.0001885	0.0002372
AT 802A	2	6	1320	0.0002248	0.0000216	0.0000047	0.0000001	0.0000000	0.0000049	0.0052	0.0001283	0.0001547
AT 802A	2	6	2608	0.0000333	0.0000032	0.0000007	0.0000000	0.0000000	0.0000007	0.0020	0.0000483	0.0000522

* AGDISP modeling for AT802A 2GPA with various application rates was used for inhalation surrogates. Therefore, the air concentrations will be the same for airblast and ground boom at the same application rates. Breathing height was assumed to be 1.7 ft.

Abbreviations: TWA = Time Weighted Average, ADD = Absorbed Daily Dose.

Appendix 2c - Drift Exposure for Infants with Ground Boom Application of Chlorpyrifos

EAS EXPOSURE ESTIMATES												
Ground Boom - Low Boom 40 swath/50th Percentile												
Drift Modeling - AgDRIFT				Dermal Dose		Incidental Oral Dose				1-hr TWA air conc.* (mg/m3)	Inhalation Dose (mg/kg/day)	Drift ADD (mg/kg/day)
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	external PBPK (mg/kg/day)	9.6% absorption (mg/kg/day)	Hand-to-Mouth (mg/kg/day)	Object-to-Mouth (mg/kg/day)	Soil Ingestion (mg/kg/day)	Combined (mg/kg/day)			
AT 802A	2	1	25	0.0015779	0.0001515	0.0000328	0.0000010	0.0000002	0.0000341	0.0292	0.0007178	0.0009034
AT 802A	2	1	50	0.0010730	0.0001030	0.0000223	0.0000007	0.0000002	0.0000232	0.0264	0.0006490	0.0007752
AT 802A	2	1	75	0.0008205	0.0000788	0.0000171	0.0000005	0.0000001	0.0000177	0.0239	0.0005870	0.0006835
AT 802A	2	1	100	0.0006312	0.0000606	0.0000131	0.0000004	0.0000001	0.0000136	0.0220	0.0005408	0.0006151
AT 802A	2	1	150	0.0004734	0.0000454	0.0000098	0.0000003	0.0000001	0.0000102	0.0194	0.0004759	0.0005316
AT 802A	2	1	200	0.0003787	0.0000364	0.0000079	0.0000002	0.0000001	0.0000082	0.0175	0.0004306	0.0004751
AT 802A	2	1	250	0.0003156	0.0000303	0.0000066	0.0000002	0.0000000	0.0000068	0.0161	0.0003958	0.0004329
AT 802A	2	1	300	0.0002840	0.0000273	0.0000059	0.0000002	0.0000000	0.0000061	0.0149	0.0003675	0.0004009
AT 802A	2	1	500	0.0001625	0.0000156	0.0000034	0.0000001	0.0000000	0.0000035	0.0117	0.0002876	0.0003067
AT 802A	2	1	1000	0.0000616	0.0000059	0.0000013	0.0000000	0.0000000	0.0000013	0.0065	0.0001598	0.0001670
AT 802A	2	1	1320	0.0000376	0.0000036	0.0000008	0.0000000	0.0000000	0.0000008	0.0046	0.0001131	0.0001175
AT 802A	2	1	2608	0.0000080	0.0000008	0.0000002	0.0000000	0.0000000	0.0000002	0.0016	0.0000393	0.0000403
AT 802A	2	2	25	0.0031558	0.0003030	0.0000657	0.0000020	0.0000005	0.0000682	0.0493	0.0012120	0.0015831
AT 802A	2	2	50	0.0021460	0.0002060	0.0000446	0.0000014	0.0000003	0.0000463	0.0437	0.0010743	0.0013267
AT 802A	2	2	75	0.0016410	0.0001575	0.0000341	0.0000010	0.0000003	0.0000354	0.0386	0.0009488	0.0011418
AT 802A	2	2	100	0.0012623	0.0001212	0.0000263	0.0000008	0.0000002	0.0000273	0.0350	0.0008604	0.0010089
AT 802A	2	2	150	0.0009467	0.0000909	0.0000197	0.0000006	0.0000001	0.0000204	0.0300	0.0007368	0.0008481
AT 802A	2	2	200	0.0007574	0.0000727	0.0000158	0.0000005	0.0000001	0.0000164	0.0264	0.0006498	0.0007388
AT 802A	2	2	250	0.0006312	0.0000606	0.0000131	0.0000004	0.0000001	0.0000136	0.0237	0.0005826	0.0006568
AT 802A	2	2	300	0.0005680	0.0000545	0.0000118	0.0000004	0.0000001	0.0000123	0.0215	0.0005280	0.0005948
AT 802A	2	2	500	0.0003251	0.0000312	0.0000068	0.0000002	0.0000001	0.0000070	0.0153	0.0003761	0.0004144
AT 802A	2	2	1000	0.0001232	0.0000118	0.0000026	0.0000001	0.0000000	0.0000027	0.0072	0.0001770	0.0001915
AT 802A	2	2	1320	0.0000752	0.0000072	0.0000016	0.0000000	0.0000000	0.0000016	0.0049	0.0001205	0.0001293
AT 802A	2	2	2608	0.0000160	0.0000015	0.0000003	0.0000000	0.0000000	0.0000003	0.0016	0.0000393	0.0000412
AT 802A	2	4	25	0.0063116	0.0006059	0.0001313	0.0000040	0.0000010	0.0001363	0.0795	0.0019539	0.0026961
AT 802A	2	4	50	0.0042919	0.0004120	0.0000893	0.0000027	0.0000007	0.0000927	0.0688	0.0016918	0.0021965
AT 802A	2	4	75	0.0032821	0.0003151	0.0000683	0.0000021	0.0000005	0.0000709	0.0594	0.0014610	0.0018470
AT 802A	2	4	100	0.0025247	0.0002424	0.0000525	0.0000016	0.0000004	0.0000545	0.0526	0.0012923	0.0015892
AT 802A	2	4	150	0.0018935	0.0001818	0.0000394	0.0000012	0.0000003	0.0000409	0.0431	0.0010603	0.0012829
AT 802A	2	4	200	0.0015148	0.0001454	0.0000315	0.0000010	0.0000002	0.0000327	0.0367	0.0009025	0.0010806
AT 802A	2	4	250	0.0012623	0.0001212	0.0000263	0.0000008	0.0000002	0.0000273	0.0315	0.0007741	0.0009226
AT 802A	2	4	300	0.0011361	0.0001091	0.0000236	0.0000007	0.0000002	0.0000245	0.0274	0.0006738	0.0008074
AT 802A	2	4	500	0.0006501	0.0000624	0.0000135	0.0000004	0.0000001	0.0000140	0.0176	0.0004322	0.0005086
AT 802A	2	4	1000	0.0002463	0.0000236	0.0000051	0.0000002	0.0000000	0.0000053	0.0076	0.0001878	0.0002168
AT 802A	2	4	1320	0.0001504	0.0000144	0.0000031	0.0000001	0.0000000	0.0000032	0.0051	0.0001259	0.0001435
AT 802A	2	4	2608	0.0000321	0.0000031	0.0000007	0.0000000	0.0000000	0.0000007	0.0019	0.0000460	0.0000497
AT 802A	2	6	25	0.0094675	0.0009089	0.0001970	0.0000060	0.0000015	0.0002045	0.1042	0.0025622	0.0036755
AT 802A	2	6	50	0.0064379	0.0006180	0.0001339	0.0000041	0.0000010	0.0001390	0.0884	0.0021732	0.0029302
AT 802A	2	6	75	0.0049231	0.0004726	0.0001024	0.0000031	0.0000008	0.0001063	0.0884	0.0021732	0.0027521
AT 802A	2	6	100	0.0037870	0.0003636	0.0000788	0.0000024	0.0000006	0.0000818	0.0650	0.0015968	0.0020421
AT 802A	2	6	150	0.0028402	0.0002727	0.0000591	0.0000018	0.0000004	0.0000613	0.0884	0.0021732	0.0025072
AT 802A	2	6	200	0.0022722	0.0002181	0.0000473	0.0000015	0.0000004	0.0000491	0.0884	0.0021732	0.0024404
AT 802A	2	6	250	0.0018935	0.0001818	0.0000394	0.0000012	0.0000003	0.0000409	0.0348	0.0008557	0.0010784
AT 802A	2	6	300	0.0017041	0.0001636	0.0000355	0.0000011	0.0000003	0.0000368	0.0884	0.0021732	0.0023736
AT 802A	2	6	500	0.0009752	0.0000936	0.0000203	0.0000006	0.0000002	0.0000211	0.0179	0.0004404	0.0005550
AT 802A	2	6	1000	0.0003695	0.0000355	0.0000077	0.0000002	0.0000001	0.0000080	0.0077	0.0001885	0.0002319
AT 802A	2	6	1320	0.0002255	0.0000217	0.0000047	0.0000001	0.0000000	0.0000049	0.0052	0.0001283	0.0001548
AT 802A	2	6	2608	0.0000481	0.0000046	0.0000010	0.0000000	0.0000000	0.0000010	0.0020	0.0000483	0.0000539

* AGDISP modeling for AT802A 2GPA with various application rates was used for inhalation surrogates. Therefore, the air concentrations will be the same for airblast and ground boom at the same application rates. Breathing height was assumed to be 1.7 ft.

Abbreviations: TWA = Time Weighted Average, ADD = Absorbed Daily Dose.

Appendix 2c - Drift Exposure for Infants with Ground Boom Application of Chlorpyrifos

EAS EXPOSURE ESTIMATES												
Ground Boom - High Boom 40 swath/90th Percentile												
Drift Modeling - AgDRIFT				Dermal Dose		Incidental Oral Dose				1-hr TWA air conc.* (mg/m3)	Inhalation Dose (mg/kg/day)	Drift ADD (mg/kg/day)
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	external PBPK (mg/kg/day)	9.6% absorption (mg/kg/day)	Hand-to-Mouth (mg/kg/day)	Object-to-Mouth (mg/kg/day)	Soil Ingestion (mg/kg/day)	Combined (mg/kg/day)			
AT 802A	2	1	25	0.0042604	0.0004090	0.0000886	0.0000027	0.0000007	0.0000920	0.0292	0.0172280	0.0177290
AT 802A	2	1	50	0.0030611	0.0002939	0.0000637	0.0000020	0.0000005	0.0000661	0.0264	0.0155760	0.0159360
AT 802A	2	1	75	0.0023669	0.0002272	0.0000492	0.0000015	0.0000004	0.0000511	0.0239	0.0140870	0.0143654
AT 802A	2	1	100	0.0018935	0.0001818	0.0000394	0.0000012	0.0000003	0.0000409	0.0220	0.0129800	0.0132027
AT 802A	2	1	150	0.0014201	0.0001363	0.0000295	0.0000009	0.0000002	0.0000307	0.0194	0.0114218	0.0115888
AT 802A	2	1	200	0.0011361	0.0001091	0.0000236	0.0000007	0.0000002	0.0000245	0.0175	0.0103339	0.0104675
AT 802A	2	1	250	0.0009467	0.0000909	0.0000197	0.0000006	0.0000001	0.0000204	0.0161	0.0094990	0.0096103
AT 802A	2	1	300	0.0008205	0.0000788	0.0000171	0.0000005	0.0000001	0.0000177	0.0149	0.0088204	0.0089169
AT 802A	2	1	500	0.0005392	0.0000518	0.0000112	0.0000003	0.0000001	0.0000116	0.0117	0.0069030	0.0069664
AT 802A	2	1	1000	0.0003012	0.0000289	0.0000063	0.0000002	0.0000000	0.0000065	0.0065	0.0038350	0.0038704
AT 802A	2	1	1320	0.0002377	0.0000228	0.0000049	0.0000002	0.0000000	0.0000051	0.0046	0.0027140	0.0027420
AT 802A	2	1	2608	0.0001320	0.0000127	0.0000027	0.0000001	0.0000000	0.0000029	0.0016	0.0009440	0.0009595
AT 802A	2	2	25	0.0085207	0.0008180	0.0001773	0.0000054	0.0000013	0.0001840	0.0493	0.0290870	0.0300890
AT 802A	2	2	50	0.0061223	0.0005877	0.0001274	0.0000039	0.0000010	0.0001322	0.0437	0.0257830	0.0265030
AT 802A	2	2	75	0.0047337	0.0004544	0.0000985	0.0000030	0.0000007	0.0001022	0.0386	0.0227713	0.0233280
AT 802A	2	2	100	0.0037870	0.0003636	0.0000788	0.0000024	0.0000006	0.0000818	0.0350	0.0206500	0.0210953
AT 802A	2	2	150	0.0028402	0.0002727	0.0000591	0.0000018	0.0000004	0.0000613	0.0300	0.0176834	0.0180174
AT 802A	2	2	200	0.0022722	0.0002181	0.0000473	0.0000015	0.0000004	0.0000491	0.0264	0.0155942	0.0158614
AT 802A	2	2	250	0.0018935	0.0001818	0.0000394	0.0000012	0.0000003	0.0000409	0.0237	0.0139830	0.0142057
AT 802A	2	2	300	0.0016410	0.0001575	0.0000341	0.0000010	0.0000003	0.0000354	0.0215	0.0126718	0.0128648
AT 802A	2	2	500	0.0010783	0.0001035	0.0000224	0.0000007	0.0000002	0.0000233	0.0153	0.0090270	0.0091538
AT 802A	2	2	1000	0.0006025	0.0000578	0.0000125	0.0000004	0.0000001	0.0000130	0.0072	0.0042480	0.0043188
AT 802A	2	2	1320	0.0004754	0.0000456	0.0000099	0.0000003	0.0000001	0.0000103	0.0049	0.0028910	0.0029469
AT 802A	2	2	2608	0.0002640	0.0000253	0.0000055	0.0000002	0.0000000	0.0000057	0.0016	0.0009440	0.0009751
AT 802A	2	4	25	0.0170414	0.0016360	0.0003545	0.0000109	0.0000026	0.0003681	0.0795	0.0468932	0.0488972
AT 802A	2	4	50	0.0122446	0.0011755	0.0002547	0.0000078	0.0000019	0.0002645	0.0688	0.0406038	0.0420437
AT 802A	2	4	75	0.0094675	0.0009089	0.0001970	0.0000060	0.0000015	0.0002045	0.0594	0.0350637	0.0361771
AT 802A	2	4	100	0.0075740	0.0007271	0.0001576	0.0000048	0.0000012	0.0001636	0.0526	0.0310163	0.0319070
AT 802A	2	4	150	0.0056805	0.0005453	0.0001182	0.0000036	0.0000009	0.0001227	0.0431	0.0254467	0.0261147
AT 802A	2	4	200	0.0045444	0.0004363	0.0000945	0.0000029	0.0000007	0.0000981	0.0367	0.0216589	0.0221933
AT 802A	2	4	250	0.0037870	0.0003636	0.0000788	0.0000024	0.0000006	0.0000818	0.0315	0.0185791	0.0190244
AT 802A	2	4	300	0.0032821	0.0003151	0.0000683	0.0000021	0.0000005	0.0000709	0.0274	0.0161719	0.0165579
AT 802A	2	4	500	0.0021567	0.0002070	0.0000449	0.0000014	0.0000003	0.0000466	0.0176	0.0103722	0.0106258
AT 802A	2	4	1000	0.0012049	0.0001157	0.0000251	0.0000008	0.0000002	0.0000260	0.0076	0.0045076	0.0046493
AT 802A	2	4	1320	0.0009509	0.0000913	0.0000198	0.0000006	0.0000001	0.0000205	0.0051	0.0030208	0.0031326
AT 802A	2	4	2608	0.0005281	0.0000507	0.0000110	0.0000003	0.0000001	0.0000114	0.0019	0.0011033	0.0011654
AT 802A	2	6	25	0.0255621	0.0024540	0.0005318	0.0000163	0.0000040	0.0005521	0.1042	0.0614780	0.0644841
AT 802A	2	6	50	0.0183669	0.0017632	0.0003821	0.0000117	0.0000029	0.0003967	0.0884	0.0521560	0.0543159
AT 802A	2	6	75	0.0142012	0.0013633	0.0002954	0.0000091	0.0000022	0.0003067	0.0752	0.0443705	0.0460405
AT 802A	2	6	100	0.0113609	0.0010907	0.0002364	0.0000073	0.0000018	0.0002454	0.0650	0.0383500	0.0396860
AT 802A	2	6	150	0.0085207	0.0008180	0.0001773	0.0000054	0.0000013	0.0001840	0.0508	0.0299761	0.0309781
AT 802A	2	6	200	0.0068166	0.0006544	0.0001418	0.0000044	0.0000011	0.0001472	0.0414	0.0244549	0.0252565
AT 802A	2	6	250	0.0056805	0.0005453	0.0001182	0.0000036	0.0000009	0.0001227	0.0348	0.0205320	0.0212000
AT 802A	2	6	300	0.0049231	0.0004726	0.0001024	0.0000031	0.0000008	0.0001063	0.0298	0.0175729	0.0181519
AT 802A	2	6	500	0.0032350	0.0003106	0.0000673	0.0000021	0.0000005	0.0000699	0.0179	0.0105610	0.0109414
AT 802A	2	6	1000	0.0018074	0.0001735	0.0000376	0.0000012	0.0000003	0.0000390	0.0077	0.0045430	0.0047555
AT 802A	2	6	1320	0.0014263	0.0001369	0.0000297	0.0000009	0.0000002	0.0000308	0.0052	0.0030680	0.0032357
AT 802A	2	6	2608	0.0007921	0.0000760	0.0000165	0.0000005	0.0000001	0.0000171	0.0020	0.0011800	0.0012732

* AGDISP modeling for AT802A 2GPA with various application rates was used for inhalation surrogates. Therefore, the air concentrations will be the same for airblast and ground boom at the same application rates. Breathing height was assumed to be 1.7 ft.

Abbreviations: TWA = Time Weighted Average, ADD = Absorbed Daily Dose.

Appendix 2c - Drift Exposure for Infants with Ground Boom Application of Chlorpyrifos

EAS EXPOSURE ESTIMATES												
Ground Boom - Low Boom 40 swath/90th Percentile												
Drift Modeling - AgDRIFT				Dermal Dose		Incidental Oral Dose				1-hr TWA air conc.* (mg/m3)	Inhalation Dose (mg/kg/day)	Drift ADD (mg/kg/day)
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	external PBPK (mg/kg/day)	9.6% absorption (mg/kg/day)	Hand-to-Mouth (mg/kg/day)	Object-to-Mouth (mg/kg/day)	Soil Ingestion (mg/kg/day)	Combined (mg/kg/day)			
AT 802A	2	1	25	0.0026824	0.0002575	0.0000558	0.0000017	0.0000004	0.0000579	0.0292	0.0172280	0.0175435
AT 802A	2	1	50	0.0019566	0.0001878	0.0000407	0.0000012	0.0000003	0.0000423	0.0264	0.0155760	0.0158061
AT 802A	2	1	75	0.0015148	0.0001454	0.0000315	0.0000010	0.0000002	0.0000327	0.0239	0.0140870	0.0142652
AT 802A	2	1	100	0.0012308	0.0001182	0.0000256	0.0000008	0.0000002	0.0000266	0.0220	0.0129800	0.0131247
AT 802A	2	1	150	0.0009152	0.0000879	0.0000190	0.0000006	0.0000001	0.0000198	0.0194	0.0114218	0.0115294
AT 802A	2	1	200	0.0007574	0.0000727	0.0000158	0.0000005	0.0000001	0.0000164	0.0175	0.0103339	0.0104230
AT 802A	2	1	250	0.0006312	0.0000606	0.0000131	0.0000004	0.0000001	0.0000136	0.0161	0.0094990	0.0095732
AT 802A	2	1	300	0.0005680	0.0000545	0.0000118	0.0000004	0.0000001	0.0000123	0.0149	0.0088204	0.0088872
AT 802A	2	1	500	0.0003811	0.0000366	0.0000079	0.0000002	0.0000001	0.0000082	0.0117	0.0069030	0.0069478
AT 802A	2	1	1000	0.0002186	0.0000210	0.0000045	0.0000001	0.0000000	0.0000047	0.0065	0.0038350	0.0038607
AT 802A	2	1	1320	0.0001738	0.0000167	0.0000036	0.0000001	0.0000000	0.0000038	0.0046	0.0027140	0.0027344
AT 802A	2	1	2608	0.0000977	0.0000094	0.0000020	0.0000001	0.0000000	0.0000021	0.0016	0.0009440	0.0009555
AT 802A	2	2	25	0.0053649	0.0005150	0.0001116	0.0000034	0.0000008	0.0001159	0.0493	0.0290870	0.0297179
AT 802A	2	2	50	0.0039132	0.0003757	0.0000814	0.0000025	0.0000006	0.0000845	0.0437	0.0257830	0.0262432
AT 802A	2	2	75	0.0030296	0.0002908	0.0000630	0.0000019	0.0000005	0.0000654	0.0386	0.0227713	0.0231276
AT 802A	2	2	100	0.0024615	0.0002363	0.0000512	0.0000016	0.0000004	0.0000532	0.0350	0.0206500	0.0209395
AT 802A	2	2	150	0.0018304	0.0001757	0.0000381	0.0000012	0.0000003	0.0000395	0.0300	0.0176834	0.0178987
AT 802A	2	2	200	0.0015148	0.0001454	0.0000315	0.0000010	0.0000002	0.0000327	0.0264	0.0155942	0.0157723
AT 802A	2	2	250	0.0012623	0.0001212	0.0000263	0.0000008	0.0000002	0.0000273	0.0237	0.0139830	0.0141314
AT 802A	2	2	300	0.0011361	0.0001091	0.0000236	0.0000007	0.0000002	0.0000245	0.0215	0.0126718	0.0128054
AT 802A	2	2	500	0.0007622	0.0000732	0.0000159	0.0000005	0.0000001	0.0000165	0.0153	0.0090270	0.0091166
AT 802A	2	2	1000	0.0004373	0.0000420	0.0000091	0.0000003	0.0000001	0.0000094	0.0072	0.0042480	0.0042994
AT 802A	2	2	1320	0.0003476	0.0000334	0.0000072	0.0000002	0.0000001	0.0000075	0.0049	0.0028910	0.0029319
AT 802A	2	2	2608	0.0001954	0.0000188	0.0000041	0.0000001	0.0000000	0.0000042	0.0016	0.0009440	0.0009670
AT 802A	2	4	25	0.0107298	0.0010301	0.0002232	0.0000069	0.0000017	0.0002317	0.0795	0.0468932	0.0481550
AT 802A	2	4	50	0.0078264	0.0007513	0.0001628	0.0000050	0.0000012	0.0001690	0.0688	0.0406038	0.0415242
AT 802A	2	4	75	0.0060592	0.0005817	0.0001261	0.0000039	0.0000009	0.0001309	0.0594	0.0350637	0.0357762
AT 802A	2	4	100	0.0049231	0.0004726	0.0001024	0.0000031	0.0000008	0.0001063	0.0526	0.0310163	0.0315952
AT 802A	2	4	150	0.0036607	0.0003514	0.0000762	0.0000023	0.0000006	0.0000791	0.0431	0.0254467	0.0258772
AT 802A	2	4	200	0.0030296	0.0002908	0.0000630	0.0000019	0.0000005	0.0000654	0.0367	0.0216589	0.0220152
AT 802A	2	4	250	0.0025247	0.0002424	0.0000525	0.0000016	0.0000004	0.0000545	0.0315	0.0185791	0.0188760
AT 802A	2	4	300	0.0022722	0.0002181	0.0000473	0.0000015	0.0000004	0.0000491	0.0274	0.0161719	0.0164391
AT 802A	2	4	500	0.0015245	0.0001464	0.0000317	0.0000010	0.0000002	0.0000329	0.0176	0.0103722	0.0105515
AT 802A	2	4	1000	0.0008745	0.0000840	0.0000182	0.0000006	0.0000001	0.0000189	0.0076	0.0045076	0.0046104
AT 802A	2	4	1320	0.0006951	0.0000667	0.0000145	0.0000004	0.0000001	0.0000150	0.0051	0.0030208	0.0031025
AT 802A	2	4	2608	0.0003907	0.0000375	0.0000081	0.0000002	0.0000001	0.0000084	0.0019	0.0011033	0.0011492
AT 802A	2	6	25	0.0160947	0.0015451	0.0003348	0.0000103	0.0000025	0.0003476	0.1042	0.0614780	0.0633707
AT 802A	2	6	50	0.0117396	0.0011270	0.0002442	0.0000075	0.0000018	0.0002536	0.0884	0.0521560	0.0535366
AT 802A	2	6	75	0.0090888	0.0008725	0.0001891	0.0000058	0.0000014	0.0001963	0.0752	0.0443705	0.0454393
AT 802A	2	6	100	0.0073846	0.0007089	0.0001536	0.0000047	0.0000011	0.0001595	0.0650	0.0383500	0.0392184
AT 802A	2	6	150	0.0054911	0.0005271	0.0001142	0.0000035	0.0000009	0.0001186	0.0508	0.0299761	0.0306218
AT 802A	2	6	200	0.0045444	0.0004363	0.0000945	0.0000029	0.0000007	0.0000981	0.0414	0.0244549	0.0249893
AT 802A	2	6	250	0.0037870	0.0003636	0.0000788	0.0000024	0.0000006	0.0000818	0.0348	0.0205320	0.0209773
AT 802A	2	6	300	0.0034083	0.0003272	0.0000709	0.0000022	0.0000005	0.0000736	0.0298	0.0175729	0.0179737
AT 802A	2	6	500	0.0022867	0.0002195	0.0000476	0.0000015	0.0000004	0.0000494	0.0179	0.0105610	0.0108299
AT 802A	2	6	1000	0.0013118	0.0001259	0.0000273	0.0000008	0.0000002	0.0000283	0.0077	0.0045430	0.0046973
AT 802A	2	6	1320	0.0010427	0.0001001	0.0000217	0.0000007	0.0000002	0.0000225	0.0052	0.0030680	0.0031906
AT 802A	2	6	2608	0.0005861	0.0000563	0.0000122	0.0000004	0.0000001	0.0000127	0.0020	0.0011800	0.0012489

* AGDISP modeling for AT802A 2GPA with various application rates was used for inhalation surrogates. Therefore, the air concentrations will be the same for airblast and ground boom at the same application rates. Breathing height was assumed to be 1.7 ft.

Abbreviations: TWA = Time Weighted Average, ADD = Absorbed Daily Dose.

Appendix 2c - Drift Exposure for Infants with Ground Boom Application of Chlorpyrifos

RAS RISK CALCULATIONS								
Ground Boom - High Boom 40 swath/50th Percentile								
Drift Modeling - AgDRIFT				Margins of Exposure[a]				
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	Dermal	Combined Incidental Oral	Inhalation	Combined Drift	Combined Drift, Diet & Drinking Water[b]
AT 802A	2	1	25	35	154	14	9	6
AT 802A	2	1	50	52	233	15	11	6
AT 802A	2	1	75	70	312	17	13	7
AT 802A	2	1	100	89	397	18	15	7
AT 802A	2	1	150	122	543	21	17	8
AT 802A	2	1	200	157	699	23	20	8
AT 802A	2	1	250	194	863	25	22	9
AT 802A	2	1	300	236	1048	27	24	9
AT 802A	2	1	500	454	2020	35	32	10
AT 802A	2	1	1000	1510	6712	63	60	11
AT 802A	2	1	1320	2781	12360	88	85	12
AT 802A	2	1	2608	18796	83545	254	250	13
AT 802A	2	2	25	17	77	8	5	4
AT 802A	2	2	50	26	116	9	6	4
AT 802A	2	2	75	35	156	11	8	5
AT 802A	2	2	100	45	198	12	9	5
AT 802A	2	2	150	61	272	14	11	6
AT 802A	2	2	200	79	349	15	12	7
AT 802A	2	2	250	97	432	17	14	7
AT 802A	2	2	300	118	524	19	16	7
AT 802A	2	2	500	227	1010	27	23	9
AT 802A	2	2	1000	755	3356	56	52	11
AT 802A	2	2	1320	1390	6180	83	77	12
AT 802A	2	2	2608	9398	41772	254	246	13
AT 802A	2	4	25	9	39	5	3	2
AT 802A	2	4	50	13	58	6	4	3
AT 802A	2	4	75	18	78	7	5	3
AT 802A	2	4	100	22	99	8	5	4
AT 802A	2	4	150	31	136	9	7	5
AT 802A	2	4	200	39	175	11	8	5
AT 802A	2	4	250	49	216	13	10	6
AT 802A	2	4	300	59	262	15	11	6
AT 802A	2	4	500	114	505	23	19	8
AT 802A	2	4	1000	378	1678	53	45	11
AT 802A	2	4	1320	695	3090	79	70	12
AT 802A	2	4	2608	4699	20886	218	206	13
AT 802A	2	6	25	6	26	4	2	2
AT 802A	2	6	50	9	39	5	3	2
AT 802A	2	6	75	12	52	5	3	3
AT 802A	2	6	100	15	66	6	4	3
AT 802A	2	6	150	20	91	5	4	3
AT 802A	2	6	200	26	116	5	4	3
AT 802A	2	6	250	32	144	12	8	5
AT 802A	2	6	300	39	175	5	4	3
AT 802A	2	6	500	76	337	23	17	8
AT 802A	2	6	1000	252	1119	53	42	11
AT 802A	2	6	1320	463	2060	78	65	12
AT 802A	2	6	2608	3133	13924	207	192	13

a/ Margin of Exposure = NOEL / Exposure. NOEL = 0.01 mg/kg based on ↑ anxiety and locomotor activity in PND21 male rats (Silva et al 2017).
b/Acute dietary exposure estimate for infants was 0.00027 mg/kg/day at the 99.9th percentile consumption rate. Acute drinking water exposure estimated for infants was 0.000439 mg/kg/day at the 99.9th percentile consumption rate for DPR's surface water monitoring data.

Appendix 2c - Drift Exposure for Infants with Ground Boom Application of Chlorpyrifos

RAS RISK CALCULATIONS								
Ground Boom - Low Boom 40 swath/50th Percentile								
Drift Modeling - AgDRIFT				Margins of Exposure[a]				
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	Dermal	Combined Incidental Oral	Inhalation	Combined Drift	Combined Drift, Diet & Drinking Water[b]
AT 802A	2	1	25	66	293	14	11	6
AT 802A	2	1	50	97	432	15	13	7
AT 802A	2	1	75	127	564	17	15	7
AT 802A	2	1	100	165	734	18	16	8
AT 802A	2	1	150	220	978	21	19	8
AT 802A	2	1	200	275	1223	23	21	8
AT 802A	2	1	250	330	1467	25	23	9
AT 802A	2	1	300	367	1630	27	25	9
AT 802A	2	1	500	641	2849	35	33	10
AT 802A	2	1	1000	1692	7519	63	60	11
AT 802A	2	1	1320	2771	12317	88	85	12
AT 802A	2	1	2608	12982	57703	254	248	13
AT 802A	2	2	25	33	147	8	6	4
AT 802A	2	2	50	49	216	9	8	5
AT 802A	2	2	75	63	282	11	9	5
AT 802A	2	2	100	83	367	12	10	6
AT 802A	2	2	150	110	489	14	12	6
AT 802A	2	2	200	138	611	15	14	7
AT 802A	2	2	250	165	734	17	15	7
AT 802A	2	2	300	183	815	19	17	8
AT 802A	2	2	500	320	1424	27	24	9
AT 802A	2	2	1000	846	3760	56	52	11
AT 802A	2	2	1320	1386	6158	83	77	12
AT 802A	2	2	2608	6491	28851	254	243	13
AT 802A	2	4	25	17	73	5	4	3
AT 802A	2	4	50	24	108	6	5	3
AT 802A	2	4	75	32	141	7	5	4
AT 802A	2	4	100	41	183	8	6	4
AT 802A	2	4	150	55	245	9	8	5
AT 802A	2	4	200	69	306	11	9	6
AT 802A	2	4	250	83	367	13	11	6
AT 802A	2	4	300	92	408	15	12	7
AT 802A	2	4	500	160	712	23	20	8
AT 802A	2	4	1000	423	1880	53	46	11
AT 802A	2	4	1320	693	3079	79	70	12
AT 802A	2	4	2608	3245	14426	218	201	13
AT 802A	2	6	25	11	49	4	3	2
AT 802A	2	6	50	16	72	5	3	3
AT 802A	2	6	75	21	94	5	4	3
AT 802A	2	6	100	28	122	6	5	4
AT 802A	2	6	150	37	163	5	4	3
AT 802A	2	6	200	46	204	5	4	3
AT 802A	2	6	250	55	245	12	9	6
AT 802A	2	6	300	61	272	5	4	3
AT 802A	2	6	500	107	475	23	18	8
AT 802A	2	6	1000	282	1253	53	43	11
AT 802A	2	6	1320	462	2053	78	65	12
AT 802A	2	6	2608	2164	9617	207	185	13

a/ Margin of Exposure = NOEL / Exposure. NOEL = 0.01 mg/kg based on ↑ anxiety and locomotor activity in PND21 male rats (Silva et al 2017).
b/Acute dietary exposure estimate for infants was 0.00027 mg/kg/day at the 99.9th percentile consumption rate. Acute drinking water exposure estimated for infants was 0.000439 mg/kg/day at the 99.9th percentile consumption rate for DPR's surface water monitoring data.

Appendix 2c - Drift Exposure for Infants with Ground Boom Application of Chlorpyrifos

RAS RISK CALCULATIONS								
Ground Boom - High Boom 40 swath/90th Percentile								
Drift Modeling - AgDRIFT				Margins of Exposure[a]				
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	Dermal	Combined Incidental Oral	Inhalation	Combined Drift	Combined Drift, Diet & Drinking Water[b]
AT 802A	2	1	25	24	109	<1	<1	<1
AT 802A	2	1	50	34	151	<1	<1	<1
AT 802A	2	1	75	44	196	<1	<1	<1
AT 802A	2	1	100	55	245	<1	<1	<1
AT 802A	2	1	150	73	326	<1	<1	<1
AT 802A	2	1	200	92	408	<1	<1	<1
AT 802A	2	1	250	110	489	1	1	<1
AT 802A	2	1	300	127	564	1	1	1
AT 802A	2	1	500	193	859	1	1	1
AT 802A	2	1	1000	346	1537	3	3	2
AT 802A	2	1	1320	438	1948	4	4	3
AT 802A	2	1	2608	789	3507	11	10	6
AT 802A	2	2	25	12	54	<1	<1	<1
AT 802A	2	2	50	17	76	<1	<1	<1
AT 802A	2	2	75	22	98	<1	<1	<1
AT 802A	2	2	100	28	122	<1	<1	<1
AT 802A	2	2	150	37	163	<1	<1	<1
AT 802A	2	2	200	46	204	<1	<1	<1
AT 802A	2	2	250	55	245	<1	<1	<1
AT 802A	2	2	300	63	282	<1	<1	<1
AT 802A	2	2	500	97	429	1	1	1
AT 802A	2	2	1000	173	769	2	2	2
AT 802A	2	2	1320	219	974	3	3	3
AT 802A	2	2	2608	394	1753	11	10	6
AT 802A	2	4	25	6	27	<1	<1	<1
AT 802A	2	4	50	9	38	<1	<1	<1
AT 802A	2	4	75	11	49	<1	<1	<1
AT 802A	2	4	100	14	61	<1	<1	<1
AT 802A	2	4	150	18	82	<1	<1	<1
AT 802A	2	4	200	23	102	<1	<1	<1
AT 802A	2	4	250	28	122	<1	<1	<1
AT 802A	2	4	300	32	141	<1	<1	<1
AT 802A	2	4	500	48	215	<1	<1	<1
AT 802A	2	4	1000	86	384	2	2	2
AT 802A	2	4	1320	110	487	3	3	3
AT 802A	2	4	2608	197	877	9	9	5
AT 802A	2	6	25	4	18	<1	<1	<1
AT 802A	2	6	50	6	25	<1	<1	<1
AT 802A	2	6	75	7	33	<1	<1	<1
AT 802A	2	6	100	9	41	<1	<1	<1
AT 802A	2	6	150	12	54	<1	<1	<1
AT 802A	2	6	200	15	68	<1	<1	<1
AT 802A	2	6	250	18	82	<1	<1	<1
AT 802A	2	6	300	21	94	<1	<1	<1
AT 802A	2	6	500	32	143	<1	<1	<1
AT 802A	2	6	1000	58	256	2	2	2
AT 802A	2	6	1320	73	325	3	3	3
AT 802A	2	6	2608	131	584	8	8	5

a/ Margin of Exposure = NOEL / Exposure. NOEL = 0.01 mg/kg based on ↑ anxiety and locomotor activity in PND21 male rats (Silva et al 2017).
b/Acute dietary exposure estimate for infants was 0.00027 mg/kg/day at the 99.9th percentile consumption rate. Acute drinking water exposure estimated for infants was 0.000439 mg/kg/day at the 99.9th percentile consumption rate for DPR's surface water monitoring data.

Appendix 2c - Drift Exposure for Infants with Ground Boom Application of Chlorpyrifos

RAS RISK CALCULATIONS								
Ground Boom - Low Boom 40 swath/90th Percentile								
Drift Modeling - AgDRIFT				Margins of Exposure[a]				
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	Dermal	Combined Incidental Oral	Inhalation	Combined Drift	Combined Drift, Diet & Drinking Water[b]
AT 802A	2	1	25	39	173	<1	<1	<1
AT 802A	2	1	50	53	237	<1	<1	<1
AT 802A	2	1	75	69	306	<1	<1	<1
AT 802A	2	1	100	85	376	<1	<1	<1
AT 802A	2	1	150	114	506	<1	<1	<1
AT 802A	2	1	200	138	611	<1	<1	<1
AT 802A	2	1	250	165	734	1	1	<1
AT 802A	2	1	300	183	815	1	1	1
AT 802A	2	1	500	273	1215	1	1	1
AT 802A	2	1	1000	476	2118	3	3	2
AT 802A	2	1	1320	599	2664	4	4	3
AT 802A	2	1	2608	1066	4740	11	10	6
AT 802A	2	2	25	19	86	<1	<1	<1
AT 802A	2	2	50	27	118	<1	<1	<1
AT 802A	2	2	75	34	153	<1	<1	<1
AT 802A	2	2	100	42	188	<1	<1	<1
AT 802A	2	2	150	57	253	<1	<1	<1
AT 802A	2	2	200	69	306	<1	<1	<1
AT 802A	2	2	250	83	367	<1	<1	<1
AT 802A	2	2	300	92	408	<1	<1	<1
AT 802A	2	2	500	137	607	1	1	1
AT 802A	2	2	1000	238	1059	2	2	2
AT 802A	2	2	1320	300	1332	3	3	3
AT 802A	2	2	2608	533	2370	11	10	6
AT 802A	2	4	25	10	43	<1	<1	<1
AT 802A	2	4	50	13	59	<1	<1	<1
AT 802A	2	4	75	17	76	<1	<1	<1
AT 802A	2	4	100	21	94	<1	<1	<1
AT 802A	2	4	150	28	126	<1	<1	<1
AT 802A	2	4	200	34	153	<1	<1	<1
AT 802A	2	4	250	41	183	<1	<1	<1
AT 802A	2	4	300	46	204	<1	<1	<1
AT 802A	2	4	500	68	304	<1	<1	<1
AT 802A	2	4	1000	119	529	2	2	2
AT 802A	2	4	1320	150	666	3	3	3
AT 802A	2	4	2608	267	1185	9	9	5
AT 802A	2	6	25	6	29	<1	<1	<1
AT 802A	2	6	50	9	39	<1	<1	<1
AT 802A	2	6	75	11	51	<1	<1	<1
AT 802A	2	6	100	14	63	<1	<1	<1
AT 802A	2	6	150	19	84	<1	<1	<1
AT 802A	2	6	200	23	102	<1	<1	<1
AT 802A	2	6	250	28	122	<1	<1	<1
AT 802A	2	6	300	31	136	<1	<1	<1
AT 802A	2	6	500	46	202	<1	<1	<1
AT 802A	2	6	1000	79	353	2	2	2
AT 802A	2	6	1320	100	444	3	3	3
AT 802A	2	6	2608	178	790	8	8	5

a/ Margin of Exposure = NOEL / Exposure. NOEL = 0.01 mg/kg based on ↑ anxiety and locomotor activity in PND21 male rats (Silva et al 2017).
b/Acute dietary exposure estimate for infants was 0.00027 mg/kg/day at the 99.9th percentile consumption rate. Acute drinking water exposure estimated for infants was 0.000439 mg/kg/day at the 99.9th percentile consumption rate for DPR's surface water monitoring data.

Appendix 2d - Drift Exposure for Children 1-2 Years Old with Aerial Application of Chlorpyrifos

EAS EXPOSURE ESTIMATES												
Drift-Modeling - AGDISP				Dermal Dose		Incidental Oral Dose				1-hr TWA air conc.* (mg/m3)	Inhalation Dose (mg/kg/day)	Drift ADD (mg/kg/day)
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	External PBPK (mg/kg/day)	9.6% Absorption (mg/kg/day)	Hand to-Mouth (mg/kg/day)	Oral-to-Mouth (mg/kg/day)	Soil Ingestion (mg/kg/day)	Combined (mg/kg/day)			
AT 802A	2	1	25	0.0302386	0.0029029	0.0006291	0.0000193	0.0000047	0.0006531	0.0292	0.0006424	0.0035500
AT 802A	2	1	50	0.0237997	0.0022848	0.0004951	0.0000152	0.0000037	0.0005140	0.0264	0.0005808	0.0028693
AT 802A	2	1	100	0.0160325	0.0015391	0.0003335	0.0000102	0.0000025	0.0003463	0.0220	0.0004840	0.0020256
AT 802A	2	1	250	0.0083576	0.0008023	0.0001739	0.0000053	0.0000013	0.0001805	0.0161	0.0003542	0.0011578
AT 802A	2	1	500	0.0049813	0.0004782	0.0001036	0.0000032	0.0000008	0.0001076	0.0117	0.0002574	0.0007364
AT 802A	2	1	1000	0.0026567	0.0002550	0.0000553	0.0000017	0.0000004	0.0000574	0.0065	0.0001430	0.0003985
AT 802A	2	1	1320	0.0017342	0.0001665	0.0000361	0.0000011	0.0000003	0.0000375	0.0046	0.0001010	0.0002677
AT 802A	2	1	2608	0.0003136	0.0000301	0.0000065	0.0000002	0.0000000	0.0000068	0.0016	0.0000354	0.0000656
Bell 205 Helicopter	2	1	25	0.0286519	0.0027506	0.0005961	0.0000183	0.0000044	0.0006188	0.0336	0.0007392	0.0034942
Bell 205 Helicopter	2	1	50	0.0175454	0.0016844	0.0003650	0.0000112	0.0000027	0.0003789	0.0274	0.0006028	0.0022899
Bell 205 Helicopter	2	1	100	0.0106637	0.0010237	0.0002218	0.0000068	0.0000017	0.0002303	0.0219	0.0004818	0.0015072
Bell 205 Helicopter	2	1	250	0.0068078	0.0006536	0.0001416	0.0000043	0.0000011	0.0001470	0.0153	0.0003366	0.0009912
Bell 205 Helicopter	2	1	500	0.0040404	0.0003879	0.0000841	0.0000026	0.0000006	0.0000873	0.0102	0.0002244	0.0006129
Bell 205 Helicopter	2	1	1000	0.0019741	0.0001895	0.0000411	0.0000013	0.0000003	0.0000426	0.0058	0.0001276	0.0003174
Bell 205 Helicopter	2	1	1320	0.0013837	0.0001328	0.0000288	0.0000009	0.0000002	0.0000299	0.0045	0.0000986	0.0002316
Bell 205 Helicopter	2	1	2608	0.0002214	0.0000213	0.0000046	0.0000001	0.0000000	0.0000048	0.0020	0.0000449	0.0000662
AT 802A	2	2	25	0.0605140	0.0058093	0.0012589	0.0000386	0.0000094	0.0013070	0.0493	0.0010846	0.0069033
AT 802A	2	2	50	0.0474518	0.0045554	0.0009872	0.0000303	0.0000074	0.0010249	0.0437	0.0009614	0.0055241
AT 802A	2	2	100	0.0316961	0.0030428	0.0006594	0.0000202	0.0000049	0.0006846	0.0350	0.0007700	0.0038177
AT 802A	2	2	250	0.0158665	0.0015232	0.0003301	0.0000101	0.0000025	0.0003427	0.0237	0.0005214	0.0020470
AT 802A	2	2	500	0.0086343	0.0008289	0.0001796	0.0000055	0.0000013	0.0001865	0.0153	0.0003366	0.0011668
AT 802A	2	2	1000	0.0033947	0.0003259	0.0000706	0.0000022	0.0000005	0.0000733	0.0072	0.0001584	0.0004848
AT 802A	2	2	1320	0.0019925	0.0001913	0.0000415	0.0000013	0.0000003	0.0000430	0.0049	0.0001082	0.0002998
AT 802A	2	2	2608	0.0003690	0.0000354	0.0000077	0.0000002	0.0000001	0.0000080	0.0016	0.0000359	0.0000713
Bell 205 Helicopter	2	2	25	0.0580787	0.0055756	0.0012083	0.0000371	0.0000090	0.0012544	0.0580	0.0012760	0.0068606
Bell 205 Helicopter	2	2	50	0.0357549	0.0034325	0.0007438	0.0000228	0.0000056	0.0007722	0.0458	0.0010076	0.0044456
Bell 205 Helicopter	2	2	100	0.0222500	0.0021360	0.0004629	0.0000142	0.0000035	0.0004806	0.0345	0.0007590	0.0028985
Bell 205 Helicopter	2	2	250	0.0123242	0.0011831	0.0002564	0.0000079	0.0000019	0.0002662	0.0215	0.0004730	0.0016580
Bell 205 Helicopter	2	2	500	0.0063097	0.0006057	0.0001313	0.0000040	0.0000010	0.0001363	0.0130	0.0002860	0.0008927
Bell 205 Helicopter	2	2	1000	0.0027674	0.0002657	0.0000576	0.0000018	0.0000004	0.0000598	0.0068	0.0001496	0.0004157
Bell 205 Helicopter	2	2	1320	0.0017711	0.0001700	0.0000368	0.0000011	0.0000003	0.0000383	0.0050	0.0001098	0.0002801
Bell 205 Helicopter	2	2	2608	0.0002952	0.0000283	0.0000061	0.0000002	0.0000000	0.0000064	0.0022	0.0000482	0.0000766
AT 802A	2	2.3	25	0.0695487	0.0066767	0.0014469	0.0000444	0.0000108	0.0015021	0.0526	0.0011568	0.0078442
AT 802A	2	2.3	50	0.0544847	0.0052305	0.0011335	0.0000348	0.0000085	0.0011768	0.0464	0.0010217	0.0062607
AT 802A	2	2.3	100	0.0363232	0.0034870	0.0007557	0.0000232	0.0000056	0.0007845	0.0371	0.0008171	0.0043097
AT 802A	2	2.3	250	0.0181616	0.0017435	0.0003778	0.0000116	0.0000028	0.0003923	0.0250	0.0005493	0.0022957
AT 802A	2	2.3	500	0.0096324	0.0009247	0.0002004	0.0000062	0.0000015	0.0002080	0.0159	0.0003489	0.0012751
AT 802A	2	2.3	1000	0.0037342	0.0003585	0.0000777	0.0000024	0.0000006	0.0000807	0.0075	0.0001641	0.0005232
AT 802A	2	2.3	1320	0.0021217	0.0002037	0.0000441	0.0000014	0.0000003	0.0000458	0.0051	0.0001122	0.0003162
AT 802A	2	2.3	2608	0.0004668	0.0000448	0.0000097	0.0000003	0.0000001	0.0000101	0.0017	0.0000370	0.0000818
Bell 205 Helicopter	2	2.3	25	0.0668329	0.0064160	0.0013904	0.0000427	0.0000104	0.0014435	0.0611	0.0013442	0.0077705
Bell 205 Helicopter	2	2.3	50	0.0411606	0.0039514	0.0008563	0.0000263	0.0000064	0.0008890	0.0482	0.0010608	0.0050186
Bell 205 Helicopter	2	2.3	100	0.0256723	0.0024645	0.0005341	0.0000164	0.0000040	0.0005545	0.0362	0.0007966	0.0032651
Bell 205 Helicopter	2	2.3	250	0.0139182	0.0013361	0.0002896	0.0000089	0.0000022	0.0003006	0.0222	0.0004880	0.0018263
Bell 205 Helicopter	2	2.3	500	0.0070015	0.0006721	0.0001457	0.0000045	0.0000011	0.0001512	0.0133	0.0002924	0.0009656
Bell 205 Helicopter	2	2.3	1000	0.0030128	0.0002892	0.0000627	0.0000019	0.0000005	0.0000651	0.0069	0.0001511	0.0004408
Bell 205 Helicopter	2	2.3	1320	0.0019095	0.0001833	0.0000397	0.0000012	0.0000003	0.0000412	0.0050	0.0001109	0.0002945
Bell 205 Helicopter	2	2.3	2608	0.0003819	0.0000367	0.0000079	0.0000002	0.0000001	0.0000082	0.0023	0.0000495	0.0000862

*Breathing height was assumed to be 1.7 ft.

Abbreviations: TWA = Time Weighted Average, ADD = Absorbed Daily Dose.

Appendix 2d - Drift Exposure for Children 1-2 Years Old with Aerial Application of Chlorpyrifos

EAS EXPOSURE ESTIMATES												
Drift-Modeling - AGDISP				Dermal Dose		Incidental Oral Dose						
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	External PBPK (mg/kg/day)	9.6% Absorption (mg/kg/day)	Hand to-Mouth (mg/kg/day)	Oral-to-Mouth (mg/kg/day)	Soil Ingestion (mg/kg/day)	Combined (mg/kg/day)	1-hr TWA air conc.* (mg/m3)	Inhalation Dose (mg/kg/day)	Drift ADD (mg/kg/day)
AT 802A	15	1	25	0.0259952	0.0024955	0.0005408	0.0000166	0.0000040	0.0005614	0.0413	0.0009088	0.0034084
AT 802A	15	1	50	0.0207925	0.0019961	0.0004326	0.0000133	0.0000032	0.0004491	0.0391	0.0008598	0.0028591
AT 802A	15	1	100	0.0139108	0.0013354	0.0002894	0.0000089	0.0000022	0.0003004	0.0348	0.0007658	0.0021034
AT 802A	15	1	250	0.0071399	0.0006854	0.0001485	0.0000046	0.0000011	0.0001542	0.0289	0.0006362	0.0013228
AT 802A	15	1	500	0.0044279	0.0004251	0.0000921	0.0000028	0.0000007	0.0000956	0.0243	0.0005344	0.0009601
AT 802A	15	1	1000	0.0033024	0.0003170	0.0000687	0.0000021	0.0000005	0.0000713	0.0190	0.0004171	0.0007347
AT 802A	15	1	1320	0.0029888	0.0002869	0.0000622	0.0000019	0.0000005	0.0000646	0.0164	0.0003610	0.0006484
AT 802A	15	1	2608	0.0008856	0.0000850	0.0000184	0.0000006	0.0000001	0.0000191	0.0090	0.0001976	0.0002827
Bell 205 Helicopter	15	1	25	0.0258845	0.0024849	0.0005385	0.0000165	0.0000040	0.0005591	0.0592	0.0013028	0.0037918
Bell 205 Helicopter	15	1	50	0.0150178	0.0014417	0.0003124	0.0000096	0.0000023	0.0003244	0.0517	0.0011370	0.0025810
Bell 205 Helicopter	15	1	100	0.0087081	0.0008360	0.0001812	0.0000056	0.0000014	0.0001881	0.0448	0.0009865	0.0018238
Bell 205 Helicopter	15	1	250	0.0060514	0.0005809	0.0001259	0.0000039	0.0000009	0.0001307	0.0367	0.0008065	0.0013884
Bell 205 Helicopter	15	1	500	0.0045386	0.0004357	0.0000944	0.0000029	0.0000007	0.0000980	0.0288	0.0006345	0.0010709
Bell 205 Helicopter	15	1	1000	0.0029704	0.0002852	0.0000618	0.0000019	0.0000005	0.0000642	0.0202	0.0004451	0.0007307
Bell 205 Helicopter	15	1	1320	0.0023800	0.0002285	0.0000495	0.0000015	0.0000004	0.0000514	0.0150	0.0003289	0.0005577
Bell 205 Helicopter	15	1	2608	0.0003874	0.0000372	0.0000081	0.0000002	0.0000001	0.0000084	0.0080	0.0001762	0.0002135
AT 802A	15	2	25	0.0543150	0.0052142	0.0011300	0.0000347	0.0000084	0.0011731	0.0703	0.0015462	0.0067688
AT 802A	15	2	50	0.0437620	0.0042011	0.0009104	0.0000279	0.0000068	0.0009452	0.0660	0.0014516	0.0056595
AT 802A	15	2	100	0.0298142	0.0028622	0.0006203	0.0000190	0.0000046	0.0006439	0.0579	0.0012729	0.0041397
AT 802A	15	2	250	0.0156820	0.0015055	0.0003262	0.0000100	0.0000024	0.0003387	0.0468	0.0010292	0.0025371
AT 802A	15	2	500	0.0099996	0.0009600	0.0002080	0.0000064	0.0000016	0.0002160	0.0381	0.0008384	0.0017999
AT 802A	15	2	1000	0.0072691	0.0006978	0.0001512	0.0000046	0.0000011	0.0001570	0.0279	0.0006129	0.0013119
AT 802A	15	2	1320	0.0063097	0.0006057	0.0001313	0.0000040	0.0000010	0.0001363	0.0227	0.0004998	0.0011066
AT 802A	15	2	2608	0.0015129	0.0001452	0.0000315	0.0000010	0.0000002	0.0000327	0.0103	0.0002268	0.0003723
Bell 205 Helicopter	15	2	25	0.0539091	0.0051753	0.0011215	0.0000344	0.0000084	0.0011643	0.0828	0.0018220	0.0070057
Bell 205 Helicopter	15	2	50	0.0321019	0.0030818	0.0006679	0.0000205	0.0000050	0.0006933	0.0715	0.0015728	0.0046596
Bell 205 Helicopter	15	2	100	0.0190029	0.0018243	0.0003953	0.0000121	0.0000030	0.0004104	0.0612	0.0013457	0.0031730
Bell 205 Helicopter	15	2	250	0.0132836	0.0012752	0.0002764	0.0000085	0.0000021	0.0002869	0.0488	0.0010736	0.0023509
Bell 205 Helicopter	15	2	500	0.0094461	0.0009068	0.0001965	0.0000060	0.0000015	0.0002040	0.0373	0.0008204	0.0017287
Bell 205 Helicopter	15	2	1000	0.0057193	0.0005491	0.0001190	0.0000037	0.0000009	0.0001235	0.0252	0.0005548	0.0011048
Bell 205 Helicopter	15	2	1320	0.0043541	0.0004180	0.0000906	0.0000028	0.0000007	0.0000940	0.0207	0.0004545	0.0008732
Bell 205 Helicopter	15	2	2608	0.0007749	0.0000744	0.0000161	0.0000005	0.0000001	0.0000167	0.0115	0.0002526	0.0003271
AT 802A	15	2.3	25	0.0628017	0.0060290	0.0013065	0.0000401	0.0000097	0.0013564	0.0779	0.0017131	0.0077519
AT 802A	15	2.3	50	0.0506657	0.0048639	0.0010541	0.0000324	0.0000079	0.0010943	0.0730	0.0016056	0.0064773
AT 802A	15	2.3	100	0.0344985	0.0033119	0.0007177	0.0000220	0.0000054	0.0007451	0.0637	0.0014007	0.0047180
AT 802A	15	2.3	250	0.0182040	0.0017476	0.0003787	0.0000116	0.0000028	0.0003932	0.0513	0.0011284	0.0028788
AT 802A	15	2.3	500	0.0115844	0.0011121	0.0002410	0.0000074	0.0000018	0.0002502	0.0415	0.0009128	0.0020267
AT 802A	15	2.3	1000	0.0084019	0.0008066	0.0001748	0.0000054	0.0000013	0.0001815	0.0299	0.0006569	0.0014648
AT 802A	15	2.3	1320	0.0070864	0.0006803	0.0001474	0.0000045	0.0000011	0.0001531	0.0241	0.0005298	0.0012112
AT 802A	15	2.3	2608	0.0017398	0.0001670	0.0000362	0.0000011	0.0000003	0.0000376	0.0106	0.0002339	0.0004011
Bell 205 Helicopter	15	2.3	25	0.0624623	0.0059964	0.0012995	0.0000399	0.0000097	0.0013491	0.0917	0.0020172	0.0080233
Bell 205 Helicopter	15	2.3	50	0.0372991	0.0035807	0.0007760	0.0000238	0.0000058	0.0008056	0.0789	0.0017358	0.0053223
Bell 205 Helicopter	15	2.3	100	0.0221503	0.0021264	0.0004608	0.0000141	0.0000034	0.0004784	0.0671	0.0014753	0.0036052
Bell 205 Helicopter	15	2.3	250	0.0153610	0.0014747	0.0003196	0.0000098	0.0000024	0.0003318	0.0532	0.0011697	0.0026468
Bell 205 Helicopter	15	2.3	500	0.0107781	0.0010347	0.0002242	0.0000069	0.0000017	0.0002328	0.0402	0.0008848	0.0019212
Bell 205 Helicopter	15	2.3	1000	0.0065348	0.0006273	0.0001360	0.0000042	0.0000010	0.0001411	0.0269	0.0005911	0.0012195
Bell 205 Helicopter	15	2.3	1320	0.0049647	0.0004766	0.0001033	0.0000032	0.0000008	0.0001072	0.0220	0.0004833	0.0009607
Bell 205 Helicopter	15	2.3	2608	0.0008911	0.0000855	0.0000185	0.0000006	0.0000001	0.0000192	0.0127	0.0002787	0.0003644

*Breathing height was assumed to be 1.7 ft.

Abbreviations: TWA = Time Weighted Average, ADD = Absorbed Daily Dose.

Appendix 2d - Drift Exposure for Children 1-2 Years Old with Aerial Application of Chlorpyrifos

RAS RISK CALCULATIONS								
Drift-Modeling - AGDISP				Margins of Exposure[a]				
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	Dermal	Combined Incidental Oral	Inhalation	Combined Drift	Combined Drift, Diet & Drinking Water[b]
AT 802A	2	1	25	3	15	16	3	2
AT 802A	2	1	50	4	19	17	3	3
AT 802A	2	1	100	6	29	21	5	4
AT 802A	2	1	250	12	55	28	9	6
AT 802A	2	1	500	21	93	39	14	7
AT 802A	2	1	1000	39	174	70	25	10
AT 802A	2	1	1320	60	267	99	37	11
AT 802A	2	1	2608	332	1476	282	152	15
Bell 205 Helicopter	2	1	25	4	16	14	3	2
Bell 205 Helicopter	2	1	50	6	26	17	4	3
Bell 205 Helicopter	2	1	100	10	43	21	7	5
Bell 205 Helicopter	2	1	250	15	68	30	10	6
Bell 205 Helicopter	2	1	500	26	115	45	16	8
Bell 205 Helicopter	2	1	1000	53	235	78	32	11
Bell 205 Helicopter	2	1	1320	75	335	101	43	12
Bell 205 Helicopter	2	1	2608	471	2091	223	151	15
AT 802A	2	2	25	2	8	9	1	1
AT 802A	2	2	50	2	10	10	2	2
AT 802A	2	2	100	3	15	13	3	2
AT 802A	2	2	250	7	29	19	5	4
AT 802A	2	2	500	12	54	30	9	6
AT 802A	2	2	1000	31	136	63	21	9
AT 802A	2	2	1320	52	232	92	33	11
AT 802A	2	2	2608	282	1255	279	140	15
Bell 205 Helicopter	2	2	25	2	8	8	1	1
Bell 205 Helicopter	2	2	50	3	13	10	2	2
Bell 205 Helicopter	2	2	100	5	21	13	3	3
Bell 205 Helicopter	2	2	250	8	38	21	6	4
Bell 205 Helicopter	2	2	500	17	73	35	11	7
Bell 205 Helicopter	2	2	1000	38	167	67	24	10
Bell 205 Helicopter	2	2	1320	59	261	91	36	11
Bell 205 Helicopter	2	2	2608	353	1568	208	131	15
AT 802A	2	2.3	25	1	7	9	1	1
AT 802A	2	2.3	50	2	8	10	2	1
AT 802A	2	2.3	100	3	13	12	2	2
AT 802A	2	2.3	250	6	25	18	4	3
AT 802A	2	2.3	500	11	48	29	8	5
AT 802A	2	2.3	1000	28	124	61	19	9
AT 802A	2	2.3	1320	49	218	89	32	11
AT 802A	2	2.3	2608	223	992	271	122	14
Bell 205 Helicopter	2	2.3	25	2	7	7	1	1
Bell 205 Helicopter	2	2.3	50	3	11	9	2	2
Bell 205 Helicopter	2	2.3	100	4	18	13	3	3
Bell 205 Helicopter	2	2.3	250	7	33	20	5	4
Bell 205 Helicopter	2	2.3	500	15	66	34	10	6
Bell 205 Helicopter	2	2.3	1000	35	154	66	23	10
Bell 205 Helicopter	2	2.3	1320	55	242	90	34	11
Bell 205 Helicopter	2	2.3	2608	273	1212	202	116	14

a/ Margin of Exposure = NOEL / Exposure. NOEL = 0.01 mg/kg based on ↑ anxiety and locomotor activity in PND21 male rats (Silva et al 2017).
b/Acute dietary exposure estimate for children 1-2 yrs old was 0.000423 mg/kg/day at the 99.9th percentile consumption rate. Acute drinking water exposure estimated for children 1-2 yrs old was 0.000186 mg/kg/day at the 99.9th percentile consumption rate for DPR's surface water monitoring data.

Appendix 2d - Drift Exposure for Children 1-2 Years Old with Aerial Application of Chlorpyrifos

RAS RISK CALCULATIONS								
Drift-Modeling - AGDISP				Margins of Exposure[a]				
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	Dermal	Combined Incidental Oral	Inhalation	Combined Drift	Combined Drift, Diet & Drinking Water[b]
AT 802A	15	1	25	4	18	11	3	2
AT 802A	15	1	50	5	22	12	3	3
AT 802A	15	1	100	7	33	13	5	4
AT 802A	15	1	250	15	65	16	8	5
AT 802A	15	1	500	24	105	19	10	6
AT 802A	15	1	1000	32	140	24	14	7
AT 802A	15	1	1320	35	155	28	15	8
AT 802A	15	1	2608	118	523	51	35	11
Bell 205 Helicopter	15	1	25	4	18	8	3	2
Bell 205 Helicopter	15	1	50	7	31	9	4	3
Bell 205 Helicopter	15	1	100	12	53	10	5	4
Bell 205 Helicopter	15	1	250	17	77	12	7	5
Bell 205 Helicopter	15	1	500	23	102	16	9	6
Bell 205 Helicopter	15	1	1000	35	156	22	14	7
Bell 205 Helicopter	15	1	1320	44	195	30	18	9
Bell 205 Helicopter	15	1	2608	269	1195	57	47	12
AT 802A	15	2	25	2	9	6	1	1
AT 802A	15	2	50	2	11	7	2	2
AT 802A	15	2	100	3	16	8	2	2
AT 802A	15	2	250	7	30	10	4	3
AT 802A	15	2	500	10	46	12	6	4
AT 802A	15	2	1000	14	64	16	8	5
AT 802A	15	2	1320	17	73	20	9	6
AT 802A	15	2	2608	69	306	44	27	10
Bell 205 Helicopter	15	2	25	2	9	5	1	1
Bell 205 Helicopter	15	2	50	3	14	6	2	2
Bell 205 Helicopter	15	2	100	5	24	7	3	3
Bell 205 Helicopter	15	2	250	8	35	9	4	3
Bell 205 Helicopter	15	2	500	11	49	12	6	4
Bell 205 Helicopter	15	2	1000	18	81	18	9	6
Bell 205 Helicopter	15	2	1320	24	106	22	11	7
Bell 205 Helicopter	15	2	2608	134	598	40	31	11
AT 802A	15	2.3	25	2	7	6	1	1
AT 802A	15	2.3	50	2	9	6	2	1
AT 802A	15	2.3	100	3	13	7	2	2
AT 802A	15	2.3	250	6	25	9	3	3
AT 802A	15	2.3	500	9	40	11	5	4
AT 802A	15	2.3	1000	12	55	15	7	5
AT 802A	15	2.3	1320	15	65	19	8	5
AT 802A	15	2.3	2608	60	266	43	25	10
Bell 205 Helicopter	15	2.3	25	2	7	5	1	1
Bell 205 Helicopter	15	2.3	50	3	12	6	2	2
Bell 205 Helicopter	15	2.3	100	5	21	7	3	2
Bell 205 Helicopter	15	2.3	250	7	30	9	4	3
Bell 205 Helicopter	15	2.3	500	10	43	11	5	4
Bell 205 Helicopter	15	2.3	1000	16	71	17	8	5
Bell 205 Helicopter	15	2.3	1320	21	93	21	10	6
Bell 205 Helicopter	15	2.3	2608	117	520	36	27	10

a/ Margin of Exposure = NOEL / Exposure. NOEL = 0.01 mg/kg based on ↑ anxiety and locomotor activity in PND21 male rats (Silva et al 2017).
b/Acute dietary exposure estimate for children 1-2 yrs old was 0.000423 mg/kg/day at the 99.9th percentile consumption rate. Acute drinking water exposure estimated for children 1-2 yrs old was 0.000186 mg/kg/day at the 99.9th percentile consumption rate for DPR's surface water monitoring data.

Appendix 2e - Drift Exposure for Children 1-2 Years Old with Airblast Application of Chlorpyrifos

EAS EXPOSURE ESTIMATES												
Orchard Airblast - Dormant Apple - 60 Swath												
Drift Modeling - AgDRIFT				Dermal Dose		Incidental Oral Dose						
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	external PBPK (mg/kg/day)	9.6% absorption (mg/kg/day)	Hand-to-Mouth (mg/kg/day)	Object-to-Mouth (mg/kg/day)	Soil Ingestion (mg/kg/day)	Combined (mg/kg/day)	1-hr TWA air conc.* (mg/m3)	Inhalation Dose (mg/kg/day)	Drift ADD (mg/kg/day)
AT 802A	2	1	25	0.0102117	0.0009803	0.0002124	0.0000065	0.0000016	0.0002206	0.0292	0.0006424	0.0018433
AT 802A	2	1	50	0.0038854	0.0003730	0.0000808	0.0000025	0.0000006	0.0000839	0.0264	0.0005808	0.0010377
AT 802A	2	1	75	0.0019058	0.0001830	0.0000396	0.0000012	0.0000003	0.0000412	0.0239	0.0005253	0.0007494
AT 802A	2	1	100	0.0010830	0.0001040	0.0000225	0.0000007	0.0000002	0.0000234	0.0220	0.0004840	0.0006114
AT 802A	2	1	150	0.0004575	0.0000439	0.0000095	0.0000003	0.0000001	0.0000099	0.0194	0.0004259	0.0004797
AT 802A	2	1	200	0.0002417	0.0000232	0.0000050	0.0000002	0.0000000	0.0000052	0.0175	0.0003853	0.0004138
AT 802A	2	1	250	0.0001458	0.0000140	0.0000030	0.0000001	0.0000000	0.0000031	0.0161	0.0003542	0.0003713
AT 802A	2	1	300	0.0000941	0.0000090	0.0000020	0.0000001	0.0000000	0.0000020	0.0149	0.0003289	0.0003400
AT 802A	2	1	500	0.0000258	0.0000025	0.0000005	0.0000000	0.0000000	0.0000006	0.0117	0.0002574	0.0002604
AT 802A	2	1	1000	0.0000047	0.0000005	0.0000001	0.0000000	0.0000000	0.0000001	0.0065	0.0001430	0.0001436
AT 802A	2	1	1320	0.0000024	0.0000002	0.0000000	0.0000000	0.0000000	0.0000001	0.0046	0.0001012	0.0001015
AT 802A	2	1	2608	0.0000004	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0016	0.0000352	0.0000353
AT 802A	2	2	25	0.0204235	0.0019607	0.0004249	0.0000130	0.0000032	0.0004411	0.0493	0.0010846	0.0034864
AT 802A	2	2	50	0.0077709	0.0007460	0.0001617	0.0000050	0.0000012	0.0001678	0.0437	0.0009614	0.0018752
AT 802A	2	2	75	0.0038116	0.0003659	0.0000793	0.0000024	0.0000006	0.0000823	0.0386	0.0008491	0.0012973
AT 802A	2	2	100	0.0021660	0.0002079	0.0000451	0.0000014	0.0000003	0.0000468	0.0350	0.0007700	0.0010247
AT 802A	2	2	150	0.0009151	0.0000878	0.0000190	0.0000006	0.0000001	0.0000198	0.0300	0.0006594	0.0007670
AT 802A	2	2	200	0.0004834	0.0000464	0.0000101	0.0000003	0.0000001	0.0000104	0.0264	0.0005815	0.0006383
AT 802A	2	2	250	0.0002915	0.0000280	0.0000061	0.0000002	0.0000000	0.0000063	0.0237	0.0005214	0.0005557
AT 802A	2	2	300	0.0001882	0.0000181	0.0000039	0.0000001	0.0000000	0.0000041	0.0215	0.0004725	0.0004946
AT 802A	2	2	500	0.0000517	0.0000050	0.0000011	0.0000000	0.0000000	0.0000011	0.0153	0.0003366	0.0003427
AT 802A	2	2	1000	0.0000095	0.0000009	0.0000002	0.0000000	0.0000000	0.0000002	0.0072	0.0001584	0.0001595
AT 802A	2	2	1320	0.0000047	0.0000005	0.0000001	0.0000000	0.0000000	0.0000001	0.0049	0.0001082	0.0001088
AT 802A	2	2	2608	0.0000009	0.0000001	0.0000000	0.0000000	0.0000000	0.0000000	0.0016	0.0000359	0.0000360
AT 802A	2	4	25	0.0408470	0.0039213	0.0008498	0.0000261	0.0000063	0.0008822	0.0795	0.0017486	0.0065521
AT 802A	2	4	50	0.0155418	0.0014920	0.0003233	0.0000099	0.0000024	0.0003357	0.0688	0.0015140	0.0033417
AT 802A	2	4	75	0.0076233	0.0007318	0.0001586	0.0000049	0.0000012	0.0001646	0.0594	0.0013075	0.0022039
AT 802A	2	4	100	0.0043319	0.0004159	0.0000901	0.0000028	0.0000007	0.0000936	0.0526	0.0011565	0.0016660
AT 802A	2	4	150	0.0018302	0.0001757	0.0000381	0.0000012	0.0000003	0.0000395	0.0431	0.0009489	0.0011641
AT 802A	2	4	200	0.0009667	0.0000928	0.0000201	0.0000006	0.0000002	0.0000209	0.0367	0.0008076	0.0009213
AT 802A	2	4	250	0.0005830	0.0000560	0.0000121	0.0000004	0.0000001	0.0000126	0.0315	0.0006928	0.0007613
AT 802A	2	4	300	0.0003764	0.0000361	0.0000078	0.0000002	0.0000001	0.0000081	0.0274	0.0006030	0.0006473
AT 802A	2	4	500	0.0001033	0.0000099	0.0000021	0.0000001	0.0000000	0.0000022	0.0176	0.0003868	0.0003989
AT 802A	2	4	1000	0.0000190	0.0000018	0.0000004	0.0000000	0.0000000	0.0000004	0.0076	0.0001681	0.0001703
AT 802A	2	4	1320	0.0000095	0.0000009	0.0000002	0.0000000	0.0000000	0.0000002	0.0051	0.0001126	0.0001138
AT 802A	2	4	2608	0.0000017	0.0000002	0.0000000	0.0000000	0.0000000	0.0000000	0.0019	0.0000411	0.0000413
AT 802A	2	6	25	0.0612704	0.0058820	0.0012747	0.0000391	0.0000095	0.0013233	0.1042	0.0022924	0.0094977
AT 802A	2	6	50	0.0233127	0.0022380	0.0004850	0.0000149	0.0000036	0.0005035	0.0884	0.0019448	0.0046863
AT 802A	2	6	75	0.0114349	0.0010978	0.0002379	0.0000073	0.0000018	0.0002470	0.0752	0.0016545	0.0029992
AT 802A	2	6	100	0.0064979	0.0006238	0.0001352	0.0000041	0.0000010	0.0001403	0.0650	0.0014300	0.0021941
AT 802A	2	6	150	0.0027453	0.0002635	0.0000571	0.0000018	0.0000004	0.0000593	0.0508	0.0011178	0.0014406
AT 802A	2	6	200	0.0014501	0.0001392	0.0000302	0.0000009	0.0000002	0.0000313	0.0414	0.0009119	0.0010824
AT 802A	2	6	250	0.0008745	0.0000840	0.0000182	0.0000006	0.0000001	0.0000189	0.0348	0.0007656	0.0008684
AT 802A	2	6	300	0.0005646	0.0000542	0.0000117	0.0000004	0.0000001	0.0000122	0.0298	0.0006553	0.0007217
AT 802A	2	6	500	0.0001550	0.0000149	0.0000032	0.0000001	0.0000000	0.0000033	0.0179	0.0003938	0.0004120
AT 802A	2	6	1000	0.0000285	0.0000027	0.0000006	0.0000000	0.0000000	0.0000006	0.0077	0.0001694	0.0001727
AT 802A	2	6	1320	0.0000142	0.0000014	0.0000003	0.0000000	0.0000000	0.0000003	0.0052	0.0001144	0.0001161
AT 802A	2	6	2608	0.0000026	0.0000002	0.0000001	0.0000000	0.0000000	0.0000001	0.0020	0.0000440	0.0000443

* AGDISP modeling for AT802A 2GPA with various application rates was used for inhalation surrogates. Therefore, the air concentrations will be the same for airblast and ground boom at the same application rates. Breathing height was assumed to be 1.7 ft.

Abbreviations: TWA = Time Weighted Average, ADD = Absorbed Daily Dose.

Appendix 2e - Drift Exposure for Children 1-2 Years Old with Airblast Application of Chlorpyrifos

EAS EXPOSURE ESTIMATES												
Orchard Airblast - Sparse Orchard - 60 Swath												
Drift Modeling - AgDRIFT				Dermal Dose		Incidental Oral Dose						
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	external PBPK (mg/kg/day)	9.6% absorption (mg/kg/day)	Hand-to-Mouth (mg/kg/day)	Object-to-Mouth (mg/kg/day)	Soil Ingestion (mg/kg/day)	Combined (mg/kg/day)	1-hr TWA air conc.* (mg/m3)	Inhalation Dose (mg/kg/day)	Drift ADD (mg/kg/day)
AT 802A	2	1	25	0.0082801	0.0007949	0.0001723	0.0000053	0.0000013	0.0001788	0.0292	0.0006424	0.0016161
AT 802A	2	1	50	0.0037711	0.0003620	0.0000785	0.0000024	0.0000006	0.0000814	0.0264	0.0005808	0.0010243
AT 802A	2	1	75	0.0021180	0.0002033	0.0000441	0.0000014	0.0000003	0.0000457	0.0239	0.0005253	0.0007744
AT 802A	2	1	100	0.0013523	0.0001298	0.0000281	0.0000009	0.0000002	0.0000292	0.0220	0.0004840	0.0006430
AT 802A	2	1	150	0.0006882	0.0000661	0.0000143	0.0000004	0.0000001	0.0000149	0.0194	0.0004259	0.0005068
AT 802A	2	1	200	0.0004151	0.0000399	0.0000086	0.0000003	0.0000001	0.0000090	0.0175	0.0003853	0.0004341
AT 802A	2	1	250	0.0002786	0.0000267	0.0000058	0.0000002	0.0000000	0.0000060	0.0161	0.0003542	0.0003870
AT 802A	2	1	300	0.0001993	0.0000191	0.0000041	0.0000001	0.0000000	0.0000043	0.0149	0.0003289	0.0003523
AT 802A	2	1	500	0.0000731	0.0000070	0.0000015	0.0000000	0.0000000	0.0000016	0.0117	0.0002574	0.0002660
AT 802A	2	1	1000	0.0000152	0.0000015	0.0000003	0.0000000	0.0000000	0.0000003	0.0065	0.0001430	0.0001448
AT 802A	2	1	1320	0.0000071	0.0000007	0.0000001	0.0000000	0.0000000	0.0000002	0.0046	0.0001012	0.0001020
AT 802A	2	1	2608	0.0000004	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0016	0.0000352	0.0000352
AT 802A	2	2	25	0.0165602	0.0015898	0.0003445	0.0000106	0.0000026	0.0003577	0.0493	0.0010846	0.0030320
AT 802A	2	2	50	0.0075421	0.0007240	0.0001569	0.0000048	0.0000012	0.0001629	0.0437	0.0009614	0.0018483
AT 802A	2	2	75	0.0042360	0.0004067	0.0000881	0.0000027	0.0000007	0.0000915	0.0386	0.0008491	0.0013472
AT 802A	2	2	100	0.0027047	0.0002596	0.0000563	0.0000017	0.0000004	0.0000584	0.0350	0.0007700	0.0010881
AT 802A	2	2	150	0.0013763	0.0001321	0.0000286	0.0000009	0.0000002	0.0000297	0.0300	0.0006594	0.0008212
AT 802A	2	2	200	0.0008302	0.0000797	0.0000173	0.0000005	0.0000001	0.0000179	0.0264	0.0005815	0.0006791
AT 802A	2	2	250	0.0005572	0.0000535	0.0000116	0.0000004	0.0000001	0.0000120	0.0237	0.0005214	0.0005869
AT 802A	2	2	300	0.0003985	0.0000383	0.0000083	0.0000003	0.0000001	0.0000086	0.0215	0.0004725	0.0005194
AT 802A	2	2	500	0.0001461	0.0000140	0.0000030	0.0000001	0.0000000	0.0000032	0.0153	0.0003366	0.0003538
AT 802A	2	2	1000	0.0000303	0.0000029	0.0000006	0.0000000	0.0000000	0.0000007	0.0072	0.0001584	0.0001620
AT 802A	2	2	1320	0.0000141	0.0000014	0.0000003	0.0000000	0.0000000	0.0000003	0.0049	0.0001078	0.0001095
AT 802A	2	2	2608	0.0000008	0.0000001	0.0000000	0.0000000	0.0000000	0.0000000	0.0016	0.0000352	0.0000353
AT 802A	2	4	25	0.0331204	0.0031796	0.0006890	0.0000212	0.0000051	0.0007153	0.0795	0.0017486	0.0056434
AT 802A	2	4	50	0.0150842	0.0014481	0.0003138	0.0000096	0.0000023	0.0003258	0.0688	0.0015140	0.0032879
AT 802A	2	4	75	0.0084720	0.0008133	0.0001763	0.0000054	0.0000013	0.0001830	0.0594	0.0013075	0.0023037
AT 802A	2	4	100	0.0054094	0.0005193	0.0001125	0.0000035	0.0000008	0.0001168	0.0526	0.0011565	0.0017927
AT 802A	2	4	150	0.0027526	0.0002643	0.0000573	0.0000018	0.0000004	0.0000595	0.0431	0.0009489	0.0012726
AT 802A	2	4	200	0.0016604	0.0001594	0.0000345	0.0000011	0.0000003	0.0000359	0.0367	0.0008076	0.0010029
AT 802A	2	4	250	0.0011143	0.0001070	0.0000232	0.0000007	0.0000002	0.0000241	0.0315	0.0006928	0.0008238
AT 802A	2	4	300	0.0007970	0.0000765	0.0000166	0.0000005	0.0000001	0.0000172	0.0274	0.0006030	0.0006967
AT 802A	2	4	500	0.0002922	0.0000281	0.0000061	0.0000002	0.0000000	0.0000063	0.0176	0.0003868	0.0004211
AT 802A	2	4	1000	0.0000606	0.0000058	0.0000013	0.0000000	0.0000000	0.0000013	0.0076	0.0001681	0.0001752
AT 802A	2	4	1320	0.0000283	0.0000027	0.0000006	0.0000000	0.0000000	0.0000006	0.0051	0.0001126	0.0001160
AT 802A	2	4	2608	0.0000015	0.0000001	0.0000000	0.0000000	0.0000000	0.0000000	0.0019	0.0000411	0.0000413
AT 802A	2	6	25	0.0496805	0.0047693	0.0010336	0.0000317	0.0000077	0.0010730	0.1042	0.0022924	0.0081347
AT 802A	2	6	50	0.0226263	0.0021721	0.0004707	0.0000145	0.0000035	0.0004887	0.0884	0.0019448	0.0046056
AT 802A	2	6	75	0.0127079	0.0012200	0.0002644	0.0000081	0.0000020	0.0002745	0.0752	0.0016545	0.0031489
AT 802A	2	6	100	0.0081140	0.0007789	0.0001688	0.0000052	0.0000013	0.0001752	0.0650	0.0014300	0.0023842
AT 802A	2	6	150	0.0041290	0.0003964	0.0000859	0.0000026	0.0000006	0.0000892	0.0508	0.0011178	0.0016033
AT 802A	2	6	200	0.0024907	0.0002391	0.0000518	0.0000016	0.0000004	0.0000538	0.0414	0.0009119	0.0012048
AT 802A	2	6	250	0.0016715	0.0001605	0.0000348	0.0000011	0.0000003	0.0000361	0.0348	0.0007656	0.0009622
AT 802A	2	6	300	0.0011955	0.0001148	0.0000249	0.0000008	0.0000002	0.0000258	0.0298	0.0006553	0.0007959
AT 802A	2	6	500	0.0004383	0.0000421	0.0000091	0.0000003	0.0000001	0.0000095	0.0179	0.0003938	0.0004453
AT 802A	2	6	1000	0.0000910	0.0000087	0.0000019	0.0000001	0.0000000	0.0000020	0.0077	0.0001694	0.0001801
AT 802A	2	6	1320	0.0000424	0.0000041	0.0000009	0.0000000	0.0000000	0.0000009	0.0052	0.0001144	0.0001194
AT 802A	2	6	2608	0.0000023	0.0000002	0.0000000	0.0000000	0.0000000	0.0000000	0.0020	0.0000440	0.0000443

* AGDISP modeling for AT802A 2GPA with various application rates was used for inhalation surrogates. Therefore, the air concentrations will be the same for airblast and ground boom at the same application rates. Breathing height was assumed to be 1.7 ft.

Abbreviations: TWA = Time Weighted Average, ADD = Absorbed Daily Dose.

RAS RISK CALCULATIONS								
Orchard Airblast - Dormant Apple - 60 Swath								
Drift Modeling - AgDRIFT				Margins of Exposure[a]				
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	Dermal	Combined Incidental Oral	Inhalation	Combined Drift	Combined Drift, Diet & Drinking Water[b]
AT 802A	2	1	25	10	45	16	5	4
AT 802A	2	1	50	27	119	17	10	6
AT 802A	2	1	75	55	243	19	13	7
AT 802A	2	1	100	96	428	21	16	8
AT 802A	2	1	150	228	1012	23	21	9
AT 802A	2	1	200	431	1916	26	24	10
AT 802A	2	1	250	715	3177	28	27	10
AT 802A	2	1	300	1107	4921	30	29	11
AT 802A	2	1	500	4033	17926	39	38	12
AT 802A	2	1	1000	21954	97582	70	70	13
AT 802A	2	1	1320	43912	195181	99	99	14
AT 802A	2	1	2608	240779	1070225	284	284	16
AT 802A	2	2	25	5	23	9	3	2
AT 802A	2	2	50	13	60	10	5	4
AT 802A	2	2	75	27	121	12	8	5
AT 802A	2	2	100	48	214	13	10	6
AT 802A	2	2	150	114	506	15	13	7
AT 802A	2	2	200	215	958	17	16	8
AT 802A	2	2	250	357	1588	19	18	9
AT 802A	2	2	300	554	2460	21	20	9
AT 802A	2	2	500	2016	8963	30	29	11
AT 802A	2	2	1000	10977	48791	63	63	13
AT 802A	2	2	1320	21956	97591	92	92	14
AT 802A	2	2	2608	120389	535113	279	278	16
AT 802A	2	4	25	3	11	6	2	1
AT 802A	2	4	50	7	30	7	3	3
AT 802A	2	4	75	14	61	8	5	4
AT 802A	2	4	100	24	107	9	6	4
AT 802A	2	4	150	57	253	11	9	6
AT 802A	2	4	200	108	479	12	11	7
AT 802A	2	4	250	179	794	14	13	7
AT 802A	2	4	300	277	1230	17	15	8
AT 802A	2	4	500	1008	4481	26	25	10
AT 802A	2	4	1000	5488	24395	59	59	13
AT 802A	2	4	1320	10978	48795	89	88	14
AT 802A	2	4	2608	60195	267557	243	242	15
AT 802A	2	6	25	2	8	4	1	<1
AT 802A	2	6	50	4	20	5	2	2
AT 802A	2	6	75	9	40	6	3	3
AT 802A	2	6	100	16	71	7	5	4
AT 802A	2	6	150	38	169	9	7	5
AT 802A	2	6	200	72	319	11	9	6
AT 802A	2	6	250	119	529	13	12	7
AT 802A	2	6	300	185	820	15	14	8
AT 802A	2	6	500	672	2988	25	24	10
AT 802A	2	6	1000	3659	16264	59	58	13
AT 802A	2	6	1320	7319	32530	87	86	14
AT 802A	2	6	2608	40130	178371	227	226	15

a/ Margin of Exposure = NOEL / Exposure. NOEL = 0.01 mg/kg based on ↑ anxiety and locomotor activity in PND21 male rats (Silva et al 2017).
b/Acute dietary exposure estimate for children 1-2 yrs old was 0.000423 mg/kg/day at the 99.9th percentile consumption rate. Acute drinking water exposure estimated for children 1-2 yrs old was 0.000186 mg/kg/day at the 99.9th percentile consumption rate for DPR's surface water

RAS RISK CALCULATIONS								
Orchard Airblast - Sparse Orchard - 60 Swath								
Drift Modeling - AgDRIFT				Margins of Exposure[a]				
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	Dermal	Combined Incidental Oral	Inhalation	Combined Drift	Combined Drift, Diet & Drinking Water[b]
AT 802A	2	1	25	13	56	16	6	4
AT 802A	2	1	50	28	123	17	10	6
AT 802A	2	1	75	49	219	19	13	7
AT 802A	2	1	100	77	342	21	16	8
AT 802A	2	1	150	151	673	23	20	9
AT 802A	2	1	200	251	1115	26	23	10
AT 802A	2	1	250	374	1662	28	26	10
AT 802A	2	1	300	523	2324	30	28	10
AT 802A	2	1	500	1426	6338	39	38	11
AT 802A	2	1	1000	6871	30538	70	69	13
AT 802A	2	1	1320	14726	65454	99	98	14
AT 802A	2	1	2608	276366	1228403	284	284	16
AT 802A	2	2	25	6	28	9	3	3
AT 802A	2	2	50	14	61	10	5	4
AT 802A	2	2	75	25	109	12	7	5
AT 802A	2	2	100	39	171	13	9	6
AT 802A	2	2	150	76	336	15	12	7
AT 802A	2	2	200	125	558	17	15	8
AT 802A	2	2	250	187	831	19	17	8
AT 802A	2	2	300	261	1162	21	19	9
AT 802A	2	2	500	713	3169	30	28	10
AT 802A	2	2	1000	3435	15269	63	62	13
AT 802A	2	2	1320	7363	32727	93	91	14
AT 802A	2	2	2608	138183	614202	284	283	16
AT 802A	2	4	25	3	14	6	2	2
AT 802A	2	4	50	7	31	7	3	3
AT 802A	2	4	75	12	55	8	4	3
AT 802A	2	4	100	19	86	9	6	4
AT 802A	2	4	150	38	168	11	8	5
AT 802A	2	4	200	63	279	12	10	6
AT 802A	2	4	250	93	415	14	12	7
AT 802A	2	4	300	131	581	17	14	8
AT 802A	2	4	500	356	1584	26	24	10
AT 802A	2	4	1000	1718	7635	59	57	13
AT 802A	2	4	1320	3681	16364	89	86	14
AT 802A	2	4	2608	69092	307101	243	242	15
AT 802A	2	6	25	2	9	4	1	1
AT 802A	2	6	50	5	20	5	2	2
AT 802A	2	6	75	8	36	6	3	3
AT 802A	2	6	100	13	57	7	4	3
AT 802A	2	6	150	25	112	9	6	5
AT 802A	2	6	200	42	186	11	8	6
AT 802A	2	6	250	62	277	13	10	6
AT 802A	2	6	300	87	387	15	13	7
AT 802A	2	6	500	238	1056	25	22	9
AT 802A	2	6	1000	1145	5090	59	56	13
AT 802A	2	6	1320	2454	10909	87	84	14
AT 802A	2	6	2608	46061	204734	227	226	15

a/ Margin of Exposure = NOEL / Exposure. NOEL = 0.01 mg/kg based on ↑ anxiety and locomotor activity in PND21 male rats (Silva et al 2017).
b/Acute dietary exposure estimate for children 1-2 yrs old was 0.000423 mg/kg/day at the 99.9th percentile consumption rate. Acute drinking water exposure estimated for children 1-2 yrs old was 0.000186 mg/kg/day at the 99.9th percentile consumption rate for DPR's surface water

Appendix 2f - Drift Exposure for Children 1-2 Years Old with Ground Boom Application of Chlorpyrifos

EAS EXPOSURE ESTIMATES												
Ground Boom - High Boom 40 swath/50th Percentile												
Drift Modeling - AgDRIFT				Dermal Dose		Incidental Oral Dose				1-hr TWA air conc.* (mg/m3)	Inhalation Dose (mg/kg/day)	Drift ADD (mg/kg/day)
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	external PBPK (mg/kg/day)	9.6% absorption (mg/kg/day)	Hand-to-Mouth (mg/kg/day)	Object-to-Mouth (mg/kg/day)	Soil Ingestion (mg/kg/day)	Combined (mg/kg/day)			
AT 802A	2	1	25	0.0017527	0.0001683	0.0000365	0.0000011	0.0000003	0.0000379	0.0292	0.0006424	0.0008485
AT 802A	2	1	50	0.0011623	0.0001116	0.0000242	0.0000007	0.0000002	0.0000251	0.0264	0.0005808	0.0007175
AT 802A	2	1	75	0.0008671	0.0000832	0.0000180	0.0000006	0.0000001	0.0000187	0.0239	0.0005253	0.0006273
AT 802A	2	1	100	0.0006826	0.0000655	0.0000142	0.0000004	0.0000001	0.0000147	0.0220	0.0004840	0.0005643
AT 802A	2	1	150	0.0004981	0.0000478	0.0000104	0.0000003	0.0000001	0.0000108	0.0194	0.0004259	0.0004845
AT 802A	2	1	200	0.0003874	0.0000372	0.0000081	0.0000002	0.0000001	0.0000084	0.0175	0.0003853	0.0004309
AT 802A	2	1	250	0.0003136	0.0000301	0.0000065	0.0000002	0.0000000	0.0000068	0.0161	0.0003542	0.0003911
AT 802A	2	1	300	0.0002583	0.0000248	0.0000054	0.0000002	0.0000000	0.0000056	0.0149	0.0003289	0.0003593
AT 802A	2	1	500	0.0001340	0.0000129	0.0000028	0.0000001	0.0000000	0.0000029	0.0117	0.0002574	0.0002732
AT 802A	2	1	1000	0.0000403	0.0000039	0.0000008	0.0000000	0.0000000	0.0000009	0.0065	0.0001430	0.0001477
AT 802A	2	1	1320	0.0000219	0.0000021	0.0000005	0.0000000	0.0000000	0.0000005	0.0046	0.0001012	0.0001038
AT 802A	2	1	2608	0.0000032	0.0000003	0.0000001	0.0000000	0.0000000	0.0000001	0.0016	0.0000352	0.0000356
AT 802A	2	2	25	0.0035054	0.0003365	0.0000729	0.0000022	0.0000005	0.0000757	0.0493	0.0010846	0.0014968
AT 802A	2	2	50	0.0023246	0.0002232	0.0000484	0.0000015	0.0000004	0.0000502	0.0437	0.0009614	0.0012348
AT 802A	2	2	75	0.0017342	0.0001665	0.0000361	0.0000011	0.0000003	0.0000375	0.0386	0.0008491	0.0010530
AT 802A	2	2	100	0.0013653	0.0001311	0.0000284	0.0000009	0.0000002	0.0000295	0.0350	0.0007700	0.0009306
AT 802A	2	2	150	0.0009963	0.0000956	0.0000207	0.0000006	0.0000002	0.0000215	0.0300	0.0006594	0.0007765
AT 802A	2	2	200	0.0007749	0.0000744	0.0000161	0.0000005	0.0000001	0.0000167	0.0264	0.0005815	0.0006726
AT 802A	2	2	250	0.0006273	0.0000602	0.0000131	0.0000004	0.0000001	0.0000135	0.0237	0.0005214	0.0005952
AT 802A	2	2	300	0.0005166	0.0000496	0.0000107	0.0000003	0.0000001	0.0000112	0.0215	0.0004725	0.0005333
AT 802A	2	2	500	0.0002681	0.0000257	0.0000056	0.0000002	0.0000000	0.0000058	0.0153	0.0003366	0.0003681
AT 802A	2	2	1000	0.0000807	0.0000077	0.0000017	0.0000001	0.0000000	0.0000017	0.0072	0.0001584	0.0001679
AT 802A	2	2	1320	0.0000438	0.0000042	0.0000009	0.0000000	0.0000000	0.0000009	0.0049	0.0001082	0.0001134
AT 802A	2	2	2608	0.0000065	0.0000006	0.0000001	0.0000000	0.0000000	0.0000001	0.0016	0.0000359	0.0000366
AT 802A	2	4	25	0.0070108	0.0006730	0.0001459	0.0000045	0.0000011	0.0001514	0.0795	0.0017486	0.0025730
AT 802A	2	4	50	0.0046492	0.0004463	0.0000967	0.0000030	0.0000007	0.0001004	0.0688	0.0015140	0.0020608
AT 802A	2	4	75	0.0034685	0.0003330	0.0000722	0.0000022	0.0000005	0.0000749	0.0594	0.0013075	0.0017153
AT 802A	2	4	100	0.0027305	0.0002621	0.0000568	0.0000017	0.0000004	0.0000590	0.0526	0.0011565	0.0014776
AT 802A	2	4	150	0.0019925	0.0001913	0.0000415	0.0000013	0.0000003	0.0000430	0.0431	0.0009489	0.0011832
AT 802A	2	4	200	0.0015497	0.0001488	0.0000322	0.0000010	0.0000002	0.0000335	0.0367	0.0008076	0.0009899
AT 802A	2	4	250	0.0012546	0.0001204	0.0000261	0.0000008	0.0000002	0.0000271	0.0315	0.0006928	0.0008403
AT 802A	2	4	300	0.0010332	0.0000992	0.0000215	0.0000007	0.0000002	0.0000223	0.0274	0.0006030	0.0007245
AT 802A	2	4	500	0.0005361	0.0000515	0.0000112	0.0000003	0.0000001	0.0000116	0.0176	0.0003868	0.0004498
AT 802A	2	4	1000	0.0001613	0.0000155	0.0000034	0.0000001	0.0000000	0.0000035	0.0076	0.0001681	0.0001870
AT 802A	2	4	1320	0.0000876	0.0000084	0.0000018	0.0000001	0.0000000	0.0000019	0.0051	0.0001126	0.0001229
AT 802A	2	4	2608	0.0000130	0.0000012	0.0000003	0.0000000	0.0000000	0.0000003	0.0019	0.0000411	0.0000427
AT 802A	2	6	25	0.0105162	0.0010096	0.0002188	0.0000067	0.0000016	0.0002271	0.1042	0.0022924	0.0035291
AT 802A	2	6	50	0.0069739	0.0006695	0.0001451	0.0000045	0.0000011	0.0001506	0.0884	0.0019448	0.0027649
AT 802A	2	6	75	0.0052027	0.0004995	0.0001082	0.0000033	0.0000008	0.0001124	0.0752	0.0016545	0.0022663
AT 802A	2	6	100	0.0040958	0.0003932	0.0000852	0.0000026	0.0000006	0.0000885	0.0650	0.0014300	0.0019117
AT 802A	2	6	150	0.0029888	0.0002869	0.0000622	0.0000019	0.0000005	0.0000646	0.0508	0.0011178	0.0014692
AT 802A	2	6	200	0.0023246	0.0002232	0.0000484	0.0000015	0.0000004	0.0000502	0.0414	0.0009119	0.0011852
AT 802A	2	6	250	0.0018818	0.0001807	0.0000392	0.0000012	0.0000003	0.0000406	0.0348	0.0007656	0.0009869
AT 802A	2	6	300	0.0015497	0.0001488	0.0000322	0.0000010	0.0000002	0.0000335	0.0298	0.0006553	0.0008375
AT 802A	2	6	500	0.0008042	0.0000772	0.0000167	0.0000005	0.0000001	0.0000174	0.0179	0.0003938	0.0004884
AT 802A	2	6	1000	0.0002420	0.0000232	0.0000050	0.0000002	0.0000000	0.0000052	0.0077	0.0001694	0.0001979
AT 802A	2	6	1320	0.0001314	0.0000126	0.0000027	0.0000001	0.0000000	0.0000028	0.0052	0.0001144	0.0001299
AT 802A	2	6	2608	0.0000194	0.0000019	0.0000004	0.0000000	0.0000000	0.0000004	0.0020	0.0000440	0.0000463

* AGDISP modeling for AT802A 2GPA with various application rates was used for inhalation surrogates. Therefore, the air concentrations will be the same for airblast and ground boom at the same application rates. Breathing height was assumed to be 1.7 ft.

Abbreviations: TWA = Time Weighted Average, ADD = Absorbed Daily Dose.

Appendix 2f - Drift Exposure for Children 1-2 Years Old with Ground Boom Application of Chlorpyrifos

EAS EXPOSURE ESTIMATES												
Ground Boom - Low Boom 40 swath/50th Percentile												
Drift Modeling - AgDRIFT				Dermal Dose		Incidental Oral Dose				1-hr TWA air conc.* (mg/m3)	Inhalation Dose (mg/kg/day)	Drift ADD (mg/kg/day)
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	external PBPK (mg/kg/day)	9.6% absorption (mg/kg/day)	Hand-to-Mouth (mg/kg/day)	Object-to-Mouth (mg/kg/day)	Soil Ingestion (mg/kg/day)	Combined (mg/kg/day)			
AT 802A	2	1	25	0.0009225	0.0000886	0.0000192	0.0000006	0.0000001	0.0000199	0.0292	0.0006424	0.0007509
AT 802A	2	1	50	0.0006273	0.0000602	0.0000131	0.0000004	0.0000001	0.0000135	0.0264	0.0005808	0.0006546
AT 802A	2	1	75	0.0004797	0.0000460	0.0000100	0.0000003	0.0000001	0.0000104	0.0239	0.0005253	0.0005817
AT 802A	2	1	100	0.0003690	0.0000354	0.0000077	0.0000002	0.0000001	0.0000080	0.0220	0.0004840	0.0005274
AT 802A	2	1	150	0.0002767	0.0000266	0.0000058	0.0000002	0.0000000	0.0000060	0.0194	0.0004259	0.0004584
AT 802A	2	1	200	0.0002214	0.0000213	0.0000046	0.0000001	0.0000000	0.0000048	0.0175	0.0003853	0.0004114
AT 802A	2	1	250	0.0001845	0.0000177	0.0000038	0.0000001	0.0000000	0.0000040	0.0161	0.0003542	0.0003759
AT 802A	2	1	300	0.0001660	0.0000159	0.0000035	0.0000001	0.0000000	0.0000036	0.0149	0.0003289	0.0003484
AT 802A	2	1	500	0.0000950	0.0000091	0.0000020	0.0000001	0.0000000	0.0000021	0.0117	0.0002574	0.0002686
AT 802A	2	1	1000	0.0000360	0.0000035	0.0000007	0.0000000	0.0000000	0.0000008	0.0065	0.0001430	0.0001472
AT 802A	2	1	1320	0.0000220	0.0000021	0.0000005	0.0000000	0.0000000	0.0000005	0.0046	0.0001012	0.0001038
AT 802A	2	1	2608	0.0000047	0.0000005	0.0000001	0.0000000	0.0000000	0.0000001	0.0016	0.0000352	0.0000358
AT 802A	2	2	25	0.0018449	0.0001771	0.0000384	0.0000012	0.0000003	0.0000398	0.0493	0.0010846	0.0013016
AT 802A	2	2	50	0.0012546	0.0001204	0.0000261	0.0000008	0.0000002	0.0000271	0.0437	0.0009614	0.0011089
AT 802A	2	2	75	0.0009594	0.0000921	0.0000200	0.0000006	0.0000001	0.0000207	0.0386	0.0008491	0.0009619
AT 802A	2	2	100	0.0007380	0.0000708	0.0000154	0.0000005	0.0000001	0.0000159	0.0350	0.0007700	0.0008568
AT 802A	2	2	150	0.0005535	0.0000531	0.0000115	0.0000004	0.0000001	0.0000120	0.0300	0.0006594	0.0007245
AT 802A	2	2	200	0.0004428	0.0000425	0.0000092	0.0000003	0.0000001	0.0000096	0.0264	0.0005815	0.0006335
AT 802A	2	2	250	0.0003690	0.0000354	0.0000077	0.0000002	0.0000001	0.0000080	0.0237	0.0005214	0.0005648
AT 802A	2	2	300	0.0003321	0.0000319	0.0000069	0.0000002	0.0000001	0.0000072	0.0215	0.0004725	0.0005116
AT 802A	2	2	500	0.0001900	0.0000182	0.0000040	0.0000001	0.0000000	0.0000041	0.0153	0.0003366	0.0003589
AT 802A	2	2	1000	0.0000720	0.0000069	0.0000015	0.0000000	0.0000000	0.0000016	0.0072	0.0001584	0.0001669
AT 802A	2	2	1320	0.0000440	0.0000042	0.0000009	0.0000000	0.0000000	0.0000009	0.0049	0.0001078	0.0001130
AT 802A	2	2	2608	0.0000094	0.0000009	0.0000002	0.0000000	0.0000000	0.0000002	0.0016	0.0000352	0.0000363
AT 802A	2	4	25	0.0036899	0.0003542	0.0000768	0.0000024	0.0000006	0.0000797	0.0795	0.0017486	0.0021825
AT 802A	2	4	50	0.0025091	0.0002409	0.0000522	0.0000016	0.0000004	0.0000542	0.0688	0.0015140	0.0018091
AT 802A	2	4	75	0.0019187	0.0001842	0.0000399	0.0000012	0.0000003	0.0000414	0.0594	0.0013075	0.0015331
AT 802A	2	4	100	0.0014760	0.0001417	0.0000307	0.0000009	0.0000002	0.0000319	0.0526	0.0011565	0.0013301
AT 802A	2	4	150	0.0011070	0.0001063	0.0000230	0.0000007	0.0000002	0.0000239	0.0431	0.0009489	0.0010790
AT 802A	2	4	200	0.0008856	0.0000850	0.0000184	0.0000006	0.0000001	0.0000191	0.0367	0.0008076	0.0009118
AT 802A	2	4	250	0.0007380	0.0000708	0.0000154	0.0000005	0.0000001	0.0000159	0.0315	0.0006928	0.0007796
AT 802A	2	4	300	0.0006642	0.0000638	0.0000138	0.0000004	0.0000001	0.0000143	0.0274	0.0006030	0.0006811
AT 802A	2	4	500	0.0003801	0.0000365	0.0000079	0.0000002	0.0000001	0.0000082	0.0176	0.0003868	0.0004315
AT 802A	2	4	1000	0.0001440	0.0000138	0.0000030	0.0000001	0.0000000	0.0000031	0.0076	0.0001681	0.0001850
AT 802A	2	4	1320	0.0000879	0.0000084	0.0000018	0.0000001	0.0000000	0.0000019	0.0051	0.0001126	0.0001230
AT 802A	2	4	2608	0.0000188	0.0000018	0.0000004	0.0000000	0.0000000	0.0000004	0.0019	0.0000411	0.0000433
AT 802A	2	6	25	0.0055348	0.0005313	0.0001151	0.0000035	0.0000009	0.0001195	0.1042	0.0022924	0.0029433
AT 802A	2	6	50	0.0037637	0.0003613	0.0000783	0.0000024	0.0000006	0.0000813	0.0884	0.0019448	0.0023874
AT 802A	2	6	75	0.0028781	0.0002763	0.0000599	0.0000018	0.0000004	0.0000622	0.0752	0.0016545	0.0019930
AT 802A	2	6	100	0.0022139	0.0002125	0.0000461	0.0000014	0.0000003	0.0000478	0.0650	0.0014300	0.0016904
AT 802A	2	6	150	0.0016604	0.0001594	0.0000345	0.0000011	0.0000003	0.0000359	0.0508	0.0011178	0.0013130
AT 802A	2	6	200	0.0013284	0.0001275	0.0000276	0.0000008	0.0000002	0.0000287	0.0414	0.0009119	0.0010681
AT 802A	2	6	250	0.0011070	0.0001063	0.0000230	0.0000007	0.0000002	0.0000239	0.0348	0.0007656	0.0008958
AT 802A	2	6	300	0.0009963	0.0000956	0.0000207	0.0000006	0.0000002	0.0000215	0.0298	0.0006553	0.0007724
AT 802A	2	6	500	0.0005701	0.0000547	0.0000119	0.0000004	0.0000001	0.0000123	0.0179	0.0003938	0.0004608
AT 802A	2	6	1000	0.0002160	0.0000207	0.0000045	0.0000001	0.0000000	0.0000047	0.0077	0.0001694	0.0001948
AT 802A	2	6	1320	0.0001319	0.0000127	0.0000027	0.0000001	0.0000000	0.0000028	0.0052	0.0001144	0.0001299
AT 802A	2	6	2608	0.0000281	0.0000027	0.0000006	0.0000000	0.0000000	0.0000006	0.0020	0.0000440	0.0000473

* AGDISP modeling for AT802A 2GPA with various application rates was used for inhalation surrogates. Therefore, the air concentrations will be the same for airblast and ground boom at the same application rates. Breathing height was assumed to be 1.7 ft.

Abbreviations: TWA = Time Weighted Average, ADD = Absorbed Daily Dose.

Appendix 2f - Drift Exposure for Children 1-2 Years Old with Ground Boom Application of Chlorpyrifos

EAS EXPOSURE ESTIMATES												
Ground Boom - High Boom 40 swath/90th Percentile												
Drift Modeling - AgDRIFT				Dermal Dose		Incidental Oral Dose				1-hr TWA air conc.* (mg/m3)	Inhalation Dose (mg/kg/day)	Drift ADD (mg/kg/day)
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	external PBPK (mg/kg/day)	9.6% absorption (mg/kg/day)	Hand-to-Mouth (mg/kg/day)	Object-to-Mouth (mg/kg/day)	Soil Ingestion (mg/kg/day)	Combined (mg/kg/day)			
AT 802A	2	1	25	0.0024907	0.0002391	0.0000518	0.0000016	0.0000004	0.0000538	0.0292	0.0151840	0.0154769
AT 802A	2	1	50	0.0017896	0.0001718	0.0000372	0.0000011	0.0000003	0.0000387	0.0264	0.0137280	0.0139385
AT 802A	2	1	75	0.0013837	0.0001328	0.0000288	0.0000009	0.0000002	0.0000299	0.0239	0.0124157	0.0125784
AT 802A	2	1	100	0.0011070	0.0001063	0.0000230	0.0000007	0.0000002	0.0000239	0.0220	0.0114400	0.0115702
AT 802A	2	1	150	0.0008302	0.0000797	0.0000173	0.0000005	0.0000001	0.0000179	0.0194	0.0100667	0.0101643
AT 802A	2	1	200	0.0006642	0.0000638	0.0000138	0.0000004	0.0000001	0.0000143	0.0175	0.0091079	0.0091860
AT 802A	2	1	250	0.0005535	0.0000531	0.0000115	0.0000004	0.0000001	0.0000120	0.0161	0.0083720	0.0084371
AT 802A	2	1	300	0.0004797	0.0000460	0.0000100	0.0000003	0.0000001	0.0000104	0.0149	0.0077739	0.0078303
AT 802A	2	1	500	0.0003152	0.0000303	0.0000066	0.0000002	0.0000000	0.0000068	0.0117	0.0060840	0.0061211
AT 802A	2	1	1000	0.0001761	0.0000169	0.0000037	0.0000001	0.0000000	0.0000038	0.0065	0.0033800	0.0034007
AT 802A	2	1	1320	0.0001390	0.0000133	0.0000029	0.0000001	0.0000000	0.0000030	0.0046	0.0023920	0.0024083
AT 802A	2	1	2608	0.0000772	0.0000074	0.0000016	0.0000000	0.0000000	0.0000017	0.0016	0.0008320	0.0008411
AT 802A	2	2	25	0.0049813	0.0004782	0.0001036	0.0000032	0.0000008	0.0001076	0.0493	0.0256360	0.0262218
AT 802A	2	2	50	0.0035792	0.0003436	0.0000745	0.0000023	0.0000006	0.0000773	0.0437	0.0227240	0.0231449
AT 802A	2	2	75	0.0027674	0.0002657	0.0000576	0.0000018	0.0000004	0.0000598	0.0386	0.0200696	0.0203950
AT 802A	2	2	100	0.0022139	0.0002125	0.0000461	0.0000014	0.0000003	0.0000478	0.0350	0.0182000	0.0184604
AT 802A	2	2	150	0.0016604	0.0001594	0.0000345	0.0000011	0.0000003	0.0000359	0.0300	0.0155854	0.0157807
AT 802A	2	2	200	0.0013284	0.0001275	0.0000276	0.0000008	0.0000002	0.0000287	0.0264	0.0137440	0.0139002
AT 802A	2	2	250	0.0011070	0.0001063	0.0000230	0.0000007	0.0000002	0.0000239	0.0237	0.0123240	0.0124542
AT 802A	2	2	300	0.0009594	0.0000921	0.0000200	0.0000006	0.0000001	0.0000207	0.0215	0.0111684	0.0112812
AT 802A	2	2	500	0.0006304	0.0000605	0.0000131	0.0000004	0.0000001	0.0000136	0.0153	0.0079560	0.0080301
AT 802A	2	2	1000	0.0003522	0.0000338	0.0000073	0.0000002	0.0000001	0.0000076	0.0072	0.0037440	0.0037854
AT 802A	2	2	1320	0.0002779	0.0000267	0.0000058	0.0000002	0.0000000	0.0000060	0.0049	0.0025480	0.0025807
AT 802A	2	2	2608	0.0001544	0.0000148	0.0000032	0.0000001	0.0000000	0.0000033	0.0016	0.0008320	0.0008502
AT 802A	2	4	25	0.0099627	0.0009564	0.0002073	0.0000064	0.0000015	0.0002152	0.0795	0.0413296	0.0425012
AT 802A	2	4	50	0.0071584	0.0006872	0.0001489	0.0000046	0.0000011	0.0001546	0.0688	0.0357864	0.0366282
AT 802A	2	4	75	0.0055348	0.0005313	0.0001151	0.0000035	0.0000009	0.0001195	0.0594	0.0309036	0.0315545
AT 802A	2	4	100	0.0044279	0.0004251	0.0000921	0.0000028	0.0000007	0.0000956	0.0526	0.0273364	0.0278571
AT 802A	2	4	150	0.0033209	0.0003188	0.0000691	0.0000021	0.0000005	0.0000717	0.0431	0.0224276	0.0228181
AT 802A	2	4	200	0.0026567	0.0002550	0.0000553	0.0000017	0.0000004	0.0000574	0.0367	0.0190892	0.0194016
AT 802A	2	4	250	0.0022139	0.0002125	0.0000461	0.0000014	0.0000003	0.0000478	0.0315	0.0163748	0.0166352
AT 802A	2	4	300	0.0019187	0.0001842	0.0000399	0.0000012	0.0000003	0.0000414	0.0274	0.0142532	0.0144788
AT 802A	2	4	500	0.0012608	0.0001210	0.0000262	0.0000008	0.0000002	0.0000272	0.0176	0.0091416	0.0092899
AT 802A	2	4	1000	0.0007044	0.0000676	0.0000147	0.0000004	0.0000001	0.0000152	0.0076	0.0039728	0.0040556
AT 802A	2	4	1320	0.0005559	0.0000534	0.0000116	0.0000004	0.0000001	0.0000120	0.0051	0.0026624	0.0027278
AT 802A	2	4	2608	0.0003087	0.0000296	0.0000064	0.0000002	0.0000000	0.0000067	0.0019	0.0009724	0.0010087
AT 802A	2	6	25	0.0149440	0.0014346	0.0003109	0.0000095	0.0000023	0.0003228	0.1042	0.0541840	0.0559414
AT 802A	2	6	50	0.0107375	0.0010308	0.0002234	0.0000069	0.0000017	0.0002319	0.0884	0.0459680	0.0472307
AT 802A	2	6	75	0.0083022	0.0007970	0.0001727	0.0000053	0.0000013	0.0001793	0.0752	0.0391062	0.0400825
AT 802A	2	6	100	0.0066418	0.0006376	0.0001382	0.0000042	0.0000010	0.0001434	0.0650	0.0338000	0.0345811
AT 802A	2	6	150	0.0049813	0.0004782	0.0001036	0.0000032	0.0000008	0.0001076	0.0508	0.0264196	0.0270054
AT 802A	2	6	200	0.0039851	0.0003826	0.0000829	0.0000025	0.0000006	0.0000861	0.0414	0.0215534	0.0220221
AT 802A	2	6	250	0.0033209	0.0003188	0.0000691	0.0000021	0.0000005	0.0000717	0.0348	0.0180960	0.0184865
AT 802A	2	6	300	0.0028781	0.0002763	0.0000599	0.0000018	0.0000004	0.0000622	0.0298	0.0154880	0.0158265
AT 802A	2	6	500	0.0018912	0.0001816	0.0000393	0.0000012	0.0000003	0.0000408	0.0179	0.0093080	0.0095304
AT 802A	2	6	1000	0.0010566	0.0001014	0.0000220	0.0000007	0.0000002	0.0000228	0.0077	0.0040040	0.0041283
AT 802A	2	6	1320	0.0008338	0.0000800	0.0000173	0.0000005	0.0000001	0.0000180	0.0052	0.0027040	0.0028021
AT 802A	2	6	2608	0.0004631	0.0000445	0.0000096	0.0000003	0.0000001	0.0000100	0.0020	0.0010400	0.0010945

* AGDISP modeling for AT802A 2GPA with various application rates was used for inhalation surrogates. Therefore, the air concentrations will be the same for airblast and ground boom at the same application rates. Breathing height was assumed to be 1.7 ft.

Abbreviations: TWA = Time Weighted Average, ADD = Absorbed Daily Dose.

Appendix 2f - Drift Exposure for Children 1-2 Years Old with Ground Boom Application of Chlorpyrifos

EAS EXPOSURE ESTIMATES												
Ground Boom - Low Boom 40 swath/90th Percentile												
Drift Modeling - AgDRIFT				Dermal Dose		Incidental Oral Dose				1-hr TWA air conc.* (mg/m3)	Inhalation Dose (mg/kg/day)	Drift ADD (mg/kg/day)
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	external PBPK (mg/kg/day)	9.6% absorption (mg/kg/day)	Hand-to-Mouth (mg/kg/day)	Object-to-Mouth (mg/kg/day)	Soil Ingestion (mg/kg/day)	Combined (mg/kg/day)			
AT 802A	2	1	25	0.0015682	0.0001505	0.0000326	0.0000010	0.0000002	0.0000339	0.0292	0.0151840	0.0153684
AT 802A	2	1	50	0.0011439	0.0001098	0.0000238	0.0000007	0.0000002	0.0000247	0.0264	0.0137280	0.0138625
AT 802A	2	1	75	0.0008856	0.0000850	0.0000184	0.0000006	0.0000001	0.0000191	0.0239	0.0124157	0.0125198
AT 802A	2	1	100	0.0007195	0.0000691	0.0000150	0.0000005	0.0000001	0.0000155	0.0220	0.0114400	0.0115246
AT 802A	2	1	150	0.0005350	0.0000514	0.0000111	0.0000003	0.0000001	0.0000116	0.0194	0.0100667	0.0101296
AT 802A	2	1	200	0.0004428	0.0000425	0.0000092	0.0000003	0.0000001	0.0000096	0.0175	0.0091079	0.0091600
AT 802A	2	1	250	0.0003690	0.0000354	0.0000077	0.0000002	0.0000001	0.0000080	0.0161	0.0083720	0.0084154
AT 802A	2	1	300	0.0003321	0.0000319	0.0000069	0.0000002	0.0000001	0.0000072	0.0149	0.0077739	0.0078130
AT 802A	2	1	500	0.0002228	0.0000214	0.0000046	0.0000001	0.0000000	0.0000048	0.0117	0.0060840	0.0061102
AT 802A	2	1	1000	0.0001278	0.0000123	0.0000027	0.0000001	0.0000000	0.0000028	0.0065	0.0033800	0.0033950
AT 802A	2	1	1320	0.0001016	0.0000098	0.0000021	0.0000001	0.0000000	0.0000022	0.0046	0.0023920	0.0024039
AT 802A	2	1	2608	0.0000571	0.0000055	0.0000012	0.0000000	0.0000000	0.0000012	0.0016	0.0008320	0.0008387
AT 802A	2	2	25	0.0031364	0.0003011	0.0000653	0.0000020	0.0000005	0.0000677	0.0493	0.0256360	0.0260048
AT 802A	2	2	50	0.0022877	0.0002196	0.0000476	0.0000015	0.0000004	0.0000494	0.0437	0.0227240	0.0229930
AT 802A	2	2	75	0.0017711	0.0001700	0.0000368	0.0000011	0.0000003	0.0000383	0.0386	0.0200696	0.0202779
AT 802A	2	2	100	0.0014391	0.0001381	0.0000299	0.0000009	0.0000002	0.0000311	0.0350	0.0182000	0.0183692
AT 802A	2	2	150	0.0010701	0.0001027	0.0000223	0.0000007	0.0000002	0.0000231	0.0300	0.0155854	0.0157112
AT 802A	2	2	200	0.0008856	0.0000850	0.0000184	0.0000006	0.0000001	0.0000191	0.0264	0.0137440	0.0138482
AT 802A	2	2	250	0.0007380	0.0000708	0.0000154	0.0000005	0.0000001	0.0000159	0.0237	0.0123240	0.0124108
AT 802A	2	2	300	0.0006642	0.0000638	0.0000138	0.0000004	0.0000001	0.0000143	0.0215	0.0111684	0.0112465
AT 802A	2	2	500	0.0004456	0.0000428	0.0000093	0.0000003	0.0000001	0.0000096	0.0153	0.0079560	0.0080084
AT 802A	2	2	1000	0.0002556	0.0000245	0.0000053	0.0000002	0.0000000	0.0000055	0.0072	0.0037440	0.0037741
AT 802A	2	2	1320	0.0002032	0.0000195	0.0000042	0.0000001	0.0000000	0.0000044	0.0049	0.0025584	0.0025823
AT 802A	2	2	2608	0.0001142	0.0000110	0.0000024	0.0000001	0.0000000	0.0000025	0.0016	0.0008476	0.0008610
AT 802A	2	4	25	0.0062728	0.0006022	0.0001305	0.0000040	0.0000010	0.0001355	0.0795	0.0413296	0.0420673
AT 802A	2	4	50	0.0045754	0.0004392	0.0000952	0.0000029	0.0000007	0.0000988	0.0688	0.0357864	0.0363245
AT 802A	2	4	75	0.0035423	0.0003401	0.0000737	0.0000023	0.0000005	0.0000765	0.0594	0.0309036	0.0313202
AT 802A	2	4	100	0.0028781	0.0002763	0.0000599	0.0000018	0.0000004	0.0000622	0.0526	0.0273364	0.0276749
AT 802A	2	4	150	0.0021401	0.0002055	0.0000445	0.0000014	0.0000003	0.0000462	0.0431	0.0224276	0.0226793
AT 802A	2	4	200	0.0017711	0.0001700	0.0000368	0.0000011	0.0000003	0.0000383	0.0367	0.0190892	0.0192975
AT 802A	2	4	250	0.0014760	0.0001417	0.0000307	0.0000009	0.0000002	0.0000319	0.0315	0.0163748	0.0165484
AT 802A	2	4	300	0.0013284	0.0001275	0.0000276	0.0000008	0.0000002	0.0000287	0.0274	0.0142532	0.0144094
AT 802A	2	4	500	0.0008912	0.0000856	0.0000185	0.0000006	0.0000001	0.0000192	0.0176	0.0091416	0.0092464
AT 802A	2	4	1000	0.0005113	0.0000491	0.0000106	0.0000003	0.0000001	0.0000110	0.0076	0.0039728	0.0040329
AT 802A	2	4	1320	0.0004064	0.0000390	0.0000085	0.0000003	0.0000001	0.0000088	0.0051	0.0026624	0.0027102
AT 802A	2	4	2608	0.0002284	0.0000219	0.0000048	0.0000001	0.0000000	0.0000049	0.0019	0.0009724	0.0009993
AT 802A	2	6	25	0.0094092	0.0009033	0.0001958	0.0000060	0.0000015	0.0002032	0.1042	0.0541840	0.0552905
AT 802A	2	6	50	0.0068632	0.0006589	0.0001428	0.0000044	0.0000011	0.0001482	0.0884	0.0459680	0.0467751
AT 802A	2	6	75	0.0053134	0.0005101	0.0001105	0.0000034	0.0000008	0.0001148	0.0752	0.0391062	0.0397310
AT 802A	2	6	100	0.0043172	0.0004144	0.0000898	0.0000028	0.0000007	0.0000932	0.0650	0.0338000	0.0343077
AT 802A	2	6	150	0.0032102	0.0003082	0.0000668	0.0000021	0.0000005	0.0000693	0.0508	0.0264196	0.0267971
AT 802A	2	6	200	0.0026567	0.0002550	0.0000553	0.0000017	0.0000004	0.0000574	0.0414	0.0215534	0.0218659
AT 802A	2	6	250	0.0022139	0.0002125	0.0000461	0.0000014	0.0000003	0.0000478	0.0348	0.0180960	0.0183564
AT 802A	2	6	300	0.0019925	0.0001913	0.0000415	0.0000013	0.0000003	0.0000430	0.0298	0.0154880	0.0157223
AT 802A	2	6	500	0.0013369	0.0001283	0.0000278	0.0000009	0.0000002	0.0000289	0.0179	0.0093080	0.0094652
AT 802A	2	6	1000	0.0007669	0.0000736	0.0000160	0.0000005	0.0000001	0.0000166	0.0077	0.0040040	0.0040942
AT 802A	2	6	1320	0.0006096	0.0000585	0.0000127	0.0000004	0.0000001	0.0000132	0.0052	0.0027040	0.0027757
AT 802A	2	6	2608	0.0003426	0.0000329	0.0000071	0.0000002	0.0000001	0.0000074	0.0020	0.0010400	0.0010803

* AGDISP modeling for AT802A 2GPA with various application rates was used for inhalation surrogates. Therefore, the air concentrations will be the same for airblast and ground boom at the same application rates. Breathing height was assumed to be 1.7 ft.

Abbreviations: TWA = Time Weighted Average, ADD = Absorbed Daily Dose.

Appendix 2f - Drift Exposure for Children 1-2 Years Old with Ground Boom Application of Chlorpyrifos

RAS RISK CALCULATIONS								
Ground Boom - High Boom 40 swath/50th Percentile								
Drift Modeling - AgDRIFT				Margins of Exposure[a]				
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	Dermal	Combined Incidental Oral	Inhalation	Combined Drift	Combined Drift, Diet & Drinking Water[b]
AT 802A	2	1	25	59	264	16	12	7
AT 802A	2	1	50	90	398	17	14	8
AT 802A	2	1	75	120	534	19	16	8
AT 802A	2	1	100	153	678	21	18	9
AT 802A	2	1	150	209	929	23	21	9
AT 802A	2	1	200	269	1195	26	23	10
AT 802A	2	1	250	332	1476	28	26	10
AT 802A	2	1	300	403	1793	30	28	10
AT 802A	2	1	500	777	3455	39	37	11
AT 802A	2	1	1000	2583	11481	70	68	13
AT 802A	2	1	1320	4757	21143	99	96	14
AT 802A	2	1	2608	32151	142906	284	281	16
AT 802A	2	2	25	30	132	9	7	5
AT 802A	2	2	50	45	199	10	8	5
AT 802A	2	2	75	60	267	12	9	6
AT 802A	2	2	100	76	339	13	11	6
AT 802A	2	2	150	105	465	15	13	7
AT 802A	2	2	200	134	598	17	15	8
AT 802A	2	2	250	166	738	19	17	8
AT 802A	2	2	300	202	896	21	19	9
AT 802A	2	2	500	389	1727	30	27	10
AT 802A	2	2	1000	1291	5740	63	60	13
AT 802A	2	2	1320	2378	10571	92	88	14
AT 802A	2	2	2608	16075	71453	279	273	15
AT 802A	2	4	25	15	66	6	4	3
AT 802A	2	4	50	22	100	7	5	4
AT 802A	2	4	75	30	133	8	6	4
AT 802A	2	4	100	38	170	9	7	5
AT 802A	2	4	150	52	232	11	8	6
AT 802A	2	4	200	67	299	12	10	6
AT 802A	2	4	250	83	369	14	12	7
AT 802A	2	4	300	101	448	17	14	7
AT 802A	2	4	500	194	864	26	22	9
AT 802A	2	4	1000	646	2870	59	53	13
AT 802A	2	4	1320	1189	5286	89	81	14
AT 802A	2	4	2608	8038	35726	243	234	15
AT 802A	2	6	25	10	44	4	3	2
AT 802A	2	6	50	15	66	5	4	3
AT 802A	2	6	75	20	89	6	4	3
AT 802A	2	6	100	25	113	7	5	4
AT 802A	2	6	150	35	155	9	7	5
AT 802A	2	6	200	45	199	11	8	6
AT 802A	2	6	250	55	246	13	10	6
AT 802A	2	6	300	67	299	15	12	7
AT 802A	2	6	500	130	576	25	20	9
AT 802A	2	6	1000	430	1913	59	51	12
AT 802A	2	6	1320	793	3524	87	77	14
AT 802A	2	6	2608	5358	23818	227	216	15

a/ Margin of Exposure = NOEL / Exposure. NOEL = 0.01 mg/kg based on ↑ anxiety and locomotor activity in PND21 male rats (Silva et al 2017).
b/Acute dietary exposure estimate for children 1-2 yrs old was 0.000423 mg/kg/day at the 99.9th percentile consumption rate. Acute drinking water exposure estimated for children 1-2 yrs old was 0.000186 mg/kg/day at the 99.9th percentile consumption rate for DPR's surface water monitoring data.

RAS RISK CALCULATIONS								
Ground Boom - Low Boom 40 swath/50th Percentile								
Drift Modeling - AgDRIFT				Margins of Exposure[a]				
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	Dermal	Combined Incidental Oral	Inhalation	Combined Drift	Combined Drift, Diet & Drinking Water[b]
AT 802A	2	1	25	113	502	16	13	7
AT 802A	2	1	50	166	738	17	15	8
AT 802A	2	1	75	217	965	19	17	8
AT 802A	2	1	100	282	1255	21	19	9
AT 802A	2	1	150	376	1673	23	22	9
AT 802A	2	1	200	471	2091	26	24	10
AT 802A	2	1	250	565	2510	28	27	10
AT 802A	2	1	300	627	2788	30	29	10
AT 802A	2	1	500	1096	4873	39	37	11
AT 802A	2	1	1000	2894	12862	70	68	13
AT 802A	2	1	1320	4740	21068	99	96	14
AT 802A	2	1	2608	22206	98702	284	280	16
AT 802A	2	2	25	56	251	9	8	5
AT 802A	2	2	50	83	369	10	9	6
AT 802A	2	2	75	109	483	12	10	6
AT 802A	2	2	100	141	627	13	12	7
AT 802A	2	2	150	188	837	15	14	7
AT 802A	2	2	200	235	1046	17	16	8
AT 802A	2	2	250	282	1255	19	18	9
AT 802A	2	2	300	314	1394	21	20	9
AT 802A	2	2	500	548	2436	30	28	10
AT 802A	2	2	1000	1447	6431	63	60	13
AT 802A	2	2	1320	2370	10534	93	89	14
AT 802A	2	2	2608	11103	49351	284	275	15
AT 802A	2	4	25	28	125	6	5	4
AT 802A	2	4	50	42	185	7	6	4
AT 802A	2	4	75	54	241	8	7	5
AT 802A	2	4	100	71	314	9	8	5
AT 802A	2	4	150	94	418	11	9	6
AT 802A	2	4	200	118	523	12	11	7
AT 802A	2	4	250	141	627	14	13	7
AT 802A	2	4	300	157	697	17	15	8
AT 802A	2	4	500	274	1218	26	23	10
AT 802A	2	4	1000	723	3216	59	54	13
AT 802A	2	4	1320	1185	5267	89	81	14
AT 802A	2	4	2608	5551	24676	243	231	15
AT 802A	2	6	25	19	84	4	3	3
AT 802A	2	6	50	28	123	5	4	3
AT 802A	2	6	75	36	161	6	5	4
AT 802A	2	6	100	47	209	7	6	4
AT 802A	2	6	150	63	279	9	8	5
AT 802A	2	6	200	78	349	11	9	6
AT 802A	2	6	250	94	418	13	11	7
AT 802A	2	6	300	105	465	15	13	7
AT 802A	2	6	500	183	812	25	22	9
AT 802A	2	6	1000	482	2144	59	51	12
AT 802A	2	6	1320	790	3511	87	77	14
AT 802A	2	6	2608	3701	16450	227	211	15

a/ Margin of Exposure = NOEL / Exposure. NOEL = 0.01 mg/kg based on ↑ anxiety and locomotor activity in PND21 male rats (Silva et al 2017).

b/Acute dietary exposure estimate for children 1-2 yrs old was 0.000423 mg/kg/day at the 99.9th percentile consumption rate. Acute drinking water exposure estimated for children 1-2 yrs old was 0.000186 mg/kg/day at the 99.9th percentile consumption rate for DPR's surface water monitoring data.

Appendix 2f - Drift Exposure for Children 1-2 Years Old with Ground Boom Application of Chlorpyrifos

RAS RISK CALCULATIONS								
Ground Boom - High Boom 40 swath/90th Percentile								
Drift Modeling - AgDRIFT				Margins of Exposure[a]				
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	Dermal	Combined Incidental Oral	Inhalation	Combined Drift	Combined Drift, Diet & Drinking Water[b]
AT 802A	2	1	25	42	186	<1	<1	<1
AT 802A	2	1	50	58	259	<1	<1	<1
AT 802A	2	1	75	75	335	<1	<1	<1
AT 802A	2	1	100	94	418	<1	<1	<1
AT 802A	2	1	150	125	558	<1	<1	<1
AT 802A	2	1	200	157	697	1	1	1
AT 802A	2	1	250	188	837	1	1	1
AT 802A	2	1	300	217	965	1	1	1
AT 802A	2	1	500	330	1469	2	2	1
AT 802A	2	1	1000	591	2629	3	3	2
AT 802A	2	1	1320	750	3332	4	4	3
AT 802A	2	1	2608	1350	5999	12	12	7
AT 802A	2	2	25	21	93	<1	<1	<1
AT 802A	2	2	50	29	129	<1	<1	<1
AT 802A	2	2	75	38	167	<1	<1	<1
AT 802A	2	2	100	47	209	<1	<1	<1
AT 802A	2	2	150	63	279	<1	<1	<1
AT 802A	2	2	200	78	349	<1	<1	<1
AT 802A	2	2	250	94	418	<1	<1	<1
AT 802A	2	2	300	109	483	<1	<1	<1
AT 802A	2	2	500	165	734	1	1	1
AT 802A	2	2	1000	296	1315	3	3	2
AT 802A	2	2	1320	375	1666	4	4	3
AT 802A	2	2	2608	675	2999	12	12	7
AT 802A	2	4	25	10	46	<1	<1	<1
AT 802A	2	4	50	15	65	<1	<1	<1
AT 802A	2	4	75	19	84	<1	<1	<1
AT 802A	2	4	100	24	105	<1	<1	<1
AT 802A	2	4	150	31	139	<1	<1	<1
AT 802A	2	4	200	39	174	<1	<1	<1
AT 802A	2	4	250	47	209	<1	<1	<1
AT 802A	2	4	300	54	241	<1	<1	<1
AT 802A	2	4	500	83	367	1	1	1
AT 802A	2	4	1000	148	657	3	2	2
AT 802A	2	4	1320	187	833	4	4	3
AT 802A	2	4	2608	337	1500	10	10	6
AT 802A	2	6	25	7	31	<1	<1	<1
AT 802A	2	6	50	10	43	<1	<1	<1
AT 802A	2	6	75	13	56	<1	<1	<1
AT 802A	2	6	100	16	70	<1	<1	<1
AT 802A	2	6	150	21	93	<1	<1	<1
AT 802A	2	6	200	26	116	<1	<1	<1
AT 802A	2	6	250	31	139	<1	<1	<1
AT 802A	2	6	300	36	161	<1	<1	<1
AT 802A	2	6	500	55	245	1	1	<1
AT 802A	2	6	1000	99	438	2	2	2
AT 802A	2	6	1320	125	555	4	4	3
AT 802A	2	6	2608	225	1000	10	9	6

a/ Margin of Exposure = NOEL / Exposure. NOEL = 0.01 mg/kg based on ↑ anxiety and locomotor activity in PND21 male rats (Silva et al 2017).
b/Acute dietary exposure estimate for children 1-2 yrs old was 0.000423 mg/kg/day at the 99.9th percentile consumption rate. Acute drinking water exposure estimated for children 1-2 yrs old was 0.000186 mg/kg/day at the 99.9th percentile consumption rate for DPR's surface water monitoring data.

Appendix 2f - Drift Exposure for Children 1-2 Years Old with Ground Boom Application of Chlorpyrifos

RAS RISK CALCULATIONS								
Ground Boom - Low Boom 40 swath/90th Percentile								
Drift Modeling - AgDRIFT				Margins of Exposure[a]				
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	Dermal	Combined Incidental Oral	Inhalation	Combined Drift	Combined Drift, Diet & Drinking Water[b]
AT 802A	2	1	25	66	295	<1	<1	<1
AT 802A	2	1	50	91	405	<1	<1	<1
AT 802A	2	1	75	118	523	<1	<1	<1
AT 802A	2	1	100	145	643	<1	<1	<1
AT 802A	2	1	150	195	865	<1	<1	<1
AT 802A	2	1	200	235	1046	1	1	1
AT 802A	2	1	250	282	1255	1	1	1
AT 802A	2	1	300	314	1394	1	1	1
AT 802A	2	1	500	468	2078	2	2	1
AT 802A	2	1	1000	815	3622	3	3	2
AT 802A	2	1	1320	1025	4558	4	4	3
AT 802A	2	1	2608	1824	8108	12	12	7
AT 802A	2	2	25	33	148	<1	<1	<1
AT 802A	2	2	50	46	202	<1	<1	<1
AT 802A	2	2	75	59	261	<1	<1	<1
AT 802A	2	2	100	72	322	<1	<1	<1
AT 802A	2	2	150	97	433	<1	<1	<1
AT 802A	2	2	200	118	523	<1	<1	<1
AT 802A	2	2	250	141	627	<1	<1	<1
AT 802A	2	2	300	157	697	<1	<1	<1
AT 802A	2	2	500	234	1039	1	1	1
AT 802A	2	2	1000	407	1811	3	3	2
AT 802A	2	2	1320	513	2279	4	4	3
AT 802A	2	2	2608	912	4054	12	12	7
AT 802A	2	4	25	17	74	<1	<1	<1
AT 802A	2	4	50	23	101	<1	<1	<1
AT 802A	2	4	75	29	131	<1	<1	<1
AT 802A	2	4	100	36	161	<1	<1	<1
AT 802A	2	4	150	49	216	<1	<1	<1
AT 802A	2	4	200	59	261	<1	<1	<1
AT 802A	2	4	250	71	314	<1	<1	<1
AT 802A	2	4	300	78	349	<1	<1	<1
AT 802A	2	4	500	117	520	1	1	1
AT 802A	2	4	1000	204	906	3	2	2
AT 802A	2	4	1320	256	1139	4	4	3
AT 802A	2	4	2608	456	2027	10	10	6
AT 802A	2	6	25	11	49	<1	<1	<1
AT 802A	2	6	50	15	67	<1	<1	<1
AT 802A	2	6	75	20	87	<1	<1	<1
AT 802A	2	6	100	24	107	<1	<1	<1
AT 802A	2	6	150	32	144	<1	<1	<1
AT 802A	2	6	200	39	174	<1	<1	<1
AT 802A	2	6	250	47	209	<1	<1	<1
AT 802A	2	6	300	52	232	<1	<1	<1
AT 802A	2	6	500	78	346	1	1	<1
AT 802A	2	6	1000	136	604	2	2	2
AT 802A	2	6	1320	171	760	4	4	3
AT 802A	2	6	2608	304	1351	10	9	6

a/ Margin of Exposure = NOEL / Exposure. NOEL = 0.01 mg/kg based on ↑ anxiety and locomotor activity in PND21 male rats (Silva et al 2017).
b/Acute dietary exposure estimate for children 1-2 yrs old was 0.000423 mg/kg/day at the 99.9th percentile consumption rate. Acute drinking water exposure estimated for children 1-2 yrs old was 0.000186 mg/kg/day at the 99.9th percentile consumption rate for DPR's surface water monitoring data.

Appendix 2g - Drift Exposure for Children 6-12 Years Old with Aerial Application of Chlorpyrifos

EAS EXPOSURE ESTIMATES												
Drift-Modeling - AGDISP				Dermal Dose		Incidental Oral Dose				1-hr TWA air conc.* (mg/m3)	Inhalation Dose (mg/kg/day)	Drift ADD (mg/kg/day)
Aircraft	Spray Vol (gal/acre)	App Rate (lb-ai/A)	Downwind Distance (ft)	external PBPK (mg/kg/day)	9.6% absorption (mg/kg/day)	Hand-to-Mouth (mg/kg/day)	Object-to-Mouth (mg/kg/day)	Soil Ingestion (mg/kg/day)	Combined (mg/kg/day)			
AT 802A	2	1	25	0.0555402	0.0053319	NA	NA	NA	NA	0.0218	0.0003488	0.0056807
AT 802A	2	1	50	0.0437138	0.0041965	NA	NA	NA	NA	0.0194	0.0003104	0.0045069
AT 802A	2	1	100	0.0294475	0.0028270	NA	NA	NA	NA	0.0163	0.0002608	0.0030878
AT 802A	2	1	250	0.0153506	0.0014737	NA	NA	NA	NA	0.0118	0.0001888	0.0016625
AT 802A	2	1	500	0.0091494	0.0008783	NA	NA	NA	NA	0.0085	0.0001360	0.0010143
AT 802A	2	1	1000	0.0048797	0.0004684	NA	NA	NA	NA	0.0047	0.0000752	0.0005436
AT 802A	2	1	1320	0.0031853	0.0003058	NA	NA	NA	NA	0.0033	0.0000528	0.0003586
AT 802A	2	1	2608	0.0005761	0.0000553	NA	NA	NA	NA	0.0012	0.0000192	0.0000745
Bell 205 Helicopter	2	1	25	0.0526260	0.0050521	NA	NA	NA	NA	0.0240	0.0003840	0.0054361
Bell 205 Helicopter	2	1	50	0.0322262	0.0030937	NA	NA	NA	NA	0.0197	0.0003152	0.0034089
Bell 205 Helicopter	2	1	100	0.0195865	0.0018803	NA	NA	NA	NA	0.0158	0.0002528	0.0021331
Bell 205 Helicopter	2	1	250	0.0125042	0.0012004	NA	NA	NA	NA	0.0111	0.0001776	0.0013780
Bell 205 Helicopter	2	1	500	0.0074212	0.0007124	NA	NA	NA	NA	0.0074	0.0001184	0.0008308
Bell 205 Helicopter	2	1	1000	0.0036259	0.0003481	NA	NA	NA	NA	0.0042	0.0000672	0.0004153
Bell 205 Helicopter	2	1	1320	0.0025415	0.0002440	NA	NA	NA	NA	0.0032	0.0000512	0.0002952
Bell 205 Helicopter	2	1	2608	0.0004066	0.0000390	NA	NA	NA	NA	0.0015	0.0000240	0.0000630
AT 802A	2	2	25	0.1111482	0.0106702	NA	NA	NA	NA	0.0367	0.0005872	0.0112574
AT 802A	2	2	50	0.0871564	0.0083670	NA	NA	NA	NA	0.0320	0.0005120	0.0088790
AT 802A	2	2	100	0.0582172	0.0055889	NA	NA	NA	NA	0.0259	0.0004144	0.0060033
AT 802A	2	2	250	0.0291425	0.0027977	NA	NA	NA	NA	0.0174	0.0002784	0.0030761
AT 802A	2	2	500	0.0158589	0.0015225	NA	NA	NA	NA	0.0111	0.0001776	0.0017001
AT 802A	2	2	1000	0.0062351	0.0005986	NA	NA	NA	NA	0.0052	0.0000832	0.0006818
AT 802A	2	2	1320	0.0036598	0.0003513	NA	NA	NA	NA	0.0036	0.0000576	0.0004089
AT 802A	2	2	2608	0.0006777	0.0000651	NA	NA	NA	NA	0.0012	0.0000192	0.0000843
Bell 205 Helicopter	2	2	25	0.1066751	0.0102408	NA	NA	NA	NA	0.0404	0.0006464	0.0108872
Bell 205 Helicopter	2	2	75	0.0523887	0.0050293	NA	NA	NA	NA	0.0292	0.0004672	0.0054965
Bell 205 Helicopter	2	2	200	0.0262960	0.0025244	NA	NA	NA	NA	0.0186	0.0002976	0.0028220
Bell 205 Helicopter	2	2	300	0.0187732	0.0018022	NA	NA	NA	NA	0.0145	0.0002320	0.0020342
Bell 205 Helicopter	2	2	500	0.0115892	0.0011126	NA	NA	NA	NA	0.0093	0.0001488	0.0012614
Bell 205 Helicopter	2	2	1000	0.0050830	0.0004880	NA	NA	NA	NA	0.0049	0.0000784	0.0005664
Bell 205 Helicopter	2	2	1320	0.0032531	0.0003123	NA	NA	NA	NA	0.0036	0.0000578	0.0003701
Bell 205 Helicopter	2	2	2608	0.0005422	0.0000520	NA	NA	NA	NA	0.0016	0.0000254	0.0000775
AT 802A	2	2.3	25	0.1277425	0.0122633	NA	NA	NA	NA	0.0394	0.0006304	0.0128937
AT 802A	2	2.3	50	0.1000740	0.0096071	NA	NA	NA	NA	0.0341	0.0005456	0.0101527
AT 802A	2	2.3	100	0.0667160	0.0064047	NA	NA	NA	NA	0.0275	0.0004400	0.0068447
AT 802A	2	2.3	250	0.0333580	0.0032024	NA	NA	NA	NA	0.0183	0.0002928	0.0034952
AT 802A	2	2.3	500	0.0176922	0.0016985	NA	NA	NA	NA	0.0115	0.0001840	0.0018825
AT 802A	2	2.3	1000	0.0068587	0.0006584	NA	NA	NA	NA	0.0054	0.0000864	0.0007448
AT 802A	2	2.3	1320	0.0038970	0.0003741	NA	NA	NA	NA	0.0037	0.0000592	0.0004333
AT 802A	2	2.3	2608	0.0008573	0.0000823	NA	NA	NA	NA	0.0012	0.0000192	0.0001015
Bell 205 Helicopter	2	2.3	25	0.1227544	0.0117844	NA	NA	NA	NA	0.0435	0.0006960	0.0124804
Bell 205 Helicopter	2	2.3	50	0.0756011	0.0072577	NA	NA	NA	NA	0.0345	0.0005520	0.0078097
Bell 205 Helicopter	2	2.3	100	0.0471533	0.0045267	NA	NA	NA	NA	0.0260	0.0004160	0.0049427
Bell 205 Helicopter	2	2.3	250	0.0255641	0.0024542	NA	NA	NA	NA	0.0160	0.0002560	0.0027102
Bell 205 Helicopter	2	2.3	500	0.0128600	0.0012346	NA	NA	NA	NA	0.0096	0.0001536	0.0013882
Bell 205 Helicopter	2	2.3	1000	0.0055337	0.0005312	NA	NA	NA	NA	0.0050	0.0000800	0.0006112
Bell 205 Helicopter	2	2.3	1320	0.0035073	0.0003367	NA	NA	NA	NA	0.0037	0.0000592	0.0003959
Bell 205 Helicopter	2	2.3	2608	0.0007015	0.0000673	NA	NA	NA	NA	0.0016	0.0000256	0.0000929

* Breathing height was assumed to be 5 ft.

Abbreviations: TWA = Time Weighted Average, ADD = Absorbed Daily Dose, NA = Not Applicable.

Appendix 2g - Drift Exposure for Children 6-12 Years Old with Aerial Application of Chlorpyrifos

EAS EXPOSURE ESTIMATES												
Drift-Modeling - AGDISP				Dermal Dose		Incidental Oral Dose				1-hr TWA air conc.* (mg/m3)	Inhalation Dose (mg/kg/day)	Drift ADD (mg/kg/day)
Aircraft	Spray Vol (gal/acre)	App Rate (lb-ai/A)	Downwind Distance (ft)	external PBPK (mg/kg/day)	9.6% absorption (mg/kg/day)	Hand-to-Mouth (mg/kg/day)	Object-to-Mouth (mg/kg/day)	Soil Ingestion (mg/kg/day)	Combined (mg/kg/day)			
AT 802A	15	1	25	0.0477463	0.0045836	NA	NA	NA	NA	0.0306	0.0004896	0.0050732
AT 802A	15	1	50	0.0381902	0.0036663	NA	NA	NA	NA	0.0287	0.0004592	0.0041255
AT 802A	15	1	100	0.0255505	0.0024529	NA	NA	NA	NA	0.0256	0.0004096	0.0028625
AT 802A	15	1	250	0.0131141	0.0012590	NA	NA	NA	NA	0.0212	0.0003392	0.0015982
AT 802A	15	1	500	0.0081328	0.0007807	NA	NA	NA	NA	0.0177	0.0002832	0.0010639
AT 802A	15	1	1000	0.0060657	0.0005823	NA	NA	NA	NA	0.0138	0.0002208	0.0008031
AT 802A	15	1	1320	0.0054896	0.0005270	NA	NA	NA	NA	0.0119	0.0001904	0.0007174
AT 802A	15	1	2608	0.0016266	0.0001561	NA	NA	NA	NA	0.0065	0.0001040	0.0002601
Bell 205 Helicopter	15	1	25	0.0475430	0.0045641	NA	NA	NA	NA	0.0426	0.0006816	0.0052457
Bell 205 Helicopter	15	1	50	0.0275837	0.0026480	NA	NA	NA	NA	0.0373	0.0005968	0.0032448
Bell 205 Helicopter	15	1	100	0.0159945	0.0015355	NA	NA	NA	NA	0.0325	0.0005200	0.0020555
Bell 205 Helicopter	15	1	250	0.0111148	0.0010670	NA	NA	NA	NA	0.0266	0.0004256	0.0014926
Bell 205 Helicopter	15	1	500	0.0083361	0.0008003	NA	NA	NA	NA	0.0209	0.0003344	0.0011347
Bell 205 Helicopter	15	1	1000	0.0054557	0.0005238	NA	NA	NA	NA	0.0147	0.0002352	0.0007590
Bell 205 Helicopter	15	1	1320	0.0043714	0.0004197	NA	NA	NA	NA	0.0108	0.0001728	0.0005925
Bell 205 Helicopter	15	1	2608	0.0007116	0.0000683	NA	NA	NA	NA	0.0064	0.0001024	0.0001707
AT 802A	15	2	25	0.0997623	0.0095772	NA	NA	NA	NA	0.0522	0.0008352	0.0104124
AT 802A	15	2	50	0.0803791	0.0077164	NA	NA	NA	NA	0.0484	0.0007744	0.0084908
AT 802A	15	2	100	0.0547608	0.0052570	NA	NA	NA	NA	0.0426	0.0006816	0.0059386
AT 802A	15	2	250	0.0288036	0.0027651	NA	NA	NA	NA	0.0342	0.0005472	0.0033123
AT 802A	15	2	500	0.0183666	0.0017632	NA	NA	NA	NA	0.0278	0.0004448	0.0022080
AT 802A	15	2	1000	0.0133513	0.0012817	NA	NA	NA	NA	0.0202	0.0003232	0.0016049
AT 802A	15	2	1320	0.0115892	0.0011126	NA	NA	NA	NA	0.0165	0.0002640	0.0013766
AT 802A	15	2	2608	0.0027787	0.0002668	NA	NA	NA	NA	0.0075	0.0001200	0.0003868
Bell 205 Helicopter	15	2	25	0.0990168	0.0095056	NA	NA	NA	NA	0.0596	0.0009536	0.0104592
Bell 205 Helicopter	15	2	50	0.0589628	0.0056604	NA	NA	NA	NA	0.0516	0.0008256	0.0064860
Bell 205 Helicopter	15	2	100	0.0349032	0.0033507	NA	NA	NA	NA	0.0443	0.0007088	0.0040595
Bell 205 Helicopter	15	2	250	0.0243984	0.0023422	NA	NA	NA	NA	0.0353	0.0005648	0.0029070
Bell 205 Helicopter	15	2	500	0.0173500	0.0016656	NA	NA	NA	NA	0.0270	0.0004320	0.0020976
Bell 205 Helicopter	15	2	1000	0.0105049	0.0010085	NA	NA	NA	NA	0.0183	0.0002928	0.0013013
Bell 205 Helicopter	15	2	1320	0.0079972	0.0007677	NA	NA	NA	NA	0.0150	0.0002400	0.0010077
Bell 205 Helicopter	15	2	2608	0.0014232	0.0001366	NA	NA	NA	NA	0.0083	0.0001328	0.0002694
AT 802A	15	2.3	25	0.1153501	0.0110736	NA	NA	NA	NA	0.0579	0.0009264	0.0120000
AT 802A	15	2.3	50	0.0930595	0.0089337	NA	NA	NA	NA	0.0536	0.0008576	0.0097913
AT 802A	15	2.3	100	0.0633646	0.0060830	NA	NA	NA	NA	0.0469	0.0007504	0.0068334
AT 802A	15	2.3	250	0.0334359	0.0032099	NA	NA	NA	NA	0.0375	0.0006000	0.0038099
AT 802A	15	2.3	500	0.0212774	0.0020426	NA	NA	NA	NA	0.0303	0.0004848	0.0025274
AT 802A	15	2.3	1000	0.0154320	0.0014815	NA	NA	NA	NA	0.0217	0.0003472	0.0018287
AT 802A	15	2.3	1320	0.0130159	0.0012495	NA	NA	NA	NA	0.0175	0.0002800	0.0015295
AT 802A	15	2.3	2608	0.0031955	0.0003068					0.0077	0.0001232	0.0004300
Bell 205 Helicopter	15	2.3	25	0.1147266	0.0110138	NA	NA	NA	NA	0.0659	0.0010544	0.0120682
Bell 205 Helicopter	15	2.3	50	0.0685086	0.0065768	NA	NA	NA	NA	0.0569	0.0009104	0.0074872
Bell 205 Helicopter	15	2.3	100	0.0406843	0.0039057	NA	NA	NA	NA	0.0485	0.0007760	0.0046817
Bell 205 Helicopter	15	2.3	250	0.0282140	0.0027085	NA	NA	NA	NA	0.0385	0.0006160	0.0033245
Bell 205 Helicopter	15	2.3	500	0.0197966	0.0019005	NA	NA	NA	NA	0.0291	0.0004656	0.0023661
Bell 205 Helicopter	15	2.3	1000	0.0120026	0.0011523	NA	NA	NA	NA	0.0195	0.0003120	0.0014643
Bell 205 Helicopter	15	2.3	1320	0.0091189	0.0008754	NA	NA	NA	NA	0.0159	0.0002544	0.0011298
Bell 205 Helicopter	15	2.3	2608	0.0016367	0.0001571	NA	NA	NA	NA	0.0092	0.0001472	0.0003043

* Breathing height was assumed to be 5 ft.

Abbreviations: TWA = Time Weighted Average, ADD = Absorbed Daily Dose, NA = Not Applicable.

RAS RISK CALCULATIONS								
Drift-Modeling - AGDISP				Margins of Exposure[a]				
Aircraft	Spray Vol (gal/acre)	App Rate (lb-ai/A)	Downwind Distance (ft)	Dermal	Combined Incidental Oral	Inhalation	Combined Drift	Combined Drift, Diet & Drinking Water[b]
AT 802A	2	1	25	2	NA	29	2	2
AT 802A	2	1	50	2	NA	32	2	2
AT 802A	2	1	100	4	NA	38	3	3
AT 802A	2	1	250	7	NA	53	6	5
AT 802A	2	1	500	11	NA	74	10	8
AT 802A	2	1	1000	21	NA	133	18	12
AT 802A	2	1	1320	33	NA	189	28	15
AT 802A	2	1	2608	181	NA	521	134	26
Bell 205 Helicopter	2	1	25	2	NA	26	2	2
Bell 205 Helicopter	2	1	50	3	NA	32	3	3
Bell 205 Helicopter	2	1	100	5	NA	40	5	4
Bell 205 Helicopter	2	1	250	8	NA	56	7	6
Bell 205 Helicopter	2	1	500	14	NA	84	12	9
Bell 205 Helicopter	2	1	1000	29	NA	149	24	14
Bell 205 Helicopter	2	1	1320	41	NA	195	34	17
Bell 205 Helicopter	2	1	2608	256	NA	417	159	27
AT 802A	2	2	25	<1	NA	17	<1	<1
AT 802A	2	2	50	1	NA	20	1	1
AT 802A	2	2	100	2	NA	24	2	2
AT 802A	2	2	250	4	NA	36	3	3
AT 802A	2	2	500	7	NA	56	6	5
AT 802A	2	2	1000	17	NA	120	15	10
AT 802A	2	2	1320	28	NA	174	24	14
AT 802A	2	2	2608	154	NA	521	119	26
Bell 205 Helicopter	2	2	25	<1	NA	15	<1	<1
Bell 205 Helicopter	2	2	75	2	NA	21	2	2
Bell 205 Helicopter	2	2	200	4	NA	34	4	3
Bell 205 Helicopter	2	2	300	6	NA	43	5	4
Bell 205 Helicopter	2	2	500	9	NA	67	8	6
Bell 205 Helicopter	2	2	1000	20	NA	128	18	11
Bell 205 Helicopter	2	2	1320	32	NA	173	27	15
Bell 205 Helicopter	2	2	2608	192	NA	393	129	26
AT 802A	2	2.3	25	<1	NA	16	<1	<1
AT 802A	2	2.3	50	1	NA	18	<1	<1
AT 802A	2	2.3	100	2	NA	23	1	1
AT 802A	2	2.3	250	3	NA	34	3	3
AT 802A	2	2.3	500	6	NA	54	5	5
AT 802A	2	2.3	1000	15	NA	116	13	10
AT 802A	2	2.3	1320	27	NA	169	23	14
AT 802A	2	2.3	2608	122	NA	521	99	25
Bell 205 Helicopter	2	2.3	25	<1	NA	14	<1	<1
Bell 205 Helicopter	2	2.3	50	1	NA	18	1	1
Bell 205 Helicopter	2	2.3	100	2	NA	24	2	2
Bell 205 Helicopter	2	2.3	250	4	NA	39	4	3
Bell 205 Helicopter	2	2.3	500	8	NA	65	7	6
Bell 205 Helicopter	2	2.3	1000	19	NA	125	16	11
Bell 205 Helicopter	2	2.3	1320	30	NA	169	25	14
Bell 205 Helicopter	2	2.3	2608	149	NA	391	108	25

a/ Margin of Exposure = NOEL / Exposure. NOEL = 0.01 mg/kg based on ↑ anxiety and locomotor activity in PND21 male rats (Silva et al 2017).
b/Acute dietary exposure estimate for children 6-12 yrs old was 0.000189 mg/kg/day at the 99.9th percentile consumption rate. Acute drinking water exposure estimated for children 6-12 yrs old was 0.000115 mg/kg/day at the 99.9th percentile consumption rate for DPR's surface water monitoring

Appendix 2g - Drift Exposure for Children 6-12 Years Old with Aerial Application of Chlorpyrifos

RAS RISK CALCULATIONS								
Drift-Modeling - AGDISP				Margins of Exposure[a]				
Aircraft	Spray Vol (gal/acre)	App Rate (lb-ai/A)	Downwind Distance (ft)	Dermal	Combined Incidental Oral	Inhalation	Combined Drift	Combined Drift, Diet & Drinking Water[b]
AT 802A	15	1	25	2	NA	20	2	2
AT 802A	15	1	50	3	NA	22	2	2
AT 802A	15	1	100	4	NA	24	3	3
AT 802A	15	1	250	8	NA	29	6	5
AT 802A	15	1	500	13	NA	35	9	7
AT 802A	15	1	1000	17	NA	45	12	9
AT 802A	15	1	1320	19	NA	53	14	10
AT 802A	15	1	2608	64	NA	96	38	18
Bell 205 Helicopter	15	1	25	2	NA	15	2	2
Bell 205 Helicopter	15	1	50	4	NA	17	3	3
Bell 205 Helicopter	15	1	100	7	NA	19	5	4
Bell 205 Helicopter	15	1	250	9	NA	23	7	6
Bell 205 Helicopter	15	1	500	12	NA	30	9	7
Bell 205 Helicopter	15	1	1000	19	NA	43	13	9
Bell 205 Helicopter	15	1	1320	24	NA	58	17	11
Bell 205 Helicopter	15	1	2608	146	NA	98	59	21
AT 802A	15	2	25	1	NA	12	<1	<1
AT 802A	15	2	50	1	NA	13	1	1
AT 802A	15	2	100	2	NA	15	2	2
AT 802A	15	2	250	4	NA	18	3	3
AT 802A	15	2	500	6	NA	22	5	4
AT 802A	15	2	1000	8	NA	31	6	5
AT 802A	15	2	1320	9	NA	38	7	6
AT 802A	15	2	2608	37	NA	83	26	14
Bell 205 Helicopter	15	2	25	1	NA	10	<1	<1
Bell 205 Helicopter	15	2	50	2	NA	12	2	1
Bell 205 Helicopter	15	2	100	3	NA	14	2	2
Bell 205 Helicopter	15	2	250	4	NA	18	3	3
Bell 205 Helicopter	15	2	500	6	NA	23	5	4
Bell 205 Helicopter	15	2	1000	10	NA	34	8	6
Bell 205 Helicopter	15	2	1320	13	NA	42	10	8
Bell 205 Helicopter	15	2	2608	73	NA	75	37	17
AT 802A	15	2.3	25	<1	NA	11	<1	<1
AT 802A	15	2.3	50	1	NA	12	1	<1
AT 802A	15	2.3	100	2	NA	13	1	1
AT 802A	15	2.3	250	3	NA	17	3	2
AT 802A	15	2.3	500	5	NA	21	4	4
AT 802A	15	2.3	1000	7	NA	29	5	5
AT 802A	15	2.3	1320	8	NA	36	7	5
AT 802A	15	2.3	2608	33	NA	81	23	14
Bell 205 Helicopter	15	2.3	25	<1	NA	9	<1	<1
Bell 205 Helicopter	15	2.3	50	2	NA	11	1	1
Bell 205 Helicopter	15	2.3	100	3	NA	13	2	2
Bell 205 Helicopter	15	2.3	250	4	NA	16	3	3
Bell 205 Helicopter	15	2.3	500	5	NA	21	4	4
Bell 205 Helicopter	15	2.3	1000	9	NA	32	7	6
Bell 205 Helicopter	15	2.3	1320	11	NA	39	9	7
Bell 205 Helicopter	15	2.3	2608	64	NA	68	33	16

a/ Margin of Exposure = NOEL / Exposure. NOEL = 0.01 mg/kg based on ↑ anxiety and locomotor activity in PND21 male rats (Silva et al 2017).
b/Acute dietary exposure estimate for children 6-12 yrs old was 0.000189 mg/kg/day at the 99.9th percentile consumption rate. Acute drinking water exposure estimated for children 6-12 yrs old was 0.000115 mg/kg/day at the 99.9th percentile consumption rate for DPR's surface water monitoring

EAS EXPOSURE ESTIMATES												
Orchard Airblast - Dormant Apple - 60 Swath												
Drift Modeling - AgDRIFT				Dermal Dose		Incidental Oral Dose						
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	external PBPK (mg/kg/day)	9.6% absorption (mg/kg/day)	Hand-to-Mouth (mg/kg/day)	Object-to-Mouth (mg/kg/day)	Soil Ingestion (mg/kg/day)	Combined (mg/kg/day)	1-hr TWA air conc.* (mg/m3)	Inhalation Dose (mg/kg/day)	Drift ADD (mg/kg/day)
AT 802A	2	1	25	0.0187563	0.0018006	NA	NA	NA	NA	0.0218	0.0003488	0.0021494
AT 802A	2	1	50	0.0071365	0.0006851	NA	NA	NA	NA	0.0194	0.0003104	0.0009955
AT 802A	2	1	75	0.0035005	0.0003360	NA	NA	NA	NA	0.0176	0.0002816	0.0006176
AT 802A	2	1	100	0.0019891	0.0001910	NA	NA	NA	NA	0.0163	0.0002608	0.0004518
AT 802A	2	1	150	0.0008404	0.0000807	NA	NA	NA	NA	0.0143	0.0002288	0.0003095
AT 802A	2	1	200	0.0004439	0.0000426	NA	NA	NA	NA	0.0129	0.0002064	0.0002490
AT 802A	2	1	250	0.0002677	0.0000257	NA	NA	NA	NA	0.0118	0.0001888	0.0002145
AT 802A	2	1	300	0.0001728	0.0000166	NA	NA	NA	NA	0.0109	0.0001744	0.0001910
AT 802A	2	1	500	0.0000474	0.0000046	NA	NA	NA	NA	0.0085	0.0001360	0.0001406
AT 802A	2	1	1000	0.0000087	0.0000008	NA	NA	NA	NA	0.0047	0.0000752	0.0000760
AT 802A	2	1	1320	0.0000044	0.0000004	NA	NA	NA	NA	0.0033	0.0000528	0.0000532
AT 802A	2	1	2608	0.0000008	0.0000001	NA	NA	NA	NA	0.0012	0.0000192	0.0000193
AT 802A	2	2	25	0.0375125	0.0036012	NA	NA	NA	NA	0.0367	0.0005872	0.0041884
AT 802A	2	2	50	0.0142731	0.0013702	NA	NA	NA	NA	0.0320	0.0005120	0.0018822
AT 802A	2	2	75	0.0070010	0.0006721	NA	NA	NA	NA	0.0285	0.0004560	0.0011281
AT 802A	2	2	100	0.0039783	0.0003819	NA	NA	NA	NA	0.0259	0.0004144	0.0007963
AT 802A	2	2	150	0.0016808	0.0001614	NA	NA	NA	NA	0.0221	0.0003536	0.0005150
AT 802A	2	2	200	0.0008878	0.0000852	NA	NA	NA	NA	0.0195	0.0003120	0.0003972
AT 802A	2	2	250	0.0005354	0.0000514	NA	NA	NA	NA	0.0174	0.0002784	0.0003298
AT 802A	2	2	300	0.0003456	0.0000332	NA	NA	NA	NA	0.0157	0.0002512	0.0002844
AT 802A	2	2	500	0.0000949	0.0000091	NA	NA	NA	NA	0.0111	0.0001776	0.0001867
AT 802A	2	2	1000	0.0000174	0.0000017	NA	NA	NA	NA	0.0052	0.0000832	0.0000849
AT 802A	2	2	1320	0.0000087	0.0000008	NA	NA	NA	NA	0.0036	0.0000576	0.0000584
AT 802A	2	2	2608	0.0000016	0.0000002	NA	NA	NA	NA	0.0012	0.0000192	0.0000194
AT 802A	2	4	25	0.0750250	0.0072024	NA	NA	NA	NA	0.0596	0.0009536	0.0081560
AT 802A	2	4	50	0.0285461	0.0027404	NA	NA	NA	NA	0.0503	0.0008048	0.0035452
AT 802A	2	4	75	0.0140020	0.0013442	NA	NA	NA	NA	0.0439	0.0007024	0.0020466
AT 802A	2	4	100	0.0079566	0.0007638	NA	NA	NA	NA	0.0389	0.0006224	0.0013862
AT 802A	2	4	150	0.0033616	0.0003227	NA	NA	NA	NA	0.0319	0.0005104	0.0008331
AT 802A	2	4	200	0.0017757	0.0001705	NA	NA	NA	NA	0.0269	0.0004304	0.0006009
AT 802A	2	4	250	0.0010708	0.0001028	NA	NA	NA	NA	0.0230	0.0003680	0.0004708
AT 802A	2	4	300	0.0006913	0.0000664	NA	NA	NA	NA	0.0200	0.0003200	0.0003864
AT 802A	2	4	500	0.0001898	0.0000182	NA	NA	NA	NA	0.0128	0.0002048	0.0002230
AT 802A	2	4	1000	0.0000349	0.0000033	NA	NA	NA	NA	0.0055	0.0000880	0.0000913
AT 802A	2	4	1320	0.0000174	0.0000017	NA	NA	NA	NA	0.0037	0.0000592	0.0000609
AT 802A	2	4	2608	0.0000032	0.0000003	NA	NA	NA	NA	0.0014	0.0000224	0.0000227
AT 802A	2	6	25	0.1125375	0.0108036	NA	NA	NA	NA	0.0781	0.0012496	0.0120532
AT 802A	2	6	50	0.0428192	0.0041106	NA	NA	NA	NA	0.0643	0.0010288	0.0051394
AT 802A	2	6	75	0.0210029	0.0020163	NA	NA	NA	NA	0.0550	0.0008800	0.0028963
AT 802A	2	6	100	0.0119349	0.0011457	NA	NA	NA	NA	0.0479	0.0007664	0.0019121
AT 802A	2	6	150	0.0050423	0.0004841	NA	NA	NA	NA	0.0377	0.0006032	0.0010873
AT 802A	2	6	200	0.0026635	0.0002557	NA	NA	NA	NA	0.0305	0.0004880	0.0007437
AT 802A	2	6	250	0.0016062	0.0001542	NA	NA	NA	NA	0.0253	0.0004048	0.0005590
AT 802A	2	6	300	0.0010369	0.0000995	NA	NA	NA	NA	0.0214	0.0003424	0.0004419
AT 802A	2	6	500	0.0002846	0.0000273	NA	NA	NA	NA	0.0130	0.0002080	0.0002353
AT 802A	2	6	1000	0.0000523	0.0000050	NA	NA	NA	NA	0.0055	0.0000880	0.0000930
AT 802A	2	6	1320	0.0000261	0.0000025	NA	NA	NA	NA	0.0038	0.0000608	0.0000633
AT 802A	2	6	2608	0.0000048	0.0000005	NA	NA	NA	NA	0.0014	0.0000224	0.0000229

* AGDISP modeling for AT802A 2GPA with various application rates was used for inhalation surrogates. Therefore, the air concentrations will be the same for airblast and ground boom at the same application rates. Breathing height was assumed to be 5 ft.

Abbreviations: TWA = Time Weighted Average, ADD = Absorbed Daily Dose, NA = Not Applicable.

EAS EXPOSURE ESTIMATES												
Orchard Airblast - Sparse Orchard - 60 Swath												
Drift Modeling - AgDRIFT				Dermal Dose		Incidental Oral Dose						
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	external PBPK (mg/kg/day)	9.6% absorption (mg/kg/day)	Hand-to-Mouth (mg/kg/day)	Object-to-Mouth (mg/kg/day)	Soil Ingestion (mg/kg/day)	Combined (mg/kg/day)	1-hr TWA air conc.* (mg/m3)	Inhalation Dose (mg/kg/day)	Drift ADD (mg/kg/day)
AT 802A	2	1	25	0.0152083	0.0014600	NA	NA	NA	NA	0.0218	0.0003488	0.0018088
AT 802A	2	1	50	0.0069264	0.0006649	NA	NA	NA	NA	0.0194	0.0003104	0.0009753
AT 802A	2	1	75	0.0038902	0.0003735	NA	NA	NA	NA	0.0176	0.0002816	0.0006551
AT 802A	2	1	100	0.0024839	0.0002385	NA	NA	NA	NA	0.0163	0.0002608	0.0004993
AT 802A	2	1	150	0.0012640	0.0001213	NA	NA	NA	NA	0.0143	0.0002288	0.0003501
AT 802A	2	1	200	0.0007624	0.0000732	NA	NA	NA	NA	0.0129	0.0002064	0.0002796
AT 802A	2	1	250	0.0005117	0.0000491	NA	NA	NA	NA	0.0118	0.0001888	0.0002379
AT 802A	2	1	300	0.0003660	0.0000351	NA	NA	NA	NA	0.0109	0.0001744	0.0002095
AT 802A	2	1	500	0.0001342	0.0000129	NA	NA	NA	NA	0.0085	0.0001360	0.0001489
AT 802A	2	1	1000	0.0000278	0.0000027	NA	NA	NA	NA	0.0047	0.0000752	0.0000779
AT 802A	2	1	1320	0.0000130	0.0000012	NA	NA	NA	NA	0.0033	0.0000528	0.0000540
AT 802A	2	1	2608	0.0000007	0.0000001	NA	NA	NA	NA	0.0012	0.0000192	0.0000193
AT 802A	2	2	25	0.0304166	0.0029200	NA	NA	NA	NA	0.0367	0.0005872	0.0035072
AT 802A	2	2	50	0.0138529	0.0013299	NA	NA	NA	NA	0.0320	0.0005120	0.0018419
AT 802A	2	2	75	0.0077804	0.0007469	NA	NA	NA	NA	0.0285	0.0004560	0.0012029
AT 802A	2	2	100	0.0049678	0.0004769	NA	NA	NA	NA	0.0259	0.0004144	0.0008913
AT 802A	2	2	150	0.0025279	0.0002427	NA	NA	NA	NA	0.0221	0.0003536	0.0005963
AT 802A	2	2	200	0.0015249	0.0001464	NA	NA	NA	NA	0.0195	0.0003120	0.0004584
AT 802A	2	2	250	0.0010234	0.0000982	NA	NA	NA	NA	0.0174	0.0002784	0.0003766
AT 802A	2	2	300	0.0007320	0.0000703	NA	NA	NA	NA	0.0157	0.0002512	0.0003215
AT 802A	2	2	500	0.0002684	0.0000258	NA	NA	NA	NA	0.0111	0.0001776	0.0002034
AT 802A	2	2	1000	0.0000557	0.0000053	NA	NA	NA	NA	0.0052	0.0000832	0.0000885
AT 802A	2	2	1320	0.0000260	0.0000025	NA	NA	NA	NA	0.0036	0.0000576	0.0000601
AT 802A	2	2	2608	0.0000014	0.0000001	NA	NA	NA	NA	0.0012	0.0000192	0.0000193
AT 802A	2	4	25	0.0608333	0.0058400	NA	NA	NA	NA	0.0596	0.0009536	0.0067936
AT 802A	2	4	50	0.0277057	0.0026597	NA	NA	NA	NA	0.0503	0.0008048	0.0034645
AT 802A	2	4	75	0.0155607	0.0014938	NA	NA	NA	NA	0.0439	0.0007024	0.0021962
AT 802A	2	4	100	0.0099356	0.0009538	NA	NA	NA	NA	0.0389	0.0006224	0.0015762
AT 802A	2	4	150	0.0050559	0.0004854	NA	NA	NA	NA	0.0319	0.0005104	0.0009958
AT 802A	2	4	200	0.0030498	0.0002928	NA	NA	NA	NA	0.0269	0.0004304	0.0007232
AT 802A	2	4	250	0.0020468	0.0001965	NA	NA	NA	NA	0.0230	0.0003680	0.0005645
AT 802A	2	4	300	0.0014639	0.0001405	NA	NA	NA	NA	0.0200	0.0003200	0.0004605
AT 802A	2	4	500	0.0005367	0.0000515	NA	NA	NA	NA	0.0128	0.0002048	0.0002563
AT 802A	2	4	1000	0.0001114	0.0000107	NA	NA	NA	NA	0.0055	0.0000880	0.0000987
AT 802A	2	4	1320	0.0000520	0.0000050	NA	NA	NA	NA	0.0037	0.0000592	0.0000642
AT 802A	2	4	2608	0.0000028	0.0000003	NA	NA	NA	NA	0.0014	0.0000224	0.0000227
AT 802A	2	6	25	0.0912499	0.0087600	NA	NA	NA	NA	0.0781	0.0012496	0.0100096
AT 802A	2	6	50	0.0415586	0.0039896	NA	NA	NA	NA	0.0643	0.0010288	0.0050184
AT 802A	2	6	75	0.0233411	0.0022407	NA	NA	NA	NA	0.0550	0.0008800	0.0031207
AT 802A	2	6	100	0.0149033	0.0014307	NA	NA	NA	NA	0.0479	0.0007664	0.0021971
AT 802A	2	6	150	0.0075838	0.0007280	NA	NA	NA	NA	0.0377	0.0006032	0.0013312
AT 802A	2	6	200	0.0045747	0.0004392	NA	NA	NA	NA	0.0305	0.0004880	0.0009272
AT 802A	2	6	250	0.0030701	0.0002947	NA	NA	NA	NA	0.0253	0.0004048	0.0006995
AT 802A	2	6	300	0.0021959	0.0002108	NA	NA	NA	NA	0.0214	0.0003424	0.0005532
AT 802A	2	6	500	0.0008051	0.0000773	NA	NA	NA	NA	0.0130	0.0002080	0.0002853
AT 802A	2	6	1000	0.0001671	0.0000160	NA	NA	NA	NA	0.0055	0.0000880	0.0001040
AT 802A	2	6	1320	0.0000780	0.0000075	NA	NA	NA	NA	0.0038	0.0000608	0.0000683
AT 802A	2	6	2608	0.0000042	0.0000004	NA	NA	NA	NA	0.0014	0.0000224	0.0000228

* AGDISP modeling for AT802A 2GPA with various application rates was used for inhalation surrogates. Therefore, the air concentrations will be the same for airblast and ground boom at the same application rates. Breathing height was assumed to be 5 ft.

Abbreviations: TWA = Time Weighted Average, ADD = Absorbed Daily Dose, NA = Not Applicable.

RAS RISK CALCULATIONS								
Orchard Airblast - Dormant Apple - 60 Swath								
Drift Modeling - AgDRIFT				Margins of Exposure[a]				
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	Dermal	Combined Incidental Oral	Inhalation	Combined Drift	Combined Drift, Diet & Drinking Water[b]
AT 802A	2	1	25	6	NA	29	5	4
AT 802A	2	1	50	15	NA	32	10	8
AT 802A	2	1	75	30	NA	36	16	11
AT 802A	2	1	100	52	NA	38	22	13
AT 802A	2	1	150	124	NA	44	32	16
AT 802A	2	1	200	235	NA	48	40	18
AT 802A	2	1	250	389	NA	53	47	19
AT 802A	2	1	300	603	NA	57	52	20
AT 802A	2	1	500	2196	NA	74	71	22
AT 802A	2	1	1000	11953	NA	133	132	26
AT 802A	2	1	1320	23908	NA	189	188	28
AT 802A	2	1	2608	131091	NA	521	519	31
AT 802A	2	2	25	3	NA	17	2	2
AT 802A	2	2	50	7	NA	20	5	5
AT 802A	2	2	75	15	NA	22	9	7
AT 802A	2	2	100	26	NA	24	13	9
AT 802A	2	2	150	62	NA	28	19	12
AT 802A	2	2	200	117	NA	32	25	14
AT 802A	2	2	250	195	NA	36	30	16
AT 802A	2	2	300	301	NA	40	35	17
AT 802A	2	2	500	1098	NA	56	54	20
AT 802A	2	2	1000	5976	NA	120	118	26
AT 802A	2	2	1320	11954	NA	174	171	28
AT 802A	2	2	2608	65545	NA	521	517	31
AT 802A	2	4	25	1	NA	10	1	1
AT 802A	2	4	50	4	NA	12	3	3
AT 802A	2	4	75	7	NA	14	5	4
AT 802A	2	4	100	13	NA	16	7	6
AT 802A	2	4	150	31	NA	20	12	9
AT 802A	2	4	200	59	NA	23	17	11
AT 802A	2	4	250	97	NA	27	21	13
AT 802A	2	4	300	151	NA	31	26	14
AT 802A	2	4	500	549	NA	49	45	19
AT 802A	2	4	1000	2988	NA	114	109	25
AT 802A	2	4	1320	5977	NA	169	164	27
AT 802A	2	4	2608	32773	NA	446	440	31
AT 802A	2	6	25	<1	NA	8	<1	<1
AT 802A	2	6	50	2	NA	10	2	2
AT 802A	2	6	75	5	NA	11	3	3
AT 802A	2	6	100	9	NA	13	5	5
AT 802A	2	6	150	21	NA	17	9	7
AT 802A	2	6	200	39	NA	20	13	10
AT 802A	2	6	250	65	NA	25	18	12
AT 802A	2	6	300	100	NA	29	23	13
AT 802A	2	6	500	366	NA	48	42	19
AT 802A	2	6	1000	1992	NA	114	108	25
AT 802A	2	6	1320	3985	NA	164	158	27
AT 802A	2	6	2608	21848	NA	446	437	31

a/ Margin of Exposure = NOEL / Exposure. NOEL = 0.01 mg/kg based on ↑ anxiety and locomotor activity in PND21 male rats (Silva et al 2017).
b/Acute dietary exposure estimate for children 6-12 yrs old was 0.000189 mg/kg/day at the 99.9th percentile consumption rate. Acute drinking water exposure estimated for children 6-12 yrs old was 0.000115 mg/kg/day at the 99.9th percentile consumption rate for DPR's surface water monitoring

RAS RISK CALCULATIONS								
Orchard Airblast - Sparse Orchard - 60 Swath								
Drift Modeling - AgDRIFT				Margins of Exposure[a]				
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	Dermal	Combined Incidental Oral	Inhalation	Combined Drift	Combined Drift, Diet & Drinking Water[b]
AT 802A	2	1	25	7	NA	29	6	5
AT 802A	2	1	50	15	NA	32	10	8
AT 802A	2	1	75	27	NA	36	15	10
AT 802A	2	1	100	42	NA	38	20	12
AT 802A	2	1	150	82	NA	44	29	15
AT 802A	2	1	200	137	NA	48	36	17
AT 802A	2	1	250	204	NA	53	42	18
AT 802A	2	1	300	285	NA	57	48	19
AT 802A	2	1	500	776	NA	74	67	22
AT 802A	2	1	1000	3741	NA	133	128	26
AT 802A	2	1	1320	8017	NA	189	185	28
AT 802A	2	1	2608	150466	NA	521	519	31
AT 802A	2	2	25	3	NA	17	3	3
AT 802A	2	2	50	8	NA	20	5	5
AT 802A	2	2	75	13	NA	22	8	7
AT 802A	2	2	100	21	NA	24	11	8
AT 802A	2	2	150	41	NA	28	17	11
AT 802A	2	2	200	68	NA	32	22	13
AT 802A	2	2	250	102	NA	36	27	15
AT 802A	2	2	300	142	NA	40	31	16
AT 802A	2	2	500	388	NA	56	49	20
AT 802A	2	2	1000	1870	NA	120	113	25
AT 802A	2	2	1320	4009	NA	174	166	27
AT 802A	2	2	2608	75233	NA	521	517	31
AT 802A	2	4	25	2	NA	10	1	1
AT 802A	2	4	50	4	NA	12	3	3
AT 802A	2	4	75	7	NA	14	5	4
AT 802A	2	4	100	10	NA	16	6	5
AT 802A	2	4	150	21	NA	20	10	8
AT 802A	2	4	200	34	NA	23	14	10
AT 802A	2	4	250	51	NA	27	18	12
AT 802A	2	4	300	71	NA	31	22	13
AT 802A	2	4	500	194	NA	49	39	18
AT 802A	2	4	1000	935	NA	114	101	25
AT 802A	2	4	1320	2004	NA	169	156	27
AT 802A	2	4	2608	37616	NA	446	441	31
AT 802A	2	6	25	1	NA	8	<1	<1
AT 802A	2	6	50	3	NA	10	2	2
AT 802A	2	6	75	4	NA	11	3	3
AT 802A	2	6	100	7	NA	13	5	4
AT 802A	2	6	150	14	NA	17	8	6
AT 802A	2	6	200	23	NA	20	11	8
AT 802A	2	6	250	34	NA	25	14	10
AT 802A	2	6	300	47	NA	29	18	12
AT 802A	2	6	500	129	NA	48	35	17
AT 802A	2	6	1000	623	NA	114	96	25
AT 802A	2	6	1320	1336	NA	164	146	27
AT 802A	2	6	2608	25078	NA	446	439	31

a/ Margin of Exposure = NOEL / Exposure. NOEL = 0.01 mg/kg based on ↑ anxiety and locomotor activity in PND21 male rats (Silva et al 2017).
b/Acute dietary exposure estimate for children 6-12 yrs old was 0.000189 mg/kg/day at the 99.9th percentile consumption rate. Acute drinking water exposure estimated for children 6-12 yrs old was 0.000115 mg/kg/day at the 99.9th percentile consumption rate for DPR's surface water monitoring

Appendix 2i - Drift Exposure for Children 6-12 Years Old with Ground Boom Application of Chlorpyrifos

EAS EXPOSURE ESTIMATES												
Ground Boom - High Boom 40 swath/50th Percentile												
Drift Modeling - AgDRIFT				Dermal Dose		Incidental Oral Dose				1-hr TWA air conc.* (mg/m3)	Inhalation Dose (mg/kg/day)	Drift ADD (mg/kg/day)
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	external PBPK (mg/kg/day)	9.6% absorption (mg/kg/day)	Hand-to-Mouth (mg/kg/day)	Object-to-Mouth (mg/kg/day)	Soil Ingestion (mg/kg/day)	Combined (mg/kg/day)			
AT 802A	2	1	25	0.0032192	0.0003090	NA	NA	NA	NA	0.0218	0.0003488	0.0006578
AT 802A	2	1	50	0.0021349	0.0002049	NA	NA	NA	NA	0.0194	0.0003104	0.0005153
AT 802A	2	1	75	0.0015927	0.0001529	NA	NA	NA	NA	0.0176	0.0002816	0.0004345
AT 802A	2	1	100	0.0012538	0.0001204	NA	NA	NA	NA	0.0163	0.0002608	0.0003812
AT 802A	2	1	150	0.0009149	0.0000878	NA	NA	NA	NA	0.0143	0.0002288	0.0003166
AT 802A	2	1	200	0.0007116	0.0000683	NA	NA	NA	NA	0.0129	0.0002064	0.0002747
AT 802A	2	1	250	0.0005761	0.0000553	NA	NA	NA	NA	0.0118	0.0001888	0.0002441
AT 802A	2	1	300	0.0004744	0.0000455	NA	NA	NA	NA	0.0109	0.0001744	0.0002199
AT 802A	2	1	500	0.0002462	0.0000236	NA	NA	NA	NA	0.0085	0.0001360	0.0001596
AT 802A	2	1	1000	0.0000741	0.0000071	NA	NA	NA	NA	0.0047	0.0000752	0.0000823
AT 802A	2	1	1320	0.0000402	0.0000039	NA	NA	NA	NA	0.0033	0.0000528	0.0000567
AT 802A	2	1	2608	0.0000060	0.0000006	NA	NA	NA	NA	0.0012	0.0000192	0.0000198
AT 802A	2	2	25	0.0064385	0.0006181	NA	NA	NA	NA	0.0367	0.0005872	0.0012053
AT 802A	2	2	50	0.0042697	0.0004099	NA	NA	NA	NA	0.0320	0.0005120	0.0009219
AT 802A	2	2	75	0.0031853	0.0003058	NA	NA	NA	NA	0.0285	0.0004560	0.0007618
AT 802A	2	2	100	0.0025076	0.0002407	NA	NA	NA	NA	0.0259	0.0004144	0.0006551
AT 802A	2	2	150	0.0018299	0.0001757	NA	NA	NA	NA	0.0221	0.0003536	0.0005293
AT 802A	2	2	200	0.0014232	0.0001366	NA	NA	NA	NA	0.0195	0.0003120	0.0004486
AT 802A	2	2	250	0.0011521	0.0001106	NA	NA	NA	NA	0.0174	0.0002784	0.0003890
AT 802A	2	2	300	0.0009488	0.0000911	NA	NA	NA	NA	0.0157	0.0002512	0.0003423
AT 802A	2	2	500	0.0004923	0.0000473	NA	NA	NA	NA	0.0111	0.0001776	0.0002249
AT 802A	2	2	1000	0.0001481	0.0000142	NA	NA	NA	NA	0.0052	0.0000832	0.0000974
AT 802A	2	2	1320	0.0000804	0.0000077	NA	NA	NA	NA	0.0036	0.0000576	0.0000653
AT 802A	2	2	2608	0.0000119	0.0000011	NA	NA	NA	NA	0.0012	0.0000192	0.0000203
AT 802A	2	4	25	0.0128769	0.0012362	NA	NA	NA	NA	0.0596	0.0009536	0.0021898
AT 802A	2	4	50	0.0085394	0.0008198	NA	NA	NA	NA	0.0503	0.0008048	0.0016246
AT 802A	2	4	75	0.0063707	0.0006116	NA	NA	NA	NA	0.0439	0.0007024	0.0013140
AT 802A	2	4	100	0.0050152	0.0004815	NA	NA	NA	NA	0.0389	0.0006224	0.0011039
AT 802A	2	4	150	0.0036598	0.0003513	NA	NA	NA	NA	0.0319	0.0005104	0.0008617
AT 802A	2	4	200	0.0028465	0.0002733	NA	NA	NA	NA	0.0269	0.0004304	0.0007037
AT 802A	2	4	250	0.0023043	0.0002212	NA	NA	NA	NA	0.0230	0.0003680	0.0005892
AT 802A	2	4	300	0.0018977	0.0001822	NA	NA	NA	NA	0.0200	0.0003200	0.0005022
AT 802A	2	4	500	0.0009847	0.0000945	NA	NA	NA	NA	0.0128	0.0002048	0.0002993
AT 802A	2	4	1000	0.0002963	0.0000284	NA	NA	NA	NA	0.0055	0.0000880	0.0001164
AT 802A	2	4	1320	0.0001609	0.0000154	NA	NA	NA	NA	0.0037	0.0000592	0.0000746
AT 802A	2	4	2608	0.0000238	0.0000023	NA	NA	NA	NA	0.0014	0.0000224	0.0000247
AT 802A	2	6	25	0.0193154	0.0018543	NA	NA	NA	NA	0.0781	0.0012496	0.0031039
AT 802A	2	6	50	0.0128092	0.0012297	NA	NA	NA	NA	0.0643	0.0010288	0.0022585
AT 802A	2	6	75	0.0095560	0.0009174	NA	NA	NA	NA	0.0550	0.0008800	0.0017974
AT 802A	2	6	100	0.0075228	0.0007222	NA	NA	NA	NA	0.0479	0.0007664	0.0014886
AT 802A	2	6	150	0.0054896	0.0005270	NA	NA	NA	NA	0.0377	0.0006032	0.0011302
AT 802A	2	6	200	0.0042697	0.0004099	NA	NA	NA	NA	0.0305	0.0004880	0.0008979
AT 802A	2	6	250	0.0034564	0.0003318	NA	NA	NA	NA	0.0253	0.0004048	0.0007366
AT 802A	2	6	300	0.0028465	0.0002733	NA	NA	NA	NA	0.0214	0.0003424	0.0006157
AT 802A	2	6	500	0.0014770	0.0001418	NA	NA	NA	NA	0.0130	0.0002080	0.0003498
AT 802A	2	6	1000	0.0004444	0.0000427	NA	NA	NA	NA	0.0055	0.0000880	0.0001307
AT 802A	2	6	1320	0.0002413	0.0000232	NA	NA	NA	NA	0.0038	0.0000608	0.0000840
AT 802A	2	6	2608	0.0000357	0.0000034	NA	NA	NA	NA	0.0014	0.0000224	0.0000258

* AGDISP modeling for AT802A 2GPA with various application rates was used for inhalation surrogates. Therefore, the air concentrations will be the same for airblast and ground boom at the same application rates. Breathing height was assumed to be 5 ft.

Abbreviations: TWA = Time Weighted Average, ADD = Absorbed Daily Dose, NA = Not Applicable.

Appendix 2i - Drift Exposure for Children 6-12 Years Old with Ground Boom Application of Chlorpyrifos

EAS EXPOSURE ESTIMATES												
Ground Boom - Low Boom 40 swath/50th Percentile												
Drift Modeling - AgDRIFT				Dermal Dose		Incidental Oral Dose						
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	external PBPK (mg/kg/day)	9.6% absorption (mg/kg/day)	Hand-to-Mouth (mg/kg/day)	Object-to-Mouth (mg/kg/day)	Soil Ingestion (mg/kg/day)	Combined (mg/kg/day)	1-hr TWA air conc.* (mg/m3)	Inhalation Dose (mg/kg/day)	Drift ADD (mg/kg/day)
AT 802A	2	1	25	0.0016943	0.0001627	NA	NA	NA	NA	0.0218	0.0003488	0.0005115
AT 802A	2	1	50	0.0011521	0.0001106	NA	NA	NA	NA	0.0194	0.0003104	0.0004210
AT 802A	2	1	75	0.0008811	0.0000846	NA	NA	NA	NA	0.0176	0.0002816	0.0003662
AT 802A	2	1	100	0.0006777	0.0000651	NA	NA	NA	NA	0.0163	0.0002608	0.0003259
AT 802A	2	1	150	0.0005083	0.0000488	NA	NA	NA	NA	0.0143	0.0002288	0.0002776
AT 802A	2	1	200	0.0004066	0.0000390	NA	NA	NA	NA	0.0129	0.0002064	0.0002454
AT 802A	2	1	250	0.0003389	0.0000325	NA	NA	NA	NA	0.0118	0.0001888	0.0002213
AT 802A	2	1	300	0.0003050	0.0000293	NA	NA	NA	NA	0.0109	0.0001744	0.0002037
AT 802A	2	1	500	0.0001745	0.0000168	NA	NA	NA	NA	0.0085	0.0001360	0.0001528
AT 802A	2	1	1000	0.0000661	0.0000063	NA	NA	NA	NA	0.0047	0.0000752	0.0000815
AT 802A	2	1	1320	0.0000404	0.0000039	NA	NA	NA	NA	0.0033	0.0000528	0.0000567
AT 802A	2	1	2608	0.0000086	0.0000008	NA	NA	NA	NA	0.0012	0.0000192	0.0000200
AT 802A	2	2	25	0.0033887	0.0003253	NA	NA	NA	NA	0.0367	0.0005872	0.0009125
AT 802A	2	2	50	0.0023043	0.0002212	NA	NA	NA	NA	0.0320	0.0005120	0.0007332
AT 802A	2	2	75	0.0017621	0.0001692	NA	NA	NA	NA	0.0285	0.0004560	0.0006252
AT 802A	2	2	100	0.0013555	0.0001301	NA	NA	NA	NA	0.0259	0.0004144	0.0005445
AT 802A	2	2	150	0.0010166	0.0000976	NA	NA	NA	NA	0.0221	0.0003536	0.0004512
AT 802A	2	2	200	0.0008133	0.0000781	NA	NA	NA	NA	0.0195	0.0003120	0.0003901
AT 802A	2	2	250	0.0006777	0.0000651	NA	NA	NA	NA	0.0174	0.0002784	0.0003435
AT 802A	2	2	300	0.0006100	0.0000586	NA	NA	NA	NA	0.0157	0.0002512	0.0003098
AT 802A	2	2	500	0.0003490	0.0000335	NA	NA	NA	NA	0.0111	0.0001776	0.0002111
AT 802A	2	2	1000	0.0001322	0.0000127	NA	NA	NA	NA	0.0052	0.0000832	0.0000959
AT 802A	2	2	1320	0.0000807	0.0000078	NA	NA	NA	NA	0.0036	0.0000576	0.0000654
AT 802A	2	2	2608	0.0000172	0.0000017	NA	NA	NA	NA	0.0012	0.0000192	0.0000209
AT 802A	2	4	25	0.0067773	0.0006506	NA	NA	NA	NA	0.0596	0.0009536	0.0016042
AT 802A	2	4	50	0.0046086	0.0004424	NA	NA	NA	NA	0.0503	0.0008048	0.0012472
AT 802A	2	4	75	0.0035242	0.0003383	NA	NA	NA	NA	0.0439	0.0007024	0.0010407
AT 802A	2	4	100	0.0027109	0.0002602	NA	NA	NA	NA	0.0389	0.0006224	0.0008826
AT 802A	2	4	150	0.0020332	0.0001952	NA	NA	NA	NA	0.0319	0.0005104	0.0007056
AT 802A	2	4	200	0.0016266	0.0001561	NA	NA	NA	NA	0.0269	0.0004304	0.0005865
AT 802A	2	4	250	0.0013555	0.0001301	NA	NA	NA	NA	0.0230	0.0003680	0.0004981
AT 802A	2	4	300	0.0012199	0.0001171	NA	NA	NA	NA	0.0200	0.0003200	0.0004371
AT 802A	2	4	500	0.0006981	0.0000670	NA	NA	NA	NA	0.0128	0.0002048	0.0002718
AT 802A	2	4	1000	0.0002645	0.0000254	NA	NA	NA	NA	0.0055	0.0000880	0.0001134
AT 802A	2	4	1320	0.0001615	0.0000155	NA	NA	NA	NA	0.0037	0.0000592	0.0000747
AT 802A	2	4	2608	0.0000345	0.0000033	NA	NA	NA	NA	0.0014	0.0000224	0.0000257
AT 802A	2	6	25	0.0101660	0.0009759	NA	NA	NA	NA	0.0781	0.0012496	0.0022255
AT 802A	2	6	50	0.0069129	0.0006636	NA	NA	NA	NA	0.0643	0.0010288	0.0016924
AT 802A	2	6	75	0.0052863	0.0005075	NA	NA	NA	NA	0.0550	0.0008800	0.0013875
AT 802A	2	6	100	0.0040664	0.0003904	NA	NA	NA	NA	0.0479	0.0007664	0.0011568
AT 802A	2	6	150	0.0030498	0.0002928	NA	NA	NA	NA	0.0377	0.0006032	0.0008960
AT 802A	2	6	200	0.0024398	0.0002342	NA	NA	NA	NA	0.0305	0.0004880	0.0007222
AT 802A	2	6	250	0.0020332	0.0001952	NA	NA	NA	NA	0.0253	0.0004048	0.0006000
AT 802A	2	6	300	0.0018299	0.0001757	NA	NA	NA	NA	0.0214	0.0003424	0.0005181
AT 802A	2	6	500	0.0010471	0.0001005	NA	NA	NA	NA	0.0130	0.0002080	0.0003085
AT 802A	2	6	1000	0.0003967	0.0000381	NA	NA	NA	NA	0.0055	0.0000880	0.0001261
AT 802A	2	6	1320	0.0002422	0.0000233	NA	NA	NA	NA	0.0038	0.0000608	0.0000841
AT 802A	2	6	2608	0.0000517	0.0000050	NA	NA	NA	NA	0.0014	0.0000224	0.0000274

* AGDISP modeling for AT802A 2GPA with various application rates was used for inhalation surrogates. Therefore, the air concentrations will be the same for airblast and ground boom at the same application rates. Breathing height was assumed to be 5 ft.

Abbreviations: TWA = Time Weighted Average, ADD = Absorbed Daily Dose, NA = Not Applicable.

Appendix 2i - Drift Exposure for Children 6-12 Years Old with Ground Boom Application of Chlorpyrifos

EAS EXPOSURE ESTIMATES												
Ground Boom - High Boom 40 swath/90th Percentile												
Drift Modeling - AgDRIFT				Dermal Dose		Incidental Oral Dose						
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	external PBPK (mg/kg/day)	9.6% absorption (mg/kg/day)	Hand-to-Mouth (mg/kg/day)	Object-to-Mouth (mg/kg/day)	Soil Ingestion (mg/kg/day)	Combined (mg/kg/day)	1-hr TWA air conc.* (mg/m3)	Inhalation Dose (mg/kg/day)	Drift ADD (mg/kg/day)
AT 802A	2	1	25	0.0045747	0.0004392	NA	NA	NA	NA	0.0218	0.0003488	0.0007880
AT 802A	2	1	50	0.0032870	0.0003156	NA	NA	NA	NA	0.0194	0.0003104	0.0006260
AT 802A	2	1	75	0.0025415	0.0002440	NA	NA	NA	NA	0.0176	0.0002816	0.0005256
AT 802A	2	1	100	0.0020332	0.0001952	NA	NA	NA	NA	0.0163	0.0002608	0.0004560
AT 802A	2	1	150	0.0015249	0.0001464	NA	NA	NA	NA	0.0143	0.0002288	0.0003752
AT 802A	2	1	200	0.0012199	0.0001171	NA	NA	NA	NA	0.0129	0.0002064	0.0003235
AT 802A	2	1	250	0.0010166	0.0000976	NA	NA	NA	NA	0.0118	0.0001888	0.0002864
AT 802A	2	1	300	0.0008811	0.0000846	NA	NA	NA	NA	0.0109	0.0001744	0.0002590
AT 802A	2	1	500	0.0005789	0.0000556	NA	NA	NA	NA	0.0085	0.0001360	0.0001916
AT 802A	2	1	1000	0.0003235	0.0000311	NA	NA	NA	NA	0.0047	0.0000752	0.0001063
AT 802A	2	1	1320	0.0002553	0.0000245	NA	NA	NA	NA	0.0033	0.0000528	0.0000773
AT 802A	2	1	2608	0.0001418	0.0000136	NA	NA	NA	NA	0.0012	0.0000192	0.0000328
AT 802A	2	2	25	0.0091494	0.0008783	NA	NA	NA	NA	0.0367	0.0005872	0.0014655
AT 802A	2	2	50	0.0065740	0.0006311	NA	NA	NA	NA	0.0320	0.0005120	0.0011431
AT 802A	2	2	75	0.0050830	0.0004880	NA	NA	NA	NA	0.0285	0.0004560	0.0009440
AT 802A	2	2	100	0.0040664	0.0003904	NA	NA	NA	NA	0.0259	0.0004144	0.0008048
AT 802A	2	2	150	0.0030498	0.0002928	NA	NA	NA	NA	0.0221	0.0003536	0.0006464
AT 802A	2	2	200	0.0024398	0.0002342	NA	NA	NA	NA	0.0195	0.0003120	0.0005462
AT 802A	2	2	250	0.0020332	0.0001952	NA	NA	NA	NA	0.0174	0.0002784	0.0004736
AT 802A	2	2	300	0.0017621	0.0001692	NA	NA	NA	NA	0.0157	0.0002512	0.0004204
AT 802A	2	2	500	0.0011579	0.0001112	NA	NA	NA	NA	0.0111	0.0001776	0.0002888
AT 802A	2	2	1000	0.0006469	0.0000621	NA	NA	NA	NA	0.0052	0.0000832	0.0001453
AT 802A	2	2	1320	0.0005105	0.0000490	NA	NA	NA	NA	0.0036	0.0000576	0.0001066
AT 802A	2	2	2608	0.0002835	0.0000272	NA	NA	NA	NA	0.0012	0.0000192	0.0000464
AT 802A	2	4	25	0.0182988	0.0017567	NA	NA	NA	NA	0.0596	0.0009536	0.0027103
AT 802A	2	4	50	0.0131480	0.0012622	NA	NA	NA	NA	0.0503	0.0008048	0.0020670
AT 802A	2	4	75	0.0101660	0.0009759	NA	NA	NA	NA	0.0439	0.0007024	0.0016783
AT 802A	2	4	100	0.0081328	0.0007807	NA	NA	NA	NA	0.0389	0.0006224	0.0014031
AT 802A	2	4	150	0.0060996	0.0005856	NA	NA	NA	NA	0.0319	0.0005104	0.0010960
AT 802A	2	4	200	0.0048797	0.0004684	NA	NA	NA	NA	0.0269	0.0004304	0.0008988
AT 802A	2	4	250	0.0040664	0.0003904	NA	NA	NA	NA	0.0230	0.0003680	0.0007584
AT 802A	2	4	300	0.0035242	0.0003383	NA	NA	NA	NA	0.0200	0.0003200	0.0006583
AT 802A	2	4	500	0.0023158	0.0002223	NA	NA	NA	NA	0.0128	0.0002048	0.0004271
AT 802A	2	4	1000	0.0012938	0.0001242	NA	NA	NA	NA	0.0055	0.0000880	0.0002122
AT 802A	2	4	1320	0.0010210	0.0000980	NA	NA	NA	NA	0.0037	0.0000592	0.0001572
AT 802A	2	4	2608	0.0005671	0.0000544	NA	NA	NA	NA	0.0014	0.0000224	0.0000768
AT 802A	2	6	25	0.0274482	0.0026350	NA	NA	NA	NA	0.0781	0.0012496	0.0038846
AT 802A	2	6	50	0.0197220	0.0018933	NA	NA	NA	NA	0.0643	0.0010288	0.0029221
AT 802A	2	6	75	0.0152490	0.0014639	NA	NA	NA	NA	0.0550	0.0008800	0.0023439
AT 802A	2	6	100	0.0121992	0.0011711	NA	NA	NA	NA	0.0479	0.0007664	0.0019375
AT 802A	2	6	150	0.0091494	0.0008783	NA	NA	NA	NA	0.0377	0.0006032	0.0014815
AT 802A	2	6	200	0.0073195	0.0007027	NA	NA	NA	NA	0.0305	0.0004880	0.0011907
AT 802A	2	6	250	0.0060996	0.0005856	NA	NA	NA	NA	0.0253	0.0004048	0.0009904
AT 802A	2	6	300	0.0052863	0.0005075	NA	NA	NA	NA	0.0214	0.0003424	0.0008499
AT 802A	2	6	500	0.0034737	0.0003335	NA	NA	NA	NA	0.0130	0.0002080	0.0005415
AT 802A	2	6	1000	0.0019408	0.0001863	NA	NA	NA	NA	0.0055	0.0000880	0.0002743
AT 802A	2	6	1320	0.0015315	0.0001470	NA	NA	NA	NA	0.0038	0.0000608	0.0002078
AT 802A	2	6	2608	0.0008506	0.0000817	NA	NA	NA	NA	0.0014	0.0000224	0.0001041

* AGDISP modeling for AT802A 2GPA with various application rates was used for inhalation surrogates. Therefore, the air concentrations will be the same for airblast and ground boom at the same application rates. Breathing height was assumed to be 5 ft.

Abbreviations: TWA = Time Weighted Average, ADD = Absorbed Daily Dose, NA = Not Applicable.

Appendix 2i - Drift Exposure for Children 6-12 Years Old with Ground Boom Application of Chlorpyrifos

EAS EXPOSURE ESTIMATES												
Ground Boom - Low Boom 40 swath/90th Percentile												
Drift Modeling - AgDRIFT				Dermal Dose		Incidental Oral Dose						
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	external PBPK (mg/kg/day)	9.6% absorption (mg/kg/day)	Hand-to-Mouth (mg/kg/day)	Object-to-Mouth (mg/kg/day)	Soil Ingestion (mg/kg/day)	Combined (mg/kg/day)	1-hr TWA air conc.* (mg/m3)	Inhalation Dose (mg/kg/day)	Drift ADD (mg/kg/day)
AT 802A	2	1	25	0.0028804	0.0002765	NA	NA	NA	NA	0.0218	0.0003488	0.0006253
AT 802A	2	1	50	0.0021010	0.0002017	NA	NA	NA	NA	0.0194	0.0003104	0.0005121
AT 802A	2	1	75	0.0016266	0.0001561	NA	NA	NA	NA	0.0176	0.0002816	0.0004377
AT 802A	2	1	100	0.0013216	0.0001269	NA	NA	NA	NA	0.0163	0.0002608	0.0003877
AT 802A	2	1	150	0.0009827	0.0000943	NA	NA	NA	NA	0.0143	0.0002288	0.0003231
AT 802A	2	1	200	0.0008133	0.0000781	NA	NA	NA	NA	0.0129	0.0002064	0.0002845
AT 802A	2	1	250	0.0006777	0.0000651	NA	NA	NA	NA	0.0118	0.0001888	0.0002539
AT 802A	2	1	300	0.0006100	0.0000586	NA	NA	NA	NA	0.0109	0.0001744	0.0002330
AT 802A	2	1	500	0.0004092	0.0000393	NA	NA	NA	NA	0.0085	0.0001360	0.0001753
AT 802A	2	1	1000	0.0002348	0.0000225	NA	NA	NA	NA	0.0047	0.0000752	0.0000977
AT 802A	2	1	1320	0.0001866	0.0000179	NA	NA	NA	NA	0.0033	0.0000528	0.0000707
AT 802A	2	1	2608	0.0001049	0.0000101	NA	NA	NA	NA	0.0012	0.0000192	0.0000293
AT 802A	2	2	25	0.0057607	0.0005530	NA	NA	NA	NA	0.0367	0.0005872	0.0011402
AT 802A	2	2	50	0.0042019	0.0004034	NA	NA	NA	NA	0.0320	0.0005120	0.0009154
AT 802A	2	2	75	0.0032531	0.0003123	NA	NA	NA	NA	0.0285	0.0004560	0.0007683
AT 802A	2	2	100	0.0026432	0.0002537	NA	NA	NA	NA	0.0259	0.0004144	0.0006681
AT 802A	2	2	150	0.0019654	0.0001887	NA	NA	NA	NA	0.0221	0.0003536	0.0005423
AT 802A	2	2	200	0.0016266	0.0001561	NA	NA	NA	NA	0.0195	0.0003120	0.0004681
AT 802A	2	2	250	0.0013555	0.0001301	NA	NA	NA	NA	0.0174	0.0002784	0.0004085
AT 802A	2	2	300	0.0012199	0.0001171	NA	NA	NA	NA	0.0157	0.0002512	0.0003683
AT 802A	2	2	500	0.0008185	0.0000786	NA	NA	NA	NA	0.0111	0.0001776	0.0002562
AT 802A	2	2	1000	0.0004695	0.0000451	NA	NA	NA	NA	0.0052	0.0000832	0.0001283
AT 802A	2	2	1320	0.0003732	0.0000358	NA	NA	NA	NA	0.0036	0.0000576	0.0000934
AT 802A	2	2	2608	0.0002098	0.0000201	NA	NA	NA	NA	0.0012	0.0000192	0.0000393
AT 802A	2	4	25	0.0115215	0.0011061	NA	NA	NA	NA	0.0596	0.0009536	0.0020597
AT 802A	2	4	50	0.0084039	0.0008068	NA	NA	NA	NA	0.0503	0.0008048	0.0016116
AT 802A	2	4	75	0.0065062	0.0006246	NA	NA	NA	NA	0.0439	0.0007024	0.0013270
AT 802A	2	4	100	0.0052863	0.0005075	NA	NA	NA	NA	0.0389	0.0006224	0.0011299
AT 802A	2	4	150	0.0039309	0.0003774	NA	NA	NA	NA	0.0319	0.0005104	0.0008878
AT 802A	2	4	200	0.0032531	0.0003123	NA	NA	NA	NA	0.0269	0.0004304	0.0007427
AT 802A	2	4	250	0.0027109	0.0002602	NA	NA	NA	NA	0.0230	0.0003680	0.0006282
AT 802A	2	4	300	0.0024398	0.0002342	NA	NA	NA	NA	0.0200	0.0003200	0.0005542
AT 802A	2	4	500	0.0016370	0.0001571	NA	NA	NA	NA	0.0128	0.0002048	0.0003619
AT 802A	2	4	1000	0.0009391	0.0000902	NA	NA	NA	NA	0.0055	0.0000880	0.0001782
AT 802A	2	4	1320	0.0007464	0.0000717	NA	NA	NA	NA	0.0037	0.0000592	0.0001309
AT 802A	2	4	2608	0.0004196	0.0000403	NA	NA	NA	NA	0.0014	0.0000224	0.0000627
AT 802A	2	6	25	0.0172822	0.0016591	NA	NA	NA	NA	0.0781	0.0012496	0.0029087
AT 802A	2	6	50	0.0126058	0.0012102	NA	NA	NA	NA	0.0643	0.0010288	0.0022390
AT 802A	2	6	75	0.0097594	0.0009369	NA	NA	NA	NA	0.0550	0.0008800	0.0018169
AT 802A	2	6	100	0.0079295	0.0007612	NA	NA	NA	NA	0.0479	0.0007664	0.0015276
AT 802A	2	6	150	0.0058963	0.0005660	NA	NA	NA	NA	0.0377	0.0006032	0.0011692
AT 802A	2	6	200	0.0048797	0.0004684	NA	NA	NA	NA	0.0305	0.0004880	0.0009564
AT 802A	2	6	250	0.0040664	0.0003904	NA	NA	NA	NA	0.0253	0.0004048	0.0007952
AT 802A	2	6	300	0.0036598	0.0003513	NA	NA	NA	NA	0.0214	0.0003424	0.0006937
AT 802A	2	6	500	0.0024554	0.0002357	NA	NA	NA	NA	0.0130	0.0002080	0.0004437
AT 802A	2	6	1000	0.0014086	0.0001352	NA	NA	NA	NA	0.0055	0.0000880	0.0002232
AT 802A	2	6	1320	0.0011196	0.0001075	NA	NA	NA	NA	0.0038	0.0000608	0.0001683
AT 802A	2	6	2608	0.0006293	0.0000604	NA	NA	NA	NA	0.0014	0.0000224	0.0000828

* AGDISP modeling for AT802A 2GPA with various application rates was used for inhalation surrogates. Therefore, the air concentrations will be the same for airblast and ground boom at the same application rates. Breathing height was assumed to be 5 ft.

Abbreviations: TWA = Time Weighted Average, ADD = Absorbed Daily Dose, NA = Not Applicable.

Appendix 2i - Drift Exposure for Children 6-12 Years Old with Ground Boom Application of Chlorpyrifos

RAS RISK CALCULATIONS								
Ground Boom - High Boom 40 swath/50th Percentile								
Drift Modeling - AgDRIFT				Margins of Exposure[a]				
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	Dermal	Combined Incidental Oral	Inhalation	Combined Drift	Combined Drift, Diet & Drinking Water[b]
AT 802A	2	1	25	32	NA	29	15	10
AT 802A	2	1	50	49	NA	32	19	12
AT 802A	2	1	75	65	NA	36	23	14
AT 802A	2	1	100	83	NA	38	26	15
AT 802A	2	1	150	114	NA	44	32	16
AT 802A	2	1	200	146	NA	48	36	17
AT 802A	2	1	250	181	NA	53	41	18
AT 802A	2	1	300	220	NA	57	45	19
AT 802A	2	1	500	423	NA	74	63	22
AT 802A	2	1	1000	1406	NA	133	121	26
AT 802A	2	1	1320	2590	NA	189	176	28
AT 802A	2	1	2608	17504	NA	521	506	31
AT 802A	2	2	25	16	NA	17	8	7
AT 802A	2	2	50	24	NA	20	11	8
AT 802A	2	2	75	33	NA	22	13	9
AT 802A	2	2	100	42	NA	24	15	10
AT 802A	2	2	150	57	NA	28	19	12
AT 802A	2	2	200	73	NA	32	22	13
AT 802A	2	2	250	90	NA	36	26	14
AT 802A	2	2	300	110	NA	40	29	15
AT 802A	2	2	500	212	NA	56	44	19
AT 802A	2	2	1000	703	NA	120	103	25
AT 802A	2	2	1320	1295	NA	174	153	27
AT 802A	2	2	2608	8752	NA	521	492	31
AT 802A	2	4	25	8	NA	10	5	4
AT 802A	2	4	50	12	NA	12	6	5
AT 802A	2	4	75	16	NA	14	8	6
AT 802A	2	4	100	21	NA	16	9	7
AT 802A	2	4	150	28	NA	20	12	9
AT 802A	2	4	200	37	NA	23	14	10
AT 802A	2	4	250	45	NA	27	17	11
AT 802A	2	4	300	55	NA	31	20	12
AT 802A	2	4	500	106	NA	49	33	17
AT 802A	2	4	1000	352	NA	114	86	24
AT 802A	2	4	1320	647	NA	169	134	26
AT 802A	2	4	2608	4376	NA	446	405	30
AT 802A	2	6	25	5	NA	8	3	3
AT 802A	2	6	50	8	NA	10	4	4
AT 802A	2	6	75	11	NA	11	6	5
AT 802A	2	6	100	14	NA	13	7	6
AT 802A	2	6	150	19	NA	17	9	7
AT 802A	2	6	200	24	NA	20	11	8
AT 802A	2	6	250	30	NA	25	14	10
AT 802A	2	6	300	37	NA	29	16	11
AT 802A	2	6	500	71	NA	48	29	15
AT 802A	2	6	1000	234	NA	114	77	23
AT 802A	2	6	1320	432	NA	164	119	26
AT 802A	2	6	2608	2917	NA	446	387	30

a/ Margin of Exposure = NOEL / Exposure. NOEL = 0.01 mg/kg based on ↑ anxiety and locomotor activity in PND21 male rats (Silva et al 2017).
b/Acute dietary exposure estimate for children 6-12 yrs old was 0.000189 mg/kg/day at the 99.9th percentile consumption rate. Acute drinking water exposure estimated for children 6-12 yrs old was 0.000115 mg/kg/day at the 99.9th percentile consumption rate for DPR's surface water monitoring data.

Appendix 2i - Drift Exposure for Children 6-12 Years Old with Ground Boom Application of Chlorpyrifos

RAS RISK CALCULATIONS								
Ground Boom - Low Boom 40 swath/50th Percentile								
Drift Modeling - AgDRIFT				Margins of Exposure[a]				
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	Dermal	Combined Incidental Oral	Inhalation	Combined Drift	Combined Drift, Diet & Drinking Water[b]
AT 802A	2	1	25	61	NA	29	20	12
AT 802A	2	1	50	90	NA	32	24	14
AT 802A	2	1	75	118	NA	36	27	15
AT 802A	2	1	100	154	NA	38	31	16
AT 802A	2	1	150	205	NA	44	36	17
AT 802A	2	1	200	256	NA	48	41	18
AT 802A	2	1	250	307	NA	53	45	19
AT 802A	2	1	300	342	NA	57	49	20
AT 802A	2	1	500	597	NA	74	65	22
AT 802A	2	1	1000	1575	NA	133	123	26
AT 802A	2	1	1320	2581	NA	189	176	28
AT 802A	2	1	2608	12090	NA	521	499	31
AT 802A	2	2	25	31	NA	17	11	8
AT 802A	2	2	50	45	NA	20	14	10
AT 802A	2	2	75	59	NA	22	16	11
AT 802A	2	2	100	77	NA	24	18	12
AT 802A	2	2	150	102	NA	28	22	13
AT 802A	2	2	200	128	NA	32	26	14
AT 802A	2	2	250	154	NA	36	29	15
AT 802A	2	2	300	171	NA	40	32	16
AT 802A	2	2	500	298	NA	56	47	19
AT 802A	2	2	1000	788	NA	120	104	25
AT 802A	2	2	1320	1290	NA	174	153	27
AT 802A	2	2	2608	6045	NA	521	480	31
AT 802A	2	4	25	15	NA	10	6	5
AT 802A	2	4	50	23	NA	12	8	6
AT 802A	2	4	75	30	NA	14	10	7
AT 802A	2	4	100	38	NA	16	11	8
AT 802A	2	4	150	51	NA	20	14	10
AT 802A	2	4	200	64	NA	23	17	11
AT 802A	2	4	250	77	NA	27	20	12
AT 802A	2	4	300	85	NA	31	23	13
AT 802A	2	4	500	149	NA	49	37	17
AT 802A	2	4	1000	394	NA	114	88	24
AT 802A	2	4	1320	645	NA	169	134	26
AT 802A	2	4	2608	3022	NA	446	389	30
AT 802A	2	6	25	10	NA	8	4	4
AT 802A	2	6	50	15	NA	10	6	5
AT 802A	2	6	75	20	NA	11	7	6
AT 802A	2	6	100	26	NA	13	9	7
AT 802A	2	6	150	34	NA	17	11	8
AT 802A	2	6	200	43	NA	20	14	10
AT 802A	2	6	250	51	NA	25	17	11
AT 802A	2	6	300	57	NA	29	19	12
AT 802A	2	6	500	99	NA	48	32	16
AT 802A	2	6	1000	263	NA	114	79	23
AT 802A	2	6	1320	430	NA	164	119	26
AT 802A	2	6	2608	2015	NA	446	365	30

a/ Margin of Exposure = NOEL / Exposure. NOEL = 0.01 mg/kg based on ↑ anxiety and locomotor activity in PND21 male rats (Silva et al 2017).
b/Acute dietary exposure estimate for children 6-12 yrs old was 0.000189 mg/kg/day at the 99.9th percentile consumption rate. Acute drinking water exposure estimated for children 6-12 yrs old was 0.000115 mg/kg/day at the 99.9th percentile consumption rate for DPR's surface water monitoring data.

Appendix 2i - Drift Exposure for Children 6-12 Years Old with Ground Boom Application of Chlorpyrifos

RAS RISK CALCULATIONS								
Ground Boom - High Boom 40 swath/90th Percentile								
Drift Modeling - AgDRIFT				Margins of Exposure[a]				
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	Dermal	Combined Incidental Oral	Inhalation	Combined Drift	Combined Drift, Diet & Drinking Water[b]
AT 802A	2	1	25	23	NA	29	13	9
AT 802A	2	1	50	32	NA	32	16	11
AT 802A	2	1	75	41	NA	36	19	12
AT 802A	2	1	100	51	NA	38	22	13
AT 802A	2	1	150	68	NA	44	27	15
AT 802A	2	1	200	85	NA	48	31	16
AT 802A	2	1	250	102	NA	53	35	17
AT 802A	2	1	300	118	NA	57	39	18
AT 802A	2	1	500	180	NA	74	52	20
AT 802A	2	1	1000	322	NA	133	94	24
AT 802A	2	1	1320	408	NA	189	129	26
AT 802A	2	1	2608	735	NA	521	305	30
AT 802A	2	2	25	11	NA	17	7	6
AT 802A	2	2	50	16	NA	20	9	7
AT 802A	2	2	75	20	NA	22	11	8
AT 802A	2	2	100	26	NA	24	12	9
AT 802A	2	2	150	34	NA	28	15	11
AT 802A	2	2	200	43	NA	32	18	12
AT 802A	2	2	250	51	NA	36	21	13
AT 802A	2	2	300	59	NA	40	24	14
AT 802A	2	2	500	90	NA	56	35	17
AT 802A	2	2	1000	161	NA	120	69	22
AT 802A	2	2	1320	204	NA	174	94	24
AT 802A	2	2	2608	367	NA	521	215	29
AT 802A	2	4	25	6	NA	10	4	3
AT 802A	2	4	50	8	NA	12	5	4
AT 802A	2	4	75	10	NA	14	6	5
AT 802A	2	4	100	13	NA	16	7	6
AT 802A	2	4	150	17	NA	20	9	7
AT 802A	2	4	200	21	NA	23	11	8
AT 802A	2	4	250	26	NA	27	13	9
AT 802A	2	4	300	30	NA	31	15	10
AT 802A	2	4	500	45	NA	49	23	14
AT 802A	2	4	1000	81	NA	114	47	19
AT 802A	2	4	1320	102	NA	169	64	22
AT 802A	2	4	2608	184	NA	446	130	26
AT 802A	2	6	25	4	NA	8	3	2
AT 802A	2	6	50	5	NA	10	3	3
AT 802A	2	6	75	7	NA	11	4	4
AT 802A	2	6	100	9	NA	13	5	4
AT 802A	2	6	150	11	NA	17	7	6
AT 802A	2	6	200	14	NA	20	8	7
AT 802A	2	6	250	17	NA	25	10	8
AT 802A	2	6	300	20	NA	29	12	9
AT 802A	2	6	500	30	NA	48	18	12
AT 802A	2	6	1000	54	NA	114	36	17
AT 802A	2	6	1320	68	NA	164	48	20
AT 802A	2	6	2608	122	NA	446	96	25

a/ Margin of Exposure = NOEL / Exposure. NOEL = 0.01 mg/kg based on ↑ anxiety and locomotor activity in PND21 male rats (Silva et al 2017).
b/Acute dietary exposure estimate for children 6-12 yrs old was 0.000189 mg/kg/day at the 99.9th percentile consumption rate. Acute drinking water exposure estimated for children 6-12 yrs old was 0.000115 mg/kg/day at the 99.9th percentile consumption rate for DPR's surface water monitoring data.

Appendix 2i - Drift Exposure for Children 6-12 Years Old with Ground Boom Application of Chlorpyrifos

RAS RISK CALCULATIONS								
Ground Boom - Low Boom 40 swath/90th Percentile								
Drift Modeling - AgDRIFT				Margins of Exposure[a]				
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	Dermal	Combined Incidental Oral	Inhalation	Combined Drift	Combined Drift, Diet & Drinking Water[b]
AT 802A	2	1	25	36	NA	29	16	11
AT 802A	2	1	50	50	NA	32	20	12
AT 802A	2	1	75	64	NA	36	23	13
AT 802A	2	1	100	79	NA	38	26	14
AT 802A	2	1	150	106	NA	44	31	16
AT 802A	2	1	200	128	NA	48	35	17
AT 802A	2	1	250	154	NA	53	39	18
AT 802A	2	1	300	171	NA	57	43	19
AT 802A	2	1	500	255	NA	74	57	21
AT 802A	2	1	1000	444	NA	133	102	25
AT 802A	2	1	1320	558	NA	189	141	27
AT 802A	2	1	2608	993	NA	521	342	30
AT 802A	2	2	25	18	NA	17	9	7
AT 802A	2	2	50	25	NA	20	11	8
AT 802A	2	2	75	32	NA	22	13	9
AT 802A	2	2	100	39	NA	24	15	10
AT 802A	2	2	150	53	NA	28	18	12
AT 802A	2	2	200	64	NA	32	21	13
AT 802A	2	2	250	77	NA	36	24	14
AT 802A	2	2	300	85	NA	40	27	15
AT 802A	2	2	500	127	NA	56	39	18
AT 802A	2	2	1000	222	NA	120	78	23
AT 802A	2	2	1320	279	NA	174	107	25
AT 802A	2	2	2608	497	NA	521	254	29
AT 802A	2	4	25	9	NA	10	5	4
AT 802A	2	4	50	12	NA	12	6	5
AT 802A	2	4	75	16	NA	14	8	6
AT 802A	2	4	100	20	NA	16	9	7
AT 802A	2	4	150	26	NA	20	11	8
AT 802A	2	4	200	32	NA	23	13	10
AT 802A	2	4	250	38	NA	27	16	11
AT 802A	2	4	300	43	NA	31	18	12
AT 802A	2	4	500	64	NA	49	28	15
AT 802A	2	4	1000	111	NA	114	56	21
AT 802A	2	4	1320	140	NA	169	76	23
AT 802A	2	4	2608	248	NA	446	160	27
AT 802A	2	6	25	6	NA	8	3	3
AT 802A	2	6	50	8	NA	10	4	4
AT 802A	2	6	75	11	NA	11	6	5
AT 802A	2	6	100	13	NA	13	7	5
AT 802A	2	6	150	18	NA	17	9	7
AT 802A	2	6	200	21	NA	20	10	8
AT 802A	2	6	250	26	NA	25	13	9
AT 802A	2	6	300	28	NA	29	14	10
AT 802A	2	6	500	42	NA	48	23	13
AT 802A	2	6	1000	74	NA	114	45	19
AT 802A	2	6	1320	93	NA	164	59	21
AT 802A	2	6	2608	166	NA	446	121	26

a/ Margin of Exposure = NOEL / Exposure. NOEL = 0.01 mg/kg based on ↑ anxiety and locomotor activity in PND21 male rats (Silva et al 2017).
b/Acute dietary exposure estimate for children 6-12 yrs old was 0.000189 mg/kg/day at the 99.9th percentile consumption rate. Acute drinking water exposure estimated for children 6-12 yrs old was 0.000115 mg/kg/day at the 99.9th percentile consumption rate for DPR's surface water monitoring data.

Appendix 2j - Drift Exposure for Females 13-49 Years Old with Aerial Application of Chlorpyrifos

EAS EXPOSURE ESTIMATES												
Drift-Modeling - AGDISP				Dermal Dose		Incidental Oral Dose				1-hr TWA air conc.* (mg/m3)	Inhalation Dose (mg/kg/day)	Drift ADD (mg/kg/day)
Aircraft	Spray Vol (gal/acre)	App Rate (lb-ai/A)	Downwind Distance (ft)	external PBPK (mg/kg/day)	9.6% absorption (mg/kg/day)	Hand-to-Mouth (mg/kg/day)	Object-to-Mouth (mg/kg/day)	Soil Ingestion (mg/kg/day)	Combined (mg/kg/day)			
AT 802A	2	1	25	0.020112	0.001931	NA	NA	NA	NA	0.0218	0.000262	0.002192
AT 802A	2	1	50	0.015829	0.001520	NA	NA	NA	NA	0.0194	0.000233	0.001752
AT 802A	2	1	100	0.010663	0.001024	NA	NA	NA	NA	0.0163	0.000196	0.001219
AT 802A	2	1	250	0.005559	0.000534	NA	NA	NA	NA	0.0118	0.000142	0.000675
AT 802A	2	1	500	0.003313	0.000318	NA	NA	NA	NA	0.0085	0.000102	0.000420
AT 802A	2	1	1000	0.001767	0.000170	NA	NA	NA	NA	0.0047	0.000056	0.000226
AT 802A	2	1	1320	0.001153	0.000111	NA	NA	NA	NA	0.0033	0.000040	0.000150
AT 802A	2	1	2608	0.000209	0.000020	NA	NA	NA	NA	0.0012	0.000014	0.000034
Bell 205 Helicopter	2	1	25	0.019057	0.001829	NA	NA	NA	NA	0.0240	0.000288	0.002117
Bell 205 Helicopter	2	1	50	0.011670	0.001120	NA	NA	NA	NA	0.0197	0.000236	0.001357
Bell 205 Helicopter	2	1	100	0.007093	0.000681	NA	NA	NA	NA	0.0158	0.000190	0.000870
Bell 205 Helicopter	2	1	250	0.004528	0.000435	NA	NA	NA	NA	0.0111	0.000133	0.000568
Bell 205 Helicopter	2	1	500	0.002687	0.000258	NA	NA	NA	NA	0.0074	0.000089	0.000347
Bell 205 Helicopter	2	1	1000	0.001313	0.000126	NA	NA	NA	NA	0.0042	0.000050	0.000176
Bell 205 Helicopter	2	1	1320	0.000920	0.000088	NA	NA	NA	NA	0.0032	0.000038	0.000127
Bell 205 Helicopter	2	1	2608	0.000147	0.000014	NA	NA	NA	NA	0.0015	0.000018	0.000032
AT 802A	2	2	25	0.040249	0.003864	NA	NA	NA	NA	0.0367	0.000440	0.004304
AT 802A	2	2	50	0.031561	0.003030	NA	NA	NA	NA	0.0320	0.000384	0.003414
AT 802A	2	2	100	0.021081	0.002024	NA	NA	NA	NA	0.0259	0.000311	0.002335
AT 802A	2	2	250	0.010553	0.001013	NA	NA	NA	NA	0.0174	0.000209	0.001222
AT 802A	2	2	500	0.005743	0.000551	NA	NA	NA	NA	0.0111	0.000133	0.000685
AT 802A	2	2	1000	0.002258	0.000217	NA	NA	NA	NA	0.0052	0.000062	0.000279
AT 802A	2	2	1320	0.001325	0.000127	NA	NA	NA	NA	0.0036	0.000043	0.000170
AT 802A	2	2	2608	0.000245	0.000024	NA	NA	NA	NA	0.0012	0.000014	0.000038
Bell 205 Helicopter	2	2	25	0.038629	0.003708	NA	NA	NA	NA	0.0404	0.000485	0.004193
Bell 205 Helicopter	2	2	50	0.023781	0.002283	NA	NA	NA	NA	0.0322	0.000386	0.002669
Bell 205 Helicopter	2	2	100	0.014799	0.001421	NA	NA	NA	NA	0.0246	0.000295	0.001716
Bell 205 Helicopter	2	2	250	0.008197	0.000787	NA	NA	NA	NA	0.0154	0.000185	0.000972
Bell 205 Helicopter	2	2	500	0.004197	0.000403	NA	NA	NA	NA	0.0093	0.000112	0.000514
Bell 205 Helicopter	2	2	1000	0.001841	0.000177	NA	NA	NA	NA	0.0049	0.000059	0.000236
Bell 205 Helicopter	2	2	1320	0.001178	0.000113	NA	NA	NA	NA	0.0036	0.000043	0.000156
Bell 205 Helicopter	2	2	2608	0.000196	0.000019	NA	NA	NA	NA	0.0016	0.000019	0.000038
AT 802A	2	2.3	25	0.046258	0.004441	NA	NA	NA	NA	0.0394	0.000473	0.004914
AT 802A	2	2.3	50	0.036239	0.003479	NA	NA	NA	NA	0.0341	0.000409	0.003888
AT 802A	2	2.3	100	0.024159	0.002319	NA	NA	NA	NA	0.0275	0.000330	0.002649
AT 802A	2	2.3	250	0.012080	0.001160	NA	NA	NA	NA	0.0183	0.000220	0.001379
AT 802A	2	2.3	500	0.006407	0.000615	NA	NA	NA	NA	0.0115	0.000138	0.000753
AT 802A	2	2.3	1000	0.002484	0.000238	NA	NA	NA	NA	0.0054	0.000065	0.000303
AT 802A	2	2.3	1320	0.001411	0.000135	NA	NA	NA	NA	0.0037	0.000044	0.000180
AT 802A	2	2.3	2608	0.000310	0.000030	NA	NA	NA	NA	0.0012	0.000014	0.000044
Bell 205 Helicopter	2	2.3	25	0.044451	0.004267	NA	NA	NA	NA	0.0435	0.000522	0.004789
Bell 205 Helicopter	2	2.3	50	0.027376	0.002628	NA	NA	NA	NA	0.0345	0.000414	0.003042
Bell 205 Helicopter	2	2.3	100	0.017075	0.001639	NA	NA	NA	NA	0.0260	0.000312	0.001951
Bell 205 Helicopter	2	2.3	250	0.009257	0.000889	NA	NA	NA	NA	0.0160	0.000192	0.001081
Bell 205 Helicopter	2	2.3	500	0.004657	0.000447	NA	NA	NA	NA	0.0096	0.000115	0.000562
Bell 205 Helicopter	2	2.3	1000	0.002004	0.000192	NA	NA	NA	NA	0.0050	0.000060	0.000252
Bell 205 Helicopter	2	2.3	1320	0.001270	0.000122	NA	NA	NA	NA	0.0037	0.000044	0.000166
Bell 205 Helicopter	2	2.3	2608	0.000254	0.000024	NA	NA	NA	NA	0.0016	0.000019	0.000044

* Breathing height was assumed to be 5 ft.

Abbreviations: TWA = Time Weighted Average, ADD = Absorbed Daily Dose, NA = Not Applicable.

Appendix 2j - Drift Exposure for Females 13-49 Years Old with Aerial Application of Chlorpyrifos

EAS EXPOSURE ESTIMATES												
Drift-Modeling - AGDISP				Dermal Dose		Incidental Oral Dose						
Aircraft	Spray Vol (gal/acre)	App Rate (lb-ai/A)	Downwind Distance (ft)	external PBPK (mg/kg/day)	9.6% absorption (mg/kg/day)	Hand-to-Mouth (mg/kg/day)	Object-to-Mouth (mg/kg/day)	Soil Ingestion (mg/kg/day)	Combined (mg/kg/day)	1-hr TWA air conc.* (mg/m3)	Inhalation Dose (mg/kg/day)	Drift ADD (mg/kg/day)
AT 802A	15	1	25	0.0172897	0.0016598	NA	NA	NA	NA	0.0306	0.0003672	0.0020270
AT 802A	15	1	50	0.0138293	0.0013276	NA	NA	NA	NA	0.0287	0.0003444	0.0016720
AT 802A	15	1	100	0.0092523	0.0008882	NA	NA	NA	NA	0.0256	0.0003072	0.0011954
AT 802A	15	1	250	0.0047488	0.0004559	NA	NA	NA	NA	0.0212	0.0002544	0.0007103
AT 802A	15	1	500	0.0029450	0.0002827	NA	NA	NA	NA	0.0177	0.0002124	0.0004951
AT 802A	15	1	1000	0.0021965	0.0002109	NA	NA	NA	NA	0.0138	0.0001656	0.0003765
AT 802A	15	1	1320	0.0019879	0.0001908	NA	NA	NA	NA	0.0119	0.0001428	0.0003336
AT 802A	15	1	2608	0.0005890	0.0000565	NA	NA	NA	NA	0.0065	0.0000780	0.0001345
Bell 205 Helicopter	15	1	25	0.0172161	0.0016527	NA	NA	NA	NA	0.0426	0.0005112	0.0021639
Bell 205 Helicopter	15	1	50	0.0099885	0.0009589	NA	NA	NA	NA	0.0373	0.0004476	0.0014065
Bell 205 Helicopter	15	1	100	0.0057919	0.0005560	NA	NA	NA	NA	0.0325	0.0003900	0.0009460
Bell 205 Helicopter	15	1	250	0.0040249	0.0003864	NA	NA	NA	NA	0.0266	0.0003192	0.0007056
Bell 205 Helicopter	15	1	500	0.0030186	0.0002898	NA	NA	NA	NA	0.0209	0.0002508	0.0005406
Bell 205 Helicopter	15	1	1000	0.0019756	0.0001897	NA	NA	NA	NA	0.0147	0.0001764	0.0003661
Bell 205 Helicopter	15	1	1320	0.0015830	0.0001520	NA	NA	NA	NA	0.0108	0.0001296	0.0002816
Bell 205 Helicopter	15	1	2608	0.0002577	0.0000247	NA	NA	NA	NA	0.0064	0.0000768	0.0001015
AT 802A	15	2	25	0.0361256	0.0034681	NA	NA	NA	NA	0.0522	0.0006264	0.0040945
AT 802A	15	2	50	0.0291066	0.0027942	NA	NA	NA	NA	0.0484	0.0005808	0.0033750
AT 802A	15	2	100	0.0198298	0.0019037	NA	NA	NA	NA	0.0426	0.0005112	0.0024149
AT 802A	15	2	250	0.0104303	0.0010013	NA	NA	NA	NA	0.0342	0.0004104	0.0014117
AT 802A	15	2	500	0.0066508	0.0006385	NA	NA	NA	NA	0.0278	0.0003336	0.0009721
AT 802A	15	2	1000	0.0048347	0.0004641	NA	NA	NA	NA	0.0202	0.0002424	0.0007065
AT 802A	15	2	1320	0.0041967	0.0004029	NA	NA	NA	NA	0.0165	0.0001980	0.0006009
AT 802A	15	2	2608	0.0010062	0.0000966	NA	NA	NA	NA	0.0075	0.0000900	0.0001866
Bell 205 Helicopter	15	2	25	0.0358557	0.0034421	NA	NA	NA	NA	0.0596	0.0007152	0.0041573
Bell 205 Helicopter	15	2	50	0.0213514	0.0020497	NA	NA	NA	NA	0.0516	0.0006192	0.0026689
Bell 205 Helicopter	15	2	100	0.0126391	0.0012133	NA	NA	NA	NA	0.0443	0.0005316	0.0017449
Bell 205 Helicopter	15	2	250	0.0088351	0.0008482	NA	NA	NA	NA	0.0353	0.0004236	0.0012718
Bell 205 Helicopter	15	2	500	0.0062827	0.0006031	NA	NA	NA	NA	0.0270	0.0003240	0.0009271
Bell 205 Helicopter	15	2	1000	0.0038040	0.0003652	NA	NA	NA	NA	0.0183	0.0002196	0.0005848
Bell 205 Helicopter	15	2	1320	0.0028959	0.0002780	NA	NA	NA	NA	0.0150	0.0001800	0.0004580
Bell 205 Helicopter	15	2	2608	0.0005154	0.0000495	NA	NA	NA	NA	0.0083	0.0000996	0.0001491
AT 802A	15	2.3	25	0.0417702	0.0040099	NA	NA	NA	NA	0.0579	0.0006948	0.0047047
AT 802A	15	2.3	50	0.0336984	0.0032350	NA	NA	NA	NA	0.0536	0.0006432	0.0038782
AT 802A	15	2.3	100	0.0229454	0.0022028	NA	NA	NA	NA	0.0469	0.0005628	0.0027656
AT 802A	15	2.3	250	0.0121077	0.0011623	NA	NA	NA	NA	0.0375	0.0004500	0.0016123
AT 802A	15	2.3	500	0.0077049	0.0007397	NA	NA	NA	NA	0.0303	0.0003636	0.0011033
AT 802A	15	2.3	1000	0.0055882	0.0005365	NA	NA	NA	NA	0.0217	0.0002604	0.0007969
AT 802A	15	2.3	1320	0.0047133	0.0004525	NA	NA	NA	NA	0.0175	0.0002100	0.0006625
AT 802A	15	2.3	2608	0.0011571	0.0001111	NA	NA	NA	NA	0.0077	0.0000924	0.0002035
Bell 205 Helicopter	15	2.3	25	0.0415445	0.0039883	NA	NA	NA	NA	0.0659	0.0007908	0.0047791
Bell 205 Helicopter	15	2.3	50	0.0248081	0.0023816	NA	NA	NA	NA	0.0569	0.0006828	0.0030644
Bell 205 Helicopter	15	2.3	100	0.0147325	0.0014143	NA	NA	NA	NA	0.0485	0.0005820	0.0019963
Bell 205 Helicopter	15	2.3	250	0.0102168	0.0009808	NA	NA	NA	NA	0.0385	0.0004620	0.0014428
Bell 205 Helicopter	15	2.3	500	0.0071687	0.0006882	NA	NA	NA	NA	0.0291	0.0003492	0.0010374
Bell 205 Helicopter	15	2.3	1000	0.0043464	0.0004173	NA	NA	NA	NA	0.0195	0.0002340	0.0006513
Bell 205 Helicopter	15	2.3	1320	0.0033021	0.0003170	NA	NA	NA	NA	0.0159	0.0001908	0.0005078
Bell 205 Helicopter	15	2.3	2608	0.0005927	0.0000569	NA	NA	NA	NA	0.0092	0.0001104	0.0001673

* Breathing height was assumed to be 5 ft.

Abbreviations: TWA = Time Weighted Average, ADD = Absorbed Daily Dose, NA = Not Applicable.

Appendix 2j - Drift Exposure for Females 13-49 Years Old with Aerial Application of Chlorpyrifos

RAS RISK CALCULATIONS								
Drift-Modeling - AGDISP				Margins of Exposure[a]				
Aircraft	Spray Vol (gal/acre)	App Rate (lb-ai/A)	Downwind Distance (ft)	Dermal	Combined Incidental Oral	Inhalation	Combined Drift	Combined Drift, Diet & Drinking Water[b]
AT 802A	2	1	25	5	NA	38	5	4
AT 802A	2	1	50	7	NA	43	6	5
AT 802A	2	1	100	10	NA	51	8	7
AT 802A	2	1	250	19	NA	71	15	11
AT 802A	2	1	500	31	NA	98	24	14
AT 802A	2	1	1000	59	NA	177	44	20
AT 802A	2	1	1320	90	NA	253	67	24
AT 802A	2	1	2608	499	NA	694	290	32
Bell 205 Helicopter	2	1	25	5	NA	35	5	4
Bell 205 Helicopter	2	1	50	9	NA	42	7	6
Bell 205 Helicopter	2	1	100	15	NA	53	11	9
Bell 205 Helicopter	2	1	250	23	NA	75	18	12
Bell 205 Helicopter	2	1	500	39	NA	113	29	16
Bell 205 Helicopter	2	1	1000	79	NA	198	57	22
Bell 205 Helicopter	2	1	1320	113	NA	260	79	25
Bell 205 Helicopter	2	1	2608	707	NA	556	311	33
AT 802A	2	2	25	3	NA	23	2	2
AT 802A	2	2	50	3	NA	26	3	3
AT 802A	2	2	100	5	NA	32	4	4
AT 802A	2	2	250	10	NA	48	8	7
AT 802A	2	2	500	18	NA	75	15	10
AT 802A	2	2	1000	46	NA	160	36	18
AT 802A	2	2	1320	79	NA	231	59	22
AT 802A	2	2	2608	424	NA	694	263	32
Bell 205 Helicopter	2	2	25	3	NA	21	2	2
Bell 205 Helicopter	2	2	50	4	NA	26	4	3
Bell 205 Helicopter	2	2	100	7	NA	34	6	5
Bell 205 Helicopter	2	2	250	13	NA	54	10	8
Bell 205 Helicopter	2	2	500	25	NA	90	19	13
Bell 205 Helicopter	2	2	1000	57	NA	170	42	20
Bell 205 Helicopter	2	2	1320	88	NA	231	64	23
Bell 205 Helicopter	2	2	2608	531	NA	524	264	32
AT 802A	2	2.3	25	2	NA	21	2	2
AT 802A	2	2.3	50	3	NA	24	3	2
AT 802A	2	2.3	100	4	NA	30	4	3
AT 802A	2	2.3	250	9	NA	46	7	6
AT 802A	2	2.3	500	16	NA	72	13	10
AT 802A	2	2.3	1000	42	NA	154	33	17
AT 802A	2	2.3	1320	74	NA	225	56	22
AT 802A	2	2.3	2608	336	NA	694	226	31
Bell 205 Helicopter	2	2.3	25	2	NA	19	2	2
Bell 205 Helicopter	2	2.3	50	4	NA	24	3	3
Bell 205 Helicopter	2	2.3	100	6	NA	32	5	4
Bell 205 Helicopter	2	2.3	250	11	NA	52	9	7
Bell 205 Helicopter	2	2.3	500	22	NA	87	18	12
Bell 205 Helicopter	2	2.3	1000	52	NA	167	40	19
Bell 205 Helicopter	2	2.3	1320	82	NA	225	60	23
Bell 205 Helicopter	2	2.3	2608	410	NA	521	229	31

a/ Margin of Exposure = NOEL / Exposure. NOEL = 0.01 mg/kg based on ↑ anxiety and locomotor activity in PND21 male rats (Silva et al 2017).
b/Acute dietary exposure estimate for females 13-49 yrs old was 0.00015 mg/kg/day at the 99.9th percentile consumption rate. Acute drinking water exposure estimated for females 13-49 yrs old was 0.000125 mg/kg/day at the 99.9th percentile consumption rate for DPR's surface water monitoring data.

Appendix 2j - Drift Exposure for Females 13-49 Years Old with Aerial Application of Chlorpyrifos

RAS RISK CALCULATIONS								
Drift-Modeling - AGDISP				Margins of Exposure[a]				
Aircraft	Spray Vol (gal/acre)	App Rate (lb-ai/A)	Downwind Distance (ft)	Dermal	Combined Incidental Oral	Inhalation	Combined Drift	Combined Drift, Diet & Drinking Water[b]
AT 802A	15	1	25	6	NA	27	5	4
AT 802A	15	1	50	8	NA	29	6	5
AT 802A	15	1	100	11	NA	33	8	7
AT 802A	15	1	250	22	NA	39	14	10
AT 802A	15	1	500	35	NA	47	20	13
AT 802A	15	1	1000	47	NA	60	27	15
AT 802A	15	1	1320	52	NA	70	30	16
AT 802A	15	1	2608	177	NA	128	74	24
Bell 205 Helicopter	15	1	25	6	NA	20	5	4
Bell 205 Helicopter	15	1	50	10	NA	22	7	6
Bell 205 Helicopter	15	1	100	18	NA	26	11	8
Bell 205 Helicopter	15	1	250	26	NA	31	14	10
Bell 205 Helicopter	15	1	500	35	NA	40	18	12
Bell 205 Helicopter	15	1	1000	53	NA	57	27	16
Bell 205 Helicopter	15	1	1320	66	NA	77	36	18
Bell 205 Helicopter	15	1	2608	404	NA	130	98	27
AT 802A	15	2	25	3	NA	16	2	2
AT 802A	15	2	50	4	NA	17	3	3
AT 802A	15	2	100	5	NA	20	4	4
AT 802A	15	2	250	10	NA	24	7	6
AT 802A	15	2	500	16	NA	30	10	8
AT 802A	15	2	1000	22	NA	41	14	10
AT 802A	15	2	1320	25	NA	51	17	11
AT 802A	15	2	2608	104	NA	111	54	22
Bell 205 Helicopter	15	2	25	3	NA	14	2	2
Bell 205 Helicopter	15	2	50	5	NA	16	4	3
Bell 205 Helicopter	15	2	100	8	NA	19	6	5
Bell 205 Helicopter	15	2	250	12	NA	24	8	6
Bell 205 Helicopter	15	2	500	17	NA	31	11	8
Bell 205 Helicopter	15	2	1000	27	NA	46	17	12
Bell 205 Helicopter	15	2	1320	36	NA	56	22	14
Bell 205 Helicopter	15	2	2608	202	NA	100	67	24
AT 802A	15	2.3	25	2	NA	14	2	2
AT 802A	15	2.3	50	3	NA	16	3	2
AT 802A	15	2.3	100	5	NA	18	4	3
AT 802A	15	2.3	250	9	NA	22	6	5
AT 802A	15	2.3	500	14	NA	28	9	7
AT 802A	15	2.3	1000	19	NA	38	13	9
AT 802A	15	2.3	1320	22	NA	48	15	11
AT 802A	15	2.3	2608	90	NA	108	49	21
Bell 205 Helicopter	15	2.3	25	3	NA	13	2	2
Bell 205 Helicopter	15	2.3	50	4	NA	15	3	3
Bell 205 Helicopter	15	2.3	100	7	NA	17	5	4
Bell 205 Helicopter	15	2.3	250	10	NA	22	7	6
Bell 205 Helicopter	15	2.3	500	15	NA	29	10	8
Bell 205 Helicopter	15	2.3	1000	24	NA	43	15	11
Bell 205 Helicopter	15	2.3	1320	32	NA	52	20	13
Bell 205 Helicopter	15	2.3	2608	176	NA	91	60	23

a/ Margin of Exposure = NOEL / Exposure. NOEL = 0.01 mg/kg based on ↑ anxiety and locomotor activity in PND21 male rats (Silva et al 2017).

b/Acute dietary exposure estimate for females 13-49 yrs old was 0.00015 mg/kg/day at the 99.9th percentile consumption rate. Acute drinking water exposure estimated for females 13-49 yrs old was 0.000125 mg/kg/day at the 99.9th percentile consumption rate for DPR's surface water monitoring data.

Appendix 2k - Drift Exposure for Females 13-49 Years Old with Airblast Application of Chlorpyrifos

EAS EXPOSURE ESTIMATES												
Orchard Airblast - Dormant Apple - 60 Swath												
Drift Modeling - AgDRIFT				Dermal Dose		Incidental Oral Dose						
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	external PBPK (mg/kg/day)	9.6% absorption (mg/kg/day)	Hand-to-Mouth (mg/kg/day)	Object-to-Mouth (mg/kg/day)	Soil Ingestion (mg/kg/day)	Combined (mg/kg/day)	1-hr TWA air conc.* (mg/m3)	Inhalation Dose (mg/kg/day)	Drift ADD (mg/kg/day)
AT 802A	2	1	25	0.0067920	0.0006520	NA	NA	NA	NA	0.0218	0.0002616	0.0009136
AT 802A	2	1	50	0.0025843	0.0002481	NA	NA	NA	NA	0.0194	0.0002328	0.0004809
AT 802A	2	1	75	0.0012676	0.0001217	NA	NA	NA	NA	0.0176	0.0002112	0.0003329
AT 802A	2	1	100	0.0007203	0.0000691	NA	NA	NA	NA	0.0163	0.0001956	0.0002647
AT 802A	2	1	150	0.0003043	0.0000292	NA	NA	NA	NA	0.0143	0.0001716	0.0002008
AT 802A	2	1	200	0.0001607	0.0000154	NA	NA	NA	NA	0.0129	0.0001548	0.0001702
AT 802A	2	1	250	0.0000969	0.0000093	NA	NA	NA	NA	0.0118	0.0001416	0.0001509
AT 802A	2	1	300	0.0000626	0.0000060	NA	NA	NA	NA	0.0109	0.0001308	0.0001368
AT 802A	2	1	500	0.0000172	0.0000016	NA	NA	NA	NA	0.0085	0.0001020	0.0001036
AT 802A	2	1	1000	0.0000032	0.0000003	NA	NA	NA	NA	0.0047	0.0000564	0.0000567
AT 802A	2	1	1320	0.0000016	0.0000002	NA	NA	NA	NA	0.0033	0.0000396	0.0000398
AT 802A	2	1	2608	0.0000003	0.0000000	NA	NA	NA	NA	0.0012	0.0000144	0.0000144
AT 802A	2	2	25	0.0135839	0.0013041	NA	NA	NA	NA	0.0367	0.0004404	0.0017445
AT 802A	2	2	50	0.0051685	0.0004962	NA	NA	NA	NA	0.0320	0.0003840	0.0008802
AT 802A	2	2	75	0.0025352	0.0002434	NA	NA	NA	NA	0.0285	0.0003420	0.0005854
AT 802A	2	2	100	0.0014406	0.0001383	NA	NA	NA	NA	0.0259	0.0003108	0.0004491
AT 802A	2	2	150	0.0006086	0.0000584	NA	NA	NA	NA	0.0221	0.0002652	0.0003236
AT 802A	2	2	200	0.0003215	0.0000309	NA	NA	NA	NA	0.0195	0.0002340	0.0002649
AT 802A	2	2	250	0.0001939	0.0000186	NA	NA	NA	NA	0.0174	0.0002088	0.0002274
AT 802A	2	2	300	0.0001252	0.0000120	NA	NA	NA	NA	0.0157	0.0001884	0.0002004
AT 802A	2	2	500	0.0000344	0.0000033	NA	NA	NA	NA	0.0111	0.0001332	0.0001365
AT 802A	2	2	1000	0.0000063	0.0000006	NA	NA	NA	NA	0.0052	0.0000624	0.0000630
AT 802A	2	2	1320	0.0000032	0.0000003	NA	NA	NA	NA	0.0036	0.0000432	0.0000435
AT 802A	2	2	2608	0.0000006	0.0000001	NA	NA	NA	NA	0.0012	0.0000144	0.0000145
AT 802A	2	4	25	0.0271678	0.0026081	NA	NA	NA	NA	0.0596	0.0007152	0.0033233
AT 802A	2	4	50	0.0103370	0.0009924	NA	NA	NA	NA	0.0503	0.0006036	0.0015960
AT 802A	2	4	75	0.0050703	0.0004868	NA	NA	NA	NA	0.0439	0.0005268	0.0010136
AT 802A	2	4	100	0.0028812	0.0002766	NA	NA	NA	NA	0.0389	0.0004668	0.0007434
AT 802A	2	4	150	0.0012173	0.0001169	NA	NA	NA	NA	0.0319	0.0003828	0.0004997
AT 802A	2	4	200	0.0006430	0.0000617	NA	NA	NA	NA	0.0269	0.0003228	0.0003845
AT 802A	2	4	250	0.0003878	0.0000372	NA	NA	NA	NA	0.0230	0.0002760	0.0003132
AT 802A	2	4	300	0.0002503	0.0000240	NA	NA	NA	NA	0.0200	0.0002400	0.0002640
AT 802A	2	4	500	0.0000687	0.0000066	NA	NA	NA	NA	0.0128	0.0001536	0.0001602
AT 802A	2	4	1000	0.0000126	0.0000012	NA	NA	NA	NA	0.0055	0.0000660	0.0000672
AT 802A	2	4	1320	0.0000063	0.0000006	NA	NA	NA	NA	0.0037	0.0000444	0.0000450
AT 802A	2	4	2608	0.0000012	0.0000001	NA	NA	NA	NA	0.0014	0.0000168	0.0000169
AT 802A	2	6	25	0.0407518	0.0039122	NA	NA	NA	NA	0.0781	0.0009372	0.0048494
AT 802A	2	6	50	0.0155055	0.0014885	NA	NA	NA	NA	0.0643	0.0007716	0.0022601
AT 802A	2	6	75	0.0076055	0.0007301	NA	NA	NA	NA	0.0550	0.0006600	0.0013901
AT 802A	2	6	100	0.0043218	0.0004149	NA	NA	NA	NA	0.0479	0.0005748	0.0009897
AT 802A	2	6	150	0.0018259	0.0001753	NA	NA	NA	NA	0.0377	0.0004524	0.0006277
AT 802A	2	6	200	0.0009645	0.0000926	NA	NA	NA	NA	0.0305	0.0003660	0.0004586
AT 802A	2	6	250	0.0005816	0.0000558	NA	NA	NA	NA	0.0253	0.0003036	0.0003594
AT 802A	2	6	300	0.0003755	0.0000360	NA	NA	NA	NA	0.0214	0.0002568	0.0002928
AT 802A	2	6	500	0.0001031	0.0000099	NA	NA	NA	NA	0.0130	0.0001560	0.0001659
AT 802A	2	6	1000	0.0000189	0.0000018	NA	NA	NA	NA	0.0055	0.0000660	0.0000678
AT 802A	2	6	1320	0.0000095	0.0000009	NA	NA	NA	NA	0.0038	0.0000456	0.0000465
AT 802A	2	6	2608	0.0000017	0.0000002	NA	NA	NA	NA	0.0014	0.0000168	0.0000170

* AGDISP modeling for AT802A 2GPA with various application rates was used for inhalation surrogates. Therefore, the air concentrations will be the same for airblast and ground boom at the same application rates. Breathing height was assumed to be 5 ft.

Abbreviations: TWA = Time Weighted Average, ADD = Absorbed Daily Dose, NA = Not Applicable.

EAS EXPOSURE ESTIMATES												
Orchard Airblast - Sparse Orchard - 60 Swath												
Drift Modeling - AgDRIFT				Dermal Dose		Incidental Oral Dose						
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	external PBPK (mg/kg/day)	9.6% absorption (mg/kg/day)	Hand-to-Mouth (mg/kg/day)	Object-to-Mouth (mg/kg/day)	Soil Ingestion (mg/kg/day)	Combined (mg/kg/day)	1-hr TWA air conc.* (mg/m3)	Inhalation Dose (mg/kg/day)	Drift ADD (mg/kg/day)
AT 802A	2	1	25	0.0055072	0.0005287	NA	NA	NA	NA	0.0218	0.0002616	0.0007903
AT 802A	2	1	50	0.0025082	0.0002408	NA	NA	NA	NA	0.0194	0.0002328	0.0004736
AT 802A	2	1	75	0.0014087	0.0001352	NA	NA	NA	NA	0.0176	0.0002112	0.0003464
AT 802A	2	1	100	0.0008995	0.0000863	NA	NA	NA	NA	0.0163	0.0001956	0.0002819
AT 802A	2	1	150	0.0004577	0.0000439	NA	NA	NA	NA	0.0143	0.0001716	0.0002155
AT 802A	2	1	200	0.0002761	0.0000265	NA	NA	NA	NA	0.0129	0.0001548	0.0001813
AT 802A	2	1	250	0.0001853	0.0000178	NA	NA	NA	NA	0.0118	0.0001416	0.0001594
AT 802A	2	1	300	0.0001325	0.0000127	NA	NA	NA	NA	0.0109	0.0001308	0.0001435
AT 802A	2	1	500	0.0000486	0.0000047	NA	NA	NA	NA	0.0085	0.0001020	0.0001067
AT 802A	2	1	1000	0.0000101	0.0000010	NA	NA	NA	NA	0.0047	0.0000564	0.0000574
AT 802A	2	1	1320	0.0000047	0.0000005	NA	NA	NA	NA	0.0033	0.0000396	0.0000401
AT 802A	2	1	2608	0.0000003	0.0000000	NA	NA	NA	NA	0.0012	0.0000144	0.0000144
AT 802A	2	2	25	0.0110144	0.0010574	NA	NA	NA	NA	0.0367	0.0004404	0.0014978
AT 802A	2	2	50	0.0050164	0.0004816	NA	NA	NA	NA	0.0320	0.0003840	0.0008656
AT 802A	2	2	75	0.0028174	0.0002705	NA	NA	NA	NA	0.0285	0.0003420	0.0006125
AT 802A	2	2	100	0.0017989	0.0001727	NA	NA	NA	NA	0.0259	0.0003108	0.0004835
AT 802A	2	2	150	0.0009154	0.0000879	NA	NA	NA	NA	0.0221	0.0002652	0.0003531
AT 802A	2	2	200	0.0005522	0.0000530	NA	NA	NA	NA	0.0195	0.0002340	0.0002870
AT 802A	2	2	250	0.0003706	0.0000356	NA	NA	NA	NA	0.0174	0.0002088	0.0002444
AT 802A	2	2	300	0.0002651	0.0000254	NA	NA	NA	NA	0.0157	0.0001884	0.0002138
AT 802A	2	2	500	0.0000972	0.0000093	NA	NA	NA	NA	0.0111	0.0001332	0.0001425
AT 802A	2	2	1000	0.0000202	0.0000019	NA	NA	NA	NA	0.0052	0.0000624	0.0000643
AT 802A	2	2	1320	0.0000094	0.0000009	NA	NA	NA	NA	0.0036	0.0000432	0.0000441
AT 802A	2	2	2608	0.0000005	0.0000000	NA	NA	NA	NA	0.0012	0.0000144	0.0000144
AT 802A	2	4	25	0.0220288	0.0021148	NA	NA	NA	NA	0.0596	0.0007152	0.0028300
AT 802A	2	4	50	0.0100327	0.0009631	NA	NA	NA	NA	0.0503	0.0006036	0.0015667
AT 802A	2	4	75	0.0056348	0.0005409	NA	NA	NA	NA	0.0439	0.0005268	0.0010677
AT 802A	2	4	100	0.0035978	0.0003454	NA	NA	NA	NA	0.0389	0.0004668	0.0008122
AT 802A	2	4	150	0.0018308	0.0001758	NA	NA	NA	NA	0.0319	0.0003828	0.0005586
AT 802A	2	4	200	0.0011044	0.0001060	NA	NA	NA	NA	0.0269	0.0003228	0.0004288
AT 802A	2	4	250	0.0007412	0.0000712	NA	NA	NA	NA	0.0230	0.0002760	0.0003472
AT 802A	2	4	300	0.0005301	0.0000509	NA	NA	NA	NA	0.0200	0.0002400	0.0002909
AT 802A	2	4	500	0.0001944	0.0000187	NA	NA	NA	NA	0.0128	0.0001536	0.0001723
AT 802A	2	4	1000	0.0000403	0.0000039	NA	NA	NA	NA	0.0055	0.0000660	0.0000699
AT 802A	2	4	1320	0.0000188	0.0000018	NA	NA	NA	NA	0.0037	0.0000444	0.0000462
AT 802A	2	4	2608	0.0000010	0.0000001	NA	NA	NA	NA	0.0014	0.0000168	0.0000169
AT 802A	2	6	25	0.0330432	0.0031721	NA	NA	NA	NA	0.0781	0.0009372	0.0041093
AT 802A	2	6	50	0.0150491	0.0014447	NA	NA	NA	NA	0.0643	0.0007716	0.0022163
AT 802A	2	6	75	0.0084522	0.0008114	NA	NA	NA	NA	0.0550	0.0006600	0.0014714
AT 802A	2	6	100	0.0053968	0.0005181	NA	NA	NA	NA	0.0479	0.0005748	0.0010929
AT 802A	2	6	150	0.0027462	0.0002636	NA	NA	NA	NA	0.0377	0.0004524	0.0007160
AT 802A	2	6	200	0.0016566	0.0001590	NA	NA	NA	NA	0.0305	0.0003660	0.0005250
AT 802A	2	6	250	0.0011117	0.0001067	NA	NA	NA	NA	0.0253	0.0003036	0.0004103
AT 802A	2	6	300	0.0007952	0.0000763	NA	NA	NA	NA	0.0214	0.0002568	0.0003331
AT 802A	2	6	500	0.0002915	0.0000280	NA	NA	NA	NA	0.0130	0.0001560	0.0001840
AT 802A	2	6	1000	0.0000605	0.0000058	NA	NA	NA	NA	0.0055	0.0000660	0.0000718
AT 802A	2	6	1320	0.0000282	0.0000027	NA	NA	NA	NA	0.0038	0.0000456	0.0000483
AT 802A	2	6	2608	0.0000015	0.0000001	NA	NA	NA	NA	0.0014	0.0000168	0.0000169

* AGDISP modeling for AT802A 2GPA with various application rates was used for inhalation surrogates. Therefore, the air concentrations will be the same for airblast and ground boom at the same application rates. Breathing height was assumed to be 5 ft.

Abbreviations: TWA = Time Weighted Average, ADD = Absorbed Daily Dose, NA = Not Applicable.

RAS RISK CALCULATIONS								
Orchard Airblast - Dormant Apple - 60 Swath								
Drift Modeling - AgDRIFT				Margins of Exposure[a]				
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	Dermal	Combined Incidental Oral	Inhalation	Combined Drift	Combined Drift, Diet & Drinking Water[b]
AT 802A	2	1	25	15	NA	38	11	8
AT 802A	2	1	50	40	NA	43	21	13
AT 802A	2	1	75	82	NA	47	30	16
AT 802A	2	1	100	145	NA	51	38	19
AT 802A	2	1	150	342	NA	58	50	21
AT 802A	2	1	200	648	NA	65	59	22
AT 802A	2	1	250	1075	NA	71	66	23
AT 802A	2	1	300	1664	NA	76	73	24
AT 802A	2	1	500	6063	NA	98	96	26
AT 802A	2	1	1000	33008	NA	177	176	30
AT 802A	2	1	1320	66021	NA	253	252	32
AT 802A	2	1	2608	362012	NA	694	693	35
AT 802A	2	2	25	8	NA	23	6	5
AT 802A	2	2	50	20	NA	26	11	9
AT 802A	2	2	75	41	NA	29	17	12
AT 802A	2	2	100	72	NA	32	22	14
AT 802A	2	2	150	171	NA	38	31	17
AT 802A	2	2	200	324	NA	43	38	19
AT 802A	2	2	250	537	NA	48	44	20
AT 802A	2	2	300	832	NA	53	50	21
AT 802A	2	2	500	3032	NA	75	73	24
AT 802A	2	2	1000	16504	NA	160	159	30
AT 802A	2	2	1320	33011	NA	231	230	31
AT 802A	2	2	2608	181006	NA	694	692	35
AT 802A	2	4	25	4	NA	14	3	3
AT 802A	2	4	50	10	NA	17	6	5
AT 802A	2	4	75	21	NA	19	10	8
AT 802A	2	4	100	36	NA	21	13	10
AT 802A	2	4	150	86	NA	26	20	13
AT 802A	2	4	200	162	NA	31	26	15
AT 802A	2	4	250	269	NA	36	32	17
AT 802A	2	4	300	416	NA	42	38	19
AT 802A	2	4	500	1516	NA	65	62	23
AT 802A	2	4	1000	8252	NA	152	149	29
AT 802A	2	4	1320	16505	NA	225	222	31
AT 802A	2	4	2608	90503	NA	595	591	34
AT 802A	2	6	25	3	NA	11	2	2
AT 802A	2	6	50	7	NA	13	4	4
AT 802A	2	6	75	14	NA	15	7	6
AT 802A	2	6	100	24	NA	17	10	8
AT 802A	2	6	150	57	NA	22	16	11
AT 802A	2	6	200	108	NA	27	22	14
AT 802A	2	6	250	179	NA	33	28	16
AT 802A	2	6	300	277	NA	39	34	18
AT 802A	2	6	500	1011	NA	64	60	23
AT 802A	2	6	1000	5501	NA	152	147	29
AT 802A	2	6	1320	11004	NA	219	215	31
AT 802A	2	6	2608	60335	NA	595	589	34

a/ Margin of Exposure = NOEL / Exposure. NOEL = 0.01 mg/kg based on ↑ anxiety and locomotor activity in PND21 male rats (Silva et al 2017).
b/Acute dietary exposure estimate for females 13-49 yrs old was 0.00015 mg/kg/day at the 99.9th percentile consumption rate. Acute drinking water exposure estimated for females 13-49 yrs old was 0.000125 mg/kg/day at the 99.9th percentile consumption rate for DPR's surface water monitoring data.

Appendix 2k - Drift Exposure for Females 13-49 Years Old with Airblast Application of Chlorpyrifos

RAS RISK CALCULATIONS								
Orchard Airblast - Sparse Orchard - 60 Swath								
Drift Modeling - AgDRIFT				Margins of Exposure[a]				
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	Dermal	Combined Incidental Oral	Inhalation	Combined Drift	Combined Drift, Diet & Drinking Water[b]
AT 802A	2	1	25	19	NA	38	13	9
AT 802A	2	1	50	42	NA	43	21	13
AT 802A	2	1	75	74	NA	47	29	16
AT 802A	2	1	100	116	NA	51	35	18
AT 802A	2	1	150	228	NA	58	46	20
AT 802A	2	1	200	377	NA	65	55	22
AT 802A	2	1	250	562	NA	71	63	23
AT 802A	2	1	300	786	NA	76	70	24
AT 802A	2	1	500	2144	NA	98	94	26
AT 802A	2	1	1000	10330	NA	177	174	30
AT 802A	2	1	1320	22140	NA	253	250	32
AT 802A	2	1	2608	415517	NA	694	693	35
AT 802A	2	2	25	9	NA	23	7	6
AT 802A	2	2	50	21	NA	26	12	9
AT 802A	2	2	75	37	NA	29	16	11
AT 802A	2	2	100	58	NA	32	21	13
AT 802A	2	2	150	114	NA	38	28	16
AT 802A	2	2	200	189	NA	43	35	18
AT 802A	2	2	250	281	NA	48	41	19
AT 802A	2	2	300	393	NA	53	47	20
AT 802A	2	2	500	1072	NA	75	70	24
AT 802A	2	2	1000	5165	NA	160	155	29
AT 802A	2	2	1320	11070	NA	231	227	31
AT 802A	2	2	2608	207759	NA	694	692	35
AT 802A	2	4	25	5	NA	14	4	3
AT 802A	2	4	50	10	NA	17	6	5
AT 802A	2	4	75	18	NA	19	9	7
AT 802A	2	4	100	29	NA	21	12	9
AT 802A	2	4	150	57	NA	26	18	12
AT 802A	2	4	200	94	NA	31	23	14
AT 802A	2	4	250	141	NA	36	29	16
AT 802A	2	4	300	197	NA	42	34	18
AT 802A	2	4	500	536	NA	65	58	22
AT 802A	2	4	1000	2582	NA	152	143	29
AT 802A	2	4	1320	5535	NA	225	216	31
AT 802A	2	4	2608	103879	NA	595	592	34
AT 802A	2	6	25	3	NA	11	2	2
AT 802A	2	6	50	7	NA	13	5	4
AT 802A	2	6	75	12	NA	15	7	6
AT 802A	2	6	100	19	NA	17	9	7
AT 802A	2	6	150	38	NA	22	14	10
AT 802A	2	6	200	63	NA	27	19	12
AT 802A	2	6	250	94	NA	33	24	15
AT 802A	2	6	300	131	NA	39	30	16
AT 802A	2	6	500	357	NA	64	54	22
AT 802A	2	6	1000	1722	NA	152	139	29
AT 802A	2	6	1320	3690	NA	219	207	31
AT 802A	2	6	2608	69253	NA	595	590	34

a/ Margin of Exposure = NOEL / Exposure. NOEL = 0.01 mg/kg based on ↑ anxiety and locomotor activity in PND21 male rats (Silva et al 2017).
b/Acute dietary exposure estimate for females 13-49 yrs old was 0.00015 mg/kg/day at the 99.9th percentile consumption rate. Acute drinking water exposure estimated for females 13-49 yrs old was 0.000125 mg/kg/day at the 99.9th percentile consumption rate for DPR's surface water monitoring data.

Appendix 2l - Drift Exposures for Females 13-49 Years Old with Ground Boom Application of Chlorpyrifos

EAS EXPOSURE ESTIMATES												
Ground Boom - High Boom 40 swath/50th Percentile												
Drift Modeling - AgDRIFT				Dermal Dose		Incidental Oral Dose						
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	external PBPK (mg/kg/day)	9.6% absorption (mg/kg/day)	Hand-to-Mouth (mg/kg/day)	Object-to-Mouth (mg/kg/day)	Soil Ingestion (mg/kg/day)	Combined (mg/kg/day)	1-hr TWA air conc.* (mg/m3)	Inhalation Dose (mg/kg/day)	Drift ADD (mg/kg/day)
AT 802A	2	1	25	0.0011657	0.0001119	NA	NA	NA	NA	0.0218	0.0002616	0.0003735
AT 802A	2	1	50	0.0007731	0.0000742	NA	NA	NA	NA	0.0194	0.0002328	0.0003070
AT 802A	2	1	75	0.0005767	0.0000554	NA	NA	NA	NA	0.0176	0.0002112	0.0002666
AT 802A	2	1	100	0.0004540	0.0000436	NA	NA	NA	NA	0.0163	0.0001956	0.0002392
AT 802A	2	1	150	0.0003313	0.0000318	NA	NA	NA	NA	0.0143	0.0001716	0.0002034
AT 802A	2	1	200	0.0002577	0.0000247	NA	NA	NA	NA	0.0129	0.0001548	0.0001795
AT 802A	2	1	250	0.0002086	0.0000200	NA	NA	NA	NA	0.0118	0.0001416	0.0001616
AT 802A	2	1	300	0.0001718	0.0000165	NA	NA	NA	NA	0.0109	0.0001308	0.0001473
AT 802A	2	1	500	0.0000891	0.0000086	NA	NA	NA	NA	0.0085	0.0001020	0.0001106
AT 802A	2	1	1000	0.0000268	0.0000026	NA	NA	NA	NA	0.0047	0.0000564	0.0000590
AT 802A	2	1	1320	0.0000146	0.0000014	NA	NA	NA	NA	0.0033	0.0000396	0.0000410
AT 802A	2	1	2608	0.0000022	0.0000002	NA	NA	NA	NA	0.0012	0.0000144	0.0000146
AT 802A	2	2	25	0.0023315	0.0002238	NA	NA	NA	NA	0.0367	0.0004404	0.0006642
AT 802A	2	2	50	0.0015461	0.0001484	NA	NA	NA	NA	0.0320	0.0003840	0.0005324
AT 802A	2	2	75	0.0011535	0.0001107	NA	NA	NA	NA	0.0285	0.0003420	0.0004527
AT 802A	2	2	100	0.0009080	0.0000872	NA	NA	NA	NA	0.0259	0.0003108	0.0003980
AT 802A	2	2	150	0.0006626	0.0000636	NA	NA	NA	NA	0.0221	0.0002652	0.0003288
AT 802A	2	2	200	0.0005154	0.0000495	NA	NA	NA	NA	0.0195	0.0002340	0.0002835
AT 802A	2	2	250	0.0004172	0.0000401	NA	NA	NA	NA	0.0174	0.0002088	0.0002489
AT 802A	2	2	300	0.0003436	0.0000330	NA	NA	NA	NA	0.0157	0.0001884	0.0002214
AT 802A	2	2	500	0.0001783	0.0000171	NA	NA	NA	NA	0.0111	0.0001332	0.0001503
AT 802A	2	2	1000	0.0000536	0.0000051	NA	NA	NA	NA	0.0052	0.0000624	0.0000675
AT 802A	2	2	1320	0.0000291	0.0000028	NA	NA	NA	NA	0.0036	0.0000432	0.0000460
AT 802A	2	2	2608	0.0000043	0.0000004	NA	NA	NA	NA	0.0012	0.0000144	0.0000148
AT 802A	2	4	25	0.0046630	0.0004476	NA	NA	NA	NA	0.0596	0.0007152	0.0011628
AT 802A	2	4	50	0.0030923	0.0002969	NA	NA	NA	NA	0.0503	0.0006036	0.0009005
AT 802A	2	4	75	0.0023069	0.0002215	NA	NA	NA	NA	0.0439	0.0005268	0.0007483
AT 802A	2	4	100	0.0018161	0.0001743	NA	NA	NA	NA	0.0389	0.0004668	0.0006411
AT 802A	2	4	150	0.0013253	0.0001272	NA	NA	NA	NA	0.0319	0.0003828	0.0005100
AT 802A	2	4	200	0.0010308	0.0000990	NA	NA	NA	NA	0.0269	0.0003228	0.0004218
AT 802A	2	4	250	0.0008344	0.0000801	NA	NA	NA	NA	0.0230	0.0002760	0.0003561
AT 802A	2	4	300	0.0006872	0.0000660	NA	NA	NA	NA	0.0200	0.0002400	0.0003060
AT 802A	2	4	500	0.0003566	0.0000342	NA	NA	NA	NA	0.0128	0.0001536	0.0001878
AT 802A	2	4	1000	0.0001073	0.0000103	NA	NA	NA	NA	0.0055	0.0000660	0.0000763
AT 802A	2	4	1320	0.0000583	0.0000056	NA	NA	NA	NA	0.0037	0.0000444	0.0000500
AT 802A	2	4	2608	0.0000086	0.0000008	NA	NA	NA	NA	0.0014	0.0000168	0.0000176
AT 802A	2	6	25	0.0069944	0.0006715	NA	NA	NA	NA	0.0781	0.0009372	0.0016087
AT 802A	2	6	50	0.0046384	0.0004453	NA	NA	NA	NA	0.0643	0.0007716	0.0012169
AT 802A	2	6	75	0.0034604	0.0003322	NA	NA	NA	NA	0.0550	0.0006600	0.0009922
AT 802A	2	6	100	0.0027241	0.0002615	NA	NA	NA	NA	0.0479	0.0005748	0.0008363
AT 802A	2	6	150	0.0019879	0.0001908	NA	NA	NA	NA	0.0377	0.0004524	0.0006432
AT 802A	2	6	200	0.0015461	0.0001484	NA	NA	NA	NA	0.0305	0.0003660	0.0005144
AT 802A	2	6	250	0.0012516	0.0001202	NA	NA	NA	NA	0.0253	0.0003036	0.0004238
AT 802A	2	6	300	0.0010308	0.0000990	NA	NA	NA	NA	0.0214	0.0002568	0.0003558
AT 802A	2	6	500	0.0005349	0.0000513	NA	NA	NA	NA	0.0130	0.0001560	0.0002073
AT 802A	2	6	1000	0.0001609	0.0000154	NA	NA	NA	NA	0.0055	0.0000660	0.0000814
AT 802A	2	6	1320	0.0000874	0.0000084	NA	NA	NA	NA	0.0038	0.0000456	0.0000540
AT 802A	2	6	2608	0.0000129	0.0000012	NA	NA	NA	NA	0.0014	0.0000168	0.0000180

* AGDISP modeling for AT802A 2GPA with various application rates was used for inhalation surrogates. Therefore, the air concentrations will be the same for airblast and ground boom at the same application rates. Breathing height was assumed to be 5 ft.

Abbreviations: TWA = Time Weighted Average, ADD = Absorbed Daily Dose, NA = Not Applicable.

Appendix 2l - Drift Exposures for Females 13-49 Years Old with Ground Boom Application of Chlorpyrifos

EAS EXPOSURE ESTIMATES												
Ground Boom - Low Boom 40 swath/50th Percentile												
Drift Modeling - AgDRIFT				Dermal Dose		Incidental Oral Dose				1-hr TWA air conc.* (mg/m3)	Inhalation Dose (mg/kg/day)	Drift ADD (mg/kg/day)
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	external PBPK (mg/kg/day)	9.6% absorption (mg/kg/day)	Hand-to-Mouth (mg/kg/day)	Object-to-Mouth (mg/kg/day)	Soil Ingestion (mg/kg/day)	Combined (mg/kg/day)			
AT 802A	2	1	25	0.0006135	0.0000589	NA	NA	NA	NA	0.0218	0.0002616	0.0003205
AT 802A	2	1	50	0.0004172	0.0000401	NA	NA	NA	NA	0.0194	0.0002328	0.0002729
AT 802A	2	1	75	0.0003190	0.0000306	NA	NA	NA	NA	0.0176	0.0002112	0.0002418
AT 802A	2	1	100	0.0002454	0.0000236	NA	NA	NA	NA	0.0163	0.0001956	0.0002192
AT 802A	2	1	150	0.0001841	0.0000177	NA	NA	NA	NA	0.0143	0.0001716	0.0001893
AT 802A	2	1	200	0.0001473	0.0000141	NA	NA	NA	NA	0.0129	0.0001548	0.0001689
AT 802A	2	1	250	0.0001227	0.0000118	NA	NA	NA	NA	0.0118	0.0001416	0.0001534
AT 802A	2	1	300	0.0001104	0.0000106	NA	NA	NA	NA	0.0109	0.0001308	0.0001414
AT 802A	2	1	500	0.0000632	0.0000061	NA	NA	NA	NA	0.0085	0.0001020	0.0001081
AT 802A	2	1	1000	0.0000239	0.0000023	NA	NA	NA	NA	0.0047	0.0000564	0.0000587
AT 802A	2	1	1320	0.0000146	0.0000014	NA	NA	NA	NA	0.0033	0.0000396	0.0000410
AT 802A	2	1	2608	0.0000031	0.0000003	NA	NA	NA	NA	0.0012	0.0000144	0.0000147
AT 802A	2	2	25	0.0012271	0.0001178	NA	NA	NA	NA	0.0367	0.0004404	0.0005582
AT 802A	2	2	50	0.0008344	0.0000801	NA	NA	NA	NA	0.0320	0.0003840	0.0004641
AT 802A	2	2	75	0.0006381	0.0000613	NA	NA	NA	NA	0.0285	0.0003420	0.0004033
AT 802A	2	2	100	0.0004908	0.0000471	NA	NA	NA	NA	0.0259	0.0003108	0.0003579
AT 802A	2	2	150	0.0003681	0.0000353	NA	NA	NA	NA	0.0221	0.0002652	0.0003005
AT 802A	2	2	200	0.0002945	0.0000283	NA	NA	NA	NA	0.0195	0.0002340	0.0002623
AT 802A	2	2	250	0.0002454	0.0000236	NA	NA	NA	NA	0.0174	0.0002088	0.0002324
AT 802A	2	2	300	0.0002209	0.0000212	NA	NA	NA	NA	0.0157	0.0001884	0.0002096
AT 802A	2	2	500	0.0001264	0.0000121	NA	NA	NA	NA	0.0111	0.0001332	0.0001453
AT 802A	2	2	1000	0.0000479	0.0000046	NA	NA	NA	NA	0.0052	0.0000624	0.0000670
AT 802A	2	2	1320	0.0000292	0.0000028	NA	NA	NA	NA	0.0036	0.0000432	0.0000460
AT 802A	2	2	2608	0.0000062	0.0000006	NA	NA	NA	NA	0.0012	0.0000144	0.0000150
AT 802A	2	4	25	0.0024542	0.0002356	NA	NA	NA	NA	0.0596	0.0007152	0.0009508
AT 802A	2	4	50	0.0016688	0.0001602	NA	NA	NA	NA	0.0503	0.0006036	0.0007638
AT 802A	2	4	75	0.0012762	0.0001225	NA	NA	NA	NA	0.0439	0.0005268	0.0006493
AT 802A	2	4	100	0.0009817	0.0000942	NA	NA	NA	NA	0.0389	0.0004668	0.0005610
AT 802A	2	4	150	0.0007363	0.0000707	NA	NA	NA	NA	0.0319	0.0003828	0.0004535
AT 802A	2	4	200	0.0005890	0.0000565	NA	NA	NA	NA	0.0269	0.0003228	0.0003793
AT 802A	2	4	250	0.0004908	0.0000471	NA	NA	NA	NA	0.0230	0.0002760	0.0003231
AT 802A	2	4	300	0.0004418	0.0000424	NA	NA	NA	NA	0.0200	0.0002400	0.0002824
AT 802A	2	4	500	0.0002528	0.0000243	NA	NA	NA	NA	0.0128	0.0001536	0.0001779
AT 802A	2	4	1000	0.0000958	0.0000092	NA	NA	NA	NA	0.0055	0.0000660	0.0000752
AT 802A	2	4	1320	0.0000585	0.0000056	NA	NA	NA	NA	0.0037	0.0000444	0.0000500
AT 802A	2	4	2608	0.0000125	0.0000012	NA	NA	NA	NA	0.0014	0.0000168	0.0000180
AT 802A	2	6	25	0.0036813	0.0003534	NA	NA	NA	NA	0.0781	0.0009372	0.0012906
AT 802A	2	6	50	0.0025033	0.0002403	NA	NA	NA	NA	0.0643	0.0007716	0.0010119
AT 802A	2	6	75	0.0019143	0.0001838	NA	NA	NA	NA	0.0550	0.0006600	0.0008438
AT 802A	2	6	100	0.0014725	0.0001414	NA	NA	NA	NA	0.0479	0.0005748	0.0007162
AT 802A	2	6	150	0.0011044	0.0001060	NA	NA	NA	NA	0.0377	0.0004524	0.0005584
AT 802A	2	6	200	0.0008835	0.0000848	NA	NA	NA	NA	0.0305	0.0003660	0.0004508
AT 802A	2	6	250	0.0007363	0.0000707	NA	NA	NA	NA	0.0253	0.0003036	0.0003743
AT 802A	2	6	300	0.0006626	0.0000636	NA	NA	NA	NA	0.0214	0.0002568	0.0003204
AT 802A	2	6	500	0.0003792	0.0000364	NA	NA	NA	NA	0.0130	0.0001560	0.0001924
AT 802A	2	6	1000	0.0001437	0.0000138	NA	NA	NA	NA	0.0055	0.0000660	0.0000798
AT 802A	2	6	1320	0.0000877	0.0000084	NA	NA	NA	NA	0.0038	0.0000456	0.0000540
AT 802A	2	6	2608	0.0000187	0.0000018	NA	NA	NA	NA	0.0014	0.0000168	0.0000186

* AGDISP modeling for AT802A 2GPA with various application rates was used for inhalation surrogates. Therefore, the air concentrations will be the same for airblast and ground boom at the same application rates. Breathing height was assumed to be 5 ft.

Abbreviations: TWA = Time Weighted Average, ADD = Absorbed Daily Dose, NA = Not Applicable.

Appendix 2l - Drift Exposures for Females 13-49 Years Old with Ground Boom Application of Chlorpyrifos

EAS EXPOSURE ESTIMATES												
Ground Boom - High Boom 40 swath/90th Percentile												
Drift Modeling - AgDRIFT				Dermal Dose		Incidental Oral Dose						
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	external PBPK (mg/kg/day)	9.6% absorption (mg/kg/day)	Hand-to-Mouth (mg/kg/day)	Object-to-Mouth (mg/kg/day)	Soil Ingestion (mg/kg/day)	Combined (mg/kg/day)	1-hr TWA air conc.* (mg/m3)	Inhalation Dose (mg/kg/day)	Drift ADD (mg/kg/day)
AT 802A	2	1	25	0.0016566	0.0001590	NA	NA	NA	NA	0.0218	0.0002616	0.0004206
AT 802A	2	1	50	0.0011903	0.0001143	NA	NA	NA	NA	0.0194	0.0002328	0.0003471
AT 802A	2	1	75	0.0009203	0.0000884	NA	NA	NA	NA	0.0176	0.0002112	0.0002996
AT 802A	2	1	100	0.0007363	0.0000707	NA	NA	NA	NA	0.0163	0.0001956	0.0002663
AT 802A	2	1	150	0.0005522	0.0000530	NA	NA	NA	NA	0.0143	0.0001716	0.0002246
AT 802A	2	1	200	0.0004418	0.0000424	NA	NA	NA	NA	0.0129	0.0001548	0.0001972
AT 802A	2	1	250	0.0003681	0.0000353	NA	NA	NA	NA	0.0118	0.0001416	0.0001769
AT 802A	2	1	300	0.0003190	0.0000306	NA	NA	NA	NA	0.0109	0.0001308	0.0001614
AT 802A	2	1	500	0.0002096	0.0000201	NA	NA	NA	NA	0.0085	0.0001020	0.0001221
AT 802A	2	1	1000	0.0001171	0.0000112	NA	NA	NA	NA	0.0047	0.0000564	0.0000676
AT 802A	2	1	1320	0.0000924	0.0000089	NA	NA	NA	NA	0.0033	0.0000396	0.0000485
AT 802A	2	1	2608	0.0000513	0.0000049	NA	NA	NA	NA	0.0012	0.0000144	0.0000193
AT 802A	2	2	25	0.0033132	0.0003181	NA	NA	NA	NA	0.0367	0.0004404	0.0007585
AT 802A	2	2	50	0.0023806	0.0002285	NA	NA	NA	NA	0.0320	0.0003840	0.0006125
AT 802A	2	2	75	0.0018406	0.0001767	NA	NA	NA	NA	0.0285	0.0003420	0.0005187
AT 802A	2	2	100	0.0014725	0.0001414	NA	NA	NA	NA	0.0259	0.0003108	0.0004522
AT 802A	2	2	150	0.0011044	0.0001060	NA	NA	NA	NA	0.0221	0.0002652	0.0003712
AT 802A	2	2	200	0.0008835	0.0000848	NA	NA	NA	NA	0.0195	0.0002340	0.0003188
AT 802A	2	2	250	0.0007363	0.0000707	NA	NA	NA	NA	0.0174	0.0002088	0.0002795
AT 802A	2	2	300	0.0006381	0.0000613	NA	NA	NA	NA	0.0157	0.0001884	0.0002497
AT 802A	2	2	500	0.0004193	0.0000403	NA	NA	NA	NA	0.0111	0.0001332	0.0001735
AT 802A	2	2	1000	0.0002343	0.0000225	NA	NA	NA	NA	0.0052	0.0000624	0.0000849
AT 802A	2	2	1320	0.0001849	0.0000177	NA	NA	NA	NA	0.0036	0.0000432	0.0000609
AT 802A	2	2	2608	0.0001027	0.0000099	NA	NA	NA	NA	0.0012	0.0000144	0.0000243
AT 802A	2	4	25	0.0066263	0.0006361	NA	NA	NA	NA	0.0596	0.0007152	0.0013513
AT 802A	2	4	50	0.0047611	0.0004571	NA	NA	NA	NA	0.0503	0.0006036	0.0010607
AT 802A	2	4	75	0.0036813	0.0003534	NA	NA	NA	NA	0.0439	0.0005268	0.0008802
AT 802A	2	4	100	0.0029450	0.0002827	NA	NA	NA	NA	0.0389	0.0004668	0.0007495
AT 802A	2	4	150	0.0022088	0.0002120	NA	NA	NA	NA	0.0319	0.0003828	0.0005948
AT 802A	2	4	200	0.0017670	0.0001696	NA	NA	NA	NA	0.0269	0.0003228	0.0004924
AT 802A	2	4	250	0.0014725	0.0001414	NA	NA	NA	NA	0.0230	0.0002760	0.0004174
AT 802A	2	4	300	0.0012762	0.0001225	NA	NA	NA	NA	0.0200	0.0002400	0.0003625
AT 802A	2	4	500	0.0008386	0.0000805	NA	NA	NA	NA	0.0128	0.0001536	0.0002341
AT 802A	2	4	1000	0.0004685	0.0000450	NA	NA	NA	NA	0.0055	0.0000660	0.0001110
AT 802A	2	4	1320	0.0003697	0.0000355	NA	NA	NA	NA	0.0037	0.0000444	0.0000799
AT 802A	2	4	2608	0.0002053	0.0000197	NA	NA	NA	NA	0.0014	0.0000168	0.0000365
AT 802A	2	6	25	0.0099395	0.0009542	NA	NA	NA	NA	0.0781	0.0009372	0.0018914
AT 802A	2	6	50	0.0071417	0.0006856	NA	NA	NA	NA	0.0643	0.0007716	0.0014572
AT 802A	2	6	75	0.0055219	0.0005301	NA	NA	NA	NA	0.0550	0.0006600	0.0011901
AT 802A	2	6	100	0.0044175	0.0004241	NA	NA	NA	NA	0.0479	0.0005748	0.0009989
AT 802A	2	6	150	0.0033132	0.0003181	NA	NA	NA	NA	0.0377	0.0004524	0.0007705
AT 802A	2	6	200	0.0026505	0.0002544	NA	NA	NA	NA	0.0305	0.0003660	0.0006204
AT 802A	2	6	250	0.0022088	0.0002120	NA	NA	NA	NA	0.0253	0.0003036	0.0005156
AT 802A	2	6	300	0.0019143	0.0001838	NA	NA	NA	NA	0.0214	0.0002568	0.0004406
AT 802A	2	6	500	0.0012579	0.0001208	NA	NA	NA	NA	0.0130	0.0001560	0.0002768
AT 802A	2	6	1000	0.0007028	0.0000675	NA	NA	NA	NA	0.0055	0.0000660	0.0001335
AT 802A	2	6	1320	0.0005546	0.0000532	NA	NA	NA	NA	0.0038	0.0000456	0.0000988
AT 802A	2	6	2608	0.0003080	0.0000296	NA	NA	NA	NA	0.0014	0.0000168	0.0000464

* AGDISP modeling for AT802A 2GPA with various application rates was used for inhalation surrogates. Therefore, the air concentrations will be the same for airblast and ground boom at the same application rates. Breathing height was assumed to be 5 ft.

Abbreviations: TWA = Time Weighted Average, ADD = Absorbed Daily Dose, NA = Not Applicable.

Appendix 2l - Drift Exposures for Females 13-49 Years Old with Ground Boom Application of Chlorpyrifos

EAS EXPOSURE ESTIMATES												
Ground Boom - Low Boom 40 swath/90th Percentile												
Drift Modeling - AgDRIFT				Dermal Dose		Incidental Oral Dose				1-hr TWA air conc.* (mg/m3)	Inhalation Dose (mg/kg/day)	Drift ADD (mg/kg/day)
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	external PBPK (mg/kg/day)	9.6% absorption (mg/kg/day)	Hand-to-Mouth (mg/kg/day)	Object-to-Mouth (mg/kg/day)	Soil Ingestion (mg/kg/day)	Combined (mg/kg/day)			
AT 802A	2	1	25	0.0010430	0.0001001	NA	NA	NA	NA	0.0218	0.0002616	0.0003617
AT 802A	2	1	50	0.0007608	0.0000730	NA	NA	NA	NA	0.0194	0.0002328	0.0003058
AT 802A	2	1	75	0.0005890	0.0000565	NA	NA	NA	NA	0.0176	0.0002112	0.0002677
AT 802A	2	1	100	0.0004786	0.0000459	NA	NA	NA	NA	0.0163	0.0001956	0.0002415
AT 802A	2	1	150	0.0003559	0.0000342	NA	NA	NA	NA	0.0143	0.0001716	0.0002058
AT 802A	2	1	200	0.0002945	0.0000283	NA	NA	NA	NA	0.0129	0.0001548	0.0001831
AT 802A	2	1	250	0.0002454	0.0000236	NA	NA	NA	NA	0.0118	0.0001416	0.0001652
AT 802A	2	1	300	0.0002209	0.0000212	NA	NA	NA	NA	0.0109	0.0001308	0.0001520
AT 802A	2	1	500	0.0001482	0.0000142	NA	NA	NA	NA	0.0085	0.0001020	0.0001162
AT 802A	2	1	1000	0.0000850	0.0000082	NA	NA	NA	NA	0.0047	0.0000564	0.0000646
AT 802A	2	1	1320	0.0000676	0.0000065	NA	NA	NA	NA	0.0033	0.0000396	0.0000461
AT 802A	2	1	2608	0.0000380	0.0000036	NA	NA	NA	NA	0.0012	0.0000144	0.0000180
AT 802A	2	2	25	0.0020861	0.0002003	NA	NA	NA	NA	0.0367	0.0004404	0.0006407
AT 802A	2	2	50	0.0015216	0.0001461	NA	NA	NA	NA	0.0320	0.0003840	0.0005301
AT 802A	2	2	75	0.0011780	0.0001131	NA	NA	NA	NA	0.0285	0.0003420	0.0004551
AT 802A	2	2	100	0.0009571	0.0000919	NA	NA	NA	NA	0.0259	0.0003108	0.0004027
AT 802A	2	2	150	0.0007117	0.0000683	NA	NA	NA	NA	0.0221	0.0002652	0.0003335
AT 802A	2	2	200	0.0005890	0.0000565	NA	NA	NA	NA	0.0195	0.0002340	0.0002905
AT 802A	2	2	250	0.0004908	0.0000471	NA	NA	NA	NA	0.0174	0.0002088	0.0002559
AT 802A	2	2	300	0.0004418	0.0000424	NA	NA	NA	NA	0.0157	0.0001884	0.0002308
AT 802A	2	2	500	0.0002964	0.0000285	NA	NA	NA	NA	0.0111	0.0001332	0.0001617
AT 802A	2	2	1000	0.0001700	0.0000163	NA	NA	NA	NA	0.0052	0.0000624	0.0000787
AT 802A	2	2	1320	0.0001351	0.0000130	NA	NA	NA	NA	0.0036	0.0000432	0.0000562
AT 802A	2	2	2608	0.0000760	0.0000073	NA	NA	NA	NA	0.0012	0.0000144	0.0000217
AT 802A	2	4	25	0.0041721	0.0004005	NA	NA	NA	NA	0.0596	0.0007152	0.0011157
AT 802A	2	4	50	0.0030432	0.0002921	NA	NA	NA	NA	0.0503	0.0006036	0.0008957
AT 802A	2	4	75	0.0023560	0.0002262	NA	NA	NA	NA	0.0439	0.0005268	0.0007530
AT 802A	2	4	100	0.0019143	0.0001838	NA	NA	NA	NA	0.0389	0.0004668	0.0006506
AT 802A	2	4	150	0.0014234	0.0001366	NA	NA	NA	NA	0.0319	0.0003828	0.0005194
AT 802A	2	4	200	0.0011780	0.0001131	NA	NA	NA	NA	0.0269	0.0003228	0.0004359
AT 802A	2	4	250	0.0009817	0.0000942	NA	NA	NA	NA	0.0230	0.0002760	0.0003702
AT 802A	2	4	300	0.0008835	0.0000848	NA	NA	NA	NA	0.0200	0.0002400	0.0003248
AT 802A	2	4	500	0.0005928	0.0000569	NA	NA	NA	NA	0.0128	0.0001536	0.0002105
AT 802A	2	4	1000	0.0003401	0.0000326	NA	NA	NA	NA	0.0055	0.0000660	0.0000986
AT 802A	2	4	1320	0.0002703	0.0000259	NA	NA	NA	NA	0.0037	0.0000444	0.0000703
AT 802A	2	4	2608	0.0001519	0.0000146	NA	NA	NA	NA	0.0014	0.0000168	0.0000314
AT 802A	2	6	25	0.0062582	0.0006008	NA	NA	NA	NA	0.0781	0.0009372	0.0015380
AT 802A	2	6	50	0.0045648	0.0004382	NA	NA	NA	NA	0.0643	0.0007716	0.0012098
AT 802A	2	6	75	0.0035340	0.0003393	NA	NA	NA	NA	0.0550	0.0006600	0.0009993
AT 802A	2	6	100	0.0028714	0.0002757	NA	NA	NA	NA	0.0479	0.0005748	0.0008505
AT 802A	2	6	150	0.0021351	0.0002050	NA	NA	NA	NA	0.0377	0.0004524	0.0006574
AT 802A	2	6	200	0.0017670	0.0001696	NA	NA	NA	NA	0.0305	0.0003660	0.0005356
AT 802A	2	6	250	0.0014725	0.0001414	NA	NA	NA	NA	0.0253	0.0003036	0.0004450
AT 802A	2	6	300	0.0013253	0.0001272	NA	NA	NA	NA	0.0214	0.0002568	0.0003840
AT 802A	2	6	500	0.0008892	0.0000854	NA	NA	NA	NA	0.0130	0.0001560	0.0002414
AT 802A	2	6	1000	0.0005101	0.0000490	NA	NA	NA	NA	0.0055	0.0000660	0.0001150
AT 802A	2	6	1320	0.0004054	0.0000389	NA	NA	NA	NA	0.0038	0.0000456	0.0000845
AT 802A	2	6	2608	0.0002279	0.0000219	NA	NA	NA	NA	0.0014	0.0000168	0.0000387

* AGDISP modeling for AT802A 2GPA with various application rates was used for inhalation surrogates. Therefore, the air concentrations will be the same for airblast and ground boom at the same application rates. Breathing height was assumed to be 5 ft.

Abbreviations: TWA = Time Weighted Average, ADD = Absorbed Daily Dose, NA = Not Applicable.

RAS RISK CALCULATIONS								
Ground Boom - High Boom 40 swath/50th Percentile								
Drift Modeling - AgDRIFT				Margins of Exposure[a]				
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	Dermal	Combined Incidental Oral	Inhalation	Combined Drift	Combined Drift, Diet & Drinking Water[b]
AT 802A	2	1	25	89	NA	38	27	15
AT 802A	2	1	50	135	NA	43	33	17
AT 802A	2	1	75	181	NA	47	38	18
AT 802A	2	1	100	229	NA	51	42	19
AT 802A	2	1	150	314	NA	58	49	21
AT 802A	2	1	200	404	NA	65	56	22
AT 802A	2	1	250	499	NA	71	62	23
AT 802A	2	1	300	606	NA	76	68	24
AT 802A	2	1	500	1169	NA	98	90	26
AT 802A	2	1	1000	3884	NA	177	170	30
AT 802A	2	1	1320	7152	NA	253	244	32
AT 802A	2	1	2608	48339	NA	694	685	35
AT 802A	2	2	25	45	NA	23	15	11
AT 802A	2	2	50	67	NA	26	19	12
AT 802A	2	2	75	90	NA	29	22	14
AT 802A	2	2	100	115	NA	32	25	15
AT 802A	2	2	150	157	NA	38	30	17
AT 802A	2	2	200	202	NA	43	35	18
AT 802A	2	2	250	250	NA	48	40	19
AT 802A	2	2	300	303	NA	53	45	20
AT 802A	2	2	500	584	NA	75	67	24
AT 802A	2	2	1000	1942	NA	160	148	29
AT 802A	2	2	1320	3576	NA	231	217	31
AT 802A	2	2	2608	24169	NA	694	675	35
AT 802A	2	4	25	22	NA	14	9	7
AT 802A	2	4	50	34	NA	17	11	9
AT 802A	2	4	75	45	NA	19	13	10
AT 802A	2	4	100	57	NA	21	16	11
AT 802A	2	4	150	79	NA	26	20	13
AT 802A	2	4	200	101	NA	31	24	14
AT 802A	2	4	250	125	NA	36	28	16
AT 802A	2	4	300	152	NA	42	33	17
AT 802A	2	4	500	292	NA	65	53	22
AT 802A	2	4	1000	971	NA	152	131	28
AT 802A	2	4	1320	1788	NA	225	200	31
AT 802A	2	4	2608	12085	NA	595	567	34
AT 802A	2	6	25	15	NA	11	6	5
AT 802A	2	6	50	22	NA	13	8	7
AT 802A	2	6	75	30	NA	15	10	8
AT 802A	2	6	100	38	NA	17	12	9
AT 802A	2	6	150	52	NA	22	16	11
AT 802A	2	6	200	67	NA	27	19	13
AT 802A	2	6	250	83	NA	33	24	14
AT 802A	2	6	300	101	NA	39	28	16
AT 802A	2	6	500	195	NA	64	48	21
AT 802A	2	6	1000	647	NA	152	123	28
AT 802A	2	6	1320	1192	NA	219	185	30
AT 802A	2	6	2608	8057	NA	595	554	34

a/ Margin of Exposure = NOEL / Exposure. NOEL = 0.01 mg/kg based on ↑ anxiety and locomotor activity in PND21 male rats (Silva et al 2017).
b/Acute dietary exposure estimate for females 13-49 yrs old was 0.00015 mg/kg/day at the 99.9th percentile consumption rate. Acute drinking water exposure estimated for females 13-49 yrs old was 0.000125 mg/kg/day at the 99.9th percentile consumption rate for DPR's surface water monitoring data.

Appendix 2l - Drift Exposures for Females 13-49 Years Old with Ground Boom Application of Chlorpyrifos

RAS RISK CALCULATIONS								
Ground Boom - Low Boom 40 swath/50th Percentile								
Drift Modeling - AgDRIFT				Margins of Exposure[a]				
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	Dermal	Combined Incidental Oral	Inhalation	Combined Drift	Combined Drift, Diet & Drinking Water[b]
AT 802A	2	1	25	170	NA	38	31	17
AT 802A	2	1	50	250	NA	43	37	18
AT 802A	2	1	75	326	NA	47	41	19
AT 802A	2	1	100	424	NA	51	46	20
AT 802A	2	1	150	566	NA	58	53	22
AT 802A	2	1	200	707	NA	65	59	23
AT 802A	2	1	250	849	NA	71	65	23
AT 802A	2	1	300	943	NA	76	71	24
AT 802A	2	1	500	1648	NA	98	93	26
AT 802A	2	1	1000	4351	NA	177	170	30
AT 802A	2	1	1320	7127	NA	253	244	32
AT 802A	2	1	2608	33387	NA	694	680	35
AT 802A	2	2	25	85	NA	23	18	12
AT 802A	2	2	50	125	NA	26	22	14
AT 802A	2	2	75	163	NA	29	25	15
AT 802A	2	2	100	212	NA	32	28	16
AT 802A	2	2	150	283	NA	38	33	17
AT 802A	2	2	200	354	NA	43	38	19
AT 802A	2	2	250	424	NA	48	43	20
AT 802A	2	2	300	472	NA	53	48	21
AT 802A	2	2	500	824	NA	75	69	24
AT 802A	2	2	1000	2175	NA	160	149	29
AT 802A	2	2	1320	3563	NA	231	217	31
AT 802A	2	2	2608	16693	NA	694	667	34
AT 802A	2	4	25	42	NA	14	11	8
AT 802A	2	4	50	62	NA	17	13	10
AT 802A	2	4	75	82	NA	19	15	11
AT 802A	2	4	100	106	NA	21	18	12
AT 802A	2	4	150	141	NA	26	22	14
AT 802A	2	4	200	177	NA	31	26	15
AT 802A	2	4	250	212	NA	36	31	17
AT 802A	2	4	300	236	NA	42	35	18
AT 802A	2	4	500	412	NA	65	56	22
AT 802A	2	4	1000	1088	NA	152	133	29
AT 802A	2	4	1320	1782	NA	225	200	31
AT 802A	2	4	2608	8347	NA	595	556	34
AT 802A	2	6	25	28	NA	11	8	6
AT 802A	2	6	50	42	NA	13	10	8
AT 802A	2	6	75	54	NA	15	12	9
AT 802A	2	6	100	71	NA	17	14	10
AT 802A	2	6	150	94	NA	22	18	12
AT 802A	2	6	200	118	NA	27	22	14
AT 802A	2	6	250	141	NA	33	27	15
AT 802A	2	6	300	157	NA	39	31	17
AT 802A	2	6	500	275	NA	64	52	21
AT 802A	2	6	1000	725	NA	152	125	28
AT 802A	2	6	1320	1188	NA	219	185	30
AT 802A	2	6	2608	5564	NA	595	538	34

a/ Margin of Exposure = NOEL / Exposure. NOEL = 0.01 mg/kg based on ↑ anxiety and locomotor activity in PND21 male rats (Silva et al 2017).
b/Acute dietary exposure estimate for females 13-49 yrs old was 0.00015 mg/kg/day at the 99.9th percentile consumption rate. Acute drinking water exposure estimated for females 13-49 yrs old was 0.000125 mg/kg/day at the 99.9th percentile consumption rate for DPR's surface water monitoring data.

Appendix 2l - Drift Exposures for Females 13-49 Years Old with Ground Boom Application of Chlorpyrifos

RAS RISK CALCULATIONS								
Ground Boom - High Boom 40 swath/90th Percentile								
Drift Modeling - AgDRIFT				Margins of Exposure[a]				
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	Dermal	Combined Incidental Oral	Inhalation	Combined Drift	Combined Drift, Diet & Drinking Water[b]
AT 802A	2	1	25	63	NA	38	24	14
AT 802A	2	1	50	88	NA	43	29	16
AT 802A	2	1	75	113	NA	47	33	17
AT 802A	2	1	100	141	NA	51	38	18
AT 802A	2	1	150	189	NA	58	45	20
AT 802A	2	1	200	236	NA	65	51	21
AT 802A	2	1	250	283	NA	71	57	22
AT 802A	2	1	300	326	NA	76	62	23
AT 802A	2	1	500	497	NA	98	82	25
AT 802A	2	1	1000	889	NA	177	148	29
AT 802A	2	1	1320	1127	NA	253	206	31
AT 802A	2	1	2608	2029	NA	694	517	34
AT 802A	2	2	25	31	NA	23	13	10
AT 802A	2	2	50	44	NA	26	16	11
AT 802A	2	2	75	57	NA	29	19	13
AT 802A	2	2	100	71	NA	32	22	14
AT 802A	2	2	150	94	NA	38	27	15
AT 802A	2	2	200	118	NA	43	31	17
AT 802A	2	2	250	141	NA	48	36	18
AT 802A	2	2	300	163	NA	53	40	19
AT 802A	2	2	500	248	NA	75	58	22
AT 802A	2	2	1000	445	NA	160	118	28
AT 802A	2	2	1320	563	NA	231	164	30
AT 802A	2	2	2608	1015	NA	694	412	33
AT 802A	2	4	25	16	NA	14	7	6
AT 802A	2	4	50	22	NA	17	9	7
AT 802A	2	4	75	28	NA	19	11	9
AT 802A	2	4	100	35	NA	21	13	10
AT 802A	2	4	150	47	NA	26	17	11
AT 802A	2	4	200	59	NA	31	20	13
AT 802A	2	4	250	71	NA	36	24	14
AT 802A	2	4	300	82	NA	42	28	16
AT 802A	2	4	500	124	NA	65	43	20
AT 802A	2	4	1000	222	NA	152	90	26
AT 802A	2	4	1320	282	NA	225	125	28
AT 802A	2	4	2608	507	NA	595	274	32
AT 802A	2	6	25	10	NA	11	5	5
AT 802A	2	6	50	15	NA	13	7	6
AT 802A	2	6	75	19	NA	15	8	7
AT 802A	2	6	100	24	NA	17	10	8
AT 802A	2	6	150	31	NA	22	13	10
AT 802A	2	6	200	39	NA	27	16	11
AT 802A	2	6	250	47	NA	33	19	13
AT 802A	2	6	300	54	NA	39	23	14
AT 802A	2	6	500	83	NA	64	36	18
AT 802A	2	6	1000	148	NA	152	75	24
AT 802A	2	6	1320	188	NA	219	101	27
AT 802A	2	6	2608	338	NA	595	216	31

a/ Margin of Exposure = NOEL / Exposure. NOEL = 0.01 mg/kg based on ↑ anxiety and locomotor activity in PND21 male rats (Silva et al 2017).
b/Acute dietary exposure estimate for females 13-49 yrs old was 0.00015 mg/kg/day at the 99.9th percentile consumption rate. Acute drinking water exposure estimated for females 13-49 yrs old was 0.000125 mg/kg/day at the 99.9th percentile consumption rate for DPR's surface water monitoring data.

Appendix 2l - Drift Exposures for Females 13-49 Years Old with Ground Boom Application of Chlorpyrifos

RAS RISK CALCULATIONS								
Ground Boom - Low Boom 40 swath/90th Percentile								
Drift Modeling - AgDRIFT				Margins of Exposure[a]				
AirCraft	Spray Vol (gal/arce)	App Rate (lb-ai/A)	Downwind Distance (ft)	Dermal	Combined Incidental Oral	Inhalation	Combined Drift	Combined Drift, Diet & Drinking Water[b]
AT 802A	2	1	25	100	NA	38	28	16
AT 802A	2	1	50	137	NA	43	33	17
AT 802A	2	1	75	177	NA	47	37	18
AT 802A	2	1	100	218	NA	51	41	19
AT 802A	2	1	150	293	NA	58	49	21
AT 802A	2	1	200	354	NA	65	55	22
AT 802A	2	1	250	424	NA	71	61	23
AT 802A	2	1	300	472	NA	76	66	23
AT 802A	2	1	500	703	NA	98	86	26
AT 802A	2	1	1000	1225	NA	177	155	29
AT 802A	2	1	1320	1542	NA	253	217	31
AT 802A	2	1	2608	2742	NA	694	554	34
AT 802A	2	2	25	50	NA	23	16	11
AT 802A	2	2	50	68	NA	26	19	12
AT 802A	2	2	75	88	NA	29	22	14
AT 802A	2	2	100	109	NA	32	25	15
AT 802A	2	2	150	146	NA	38	30	16
AT 802A	2	2	200	177	NA	43	34	18
AT 802A	2	2	250	212	NA	48	39	19
AT 802A	2	2	300	236	NA	53	43	20
AT 802A	2	2	500	351	NA	75	62	23
AT 802A	2	2	1000	613	NA	160	127	28
AT 802A	2	2	1320	771	NA	231	178	30
AT 802A	2	2	2608	1371	NA	694	461	34
AT 802A	2	4	25	25	NA	14	9	7
AT 802A	2	4	50	34	NA	17	11	9
AT 802A	2	4	75	44	NA	19	13	10
AT 802A	2	4	100	54	NA	21	15	11
AT 802A	2	4	150	73	NA	26	19	13
AT 802A	2	4	200	88	NA	31	23	14
AT 802A	2	4	250	106	NA	36	27	15
AT 802A	2	4	300	118	NA	42	31	17
AT 802A	2	4	500	176	NA	65	48	21
AT 802A	2	4	1000	306	NA	152	101	27
AT 802A	2	4	1320	385	NA	225	142	29
AT 802A	2	4	2608	686	NA	595	319	33
AT 802A	2	6	25	17	NA	11	7	6
AT 802A	2	6	50	23	NA	13	8	7
AT 802A	2	6	75	29	NA	15	10	8
AT 802A	2	6	100	36	NA	17	12	9
AT 802A	2	6	150	49	NA	22	15	11
AT 802A	2	6	200	59	NA	27	19	12
AT 802A	2	6	250	71	NA	33	22	14
AT 802A	2	6	300	79	NA	39	26	15
AT 802A	2	6	500	117	NA	64	41	19
AT 802A	2	6	1000	204	NA	152	87	26
AT 802A	2	6	1320	257	NA	219	118	28
AT 802A	2	6	2608	457	NA	595	259	32

a/ Margin of Exposure = NOEL / Exposure. NOEL = 0.01 mg/kg based on ↑ anxiety and locomotor activity in PND21 male rats (Silva et al 2017).
b/Acute dietary exposure estimate for females 13-49 yrs old was 0.00015 mg/kg/day at the 99.9th percentile consumption rate. Acute drinking water exposure estimated for females 13-49 yrs old was 0.000125 mg/kg/day at the 99.9th percentile consumption rate for DPR's surface water monitoring data.

APPENDIX 3

REVISED MARGINS OF EXPOSURE FOR ACETYLCHOLINESTERASE INHIBITION

APPENDIX 3

Revised Margins of Exposure for Acetylcholinesterase Inhibition

Introduction

Chlorpyrifos first entered the comprehensive human health risk assessment process after being given a "High" priority status by the California Department of Pesticide Regulation (DPR) in 2011. Human health concerns originally focused on potential neurodevelopmental and neurobehavioral effects, genotoxicity and reproductive toxicity in rats, probable human exposure due to spray drift, possible children hand-to-mouth exposure, and exposure through food and drinking water. The first draft comprehensive human health risk assessment was published in December 2015 (DPR, 2015).

In its December 2015 draft risk assessment, the Human Health Assessment (HHA) Branch of DPR initially adopted the points of departure (PoD) from the 2014 US EPA Revised Human Health Risk Assessment for Chlorpyrifos (US EPA, 2014) which utilized an acetylcholinesterase (AChE) inhibition endpoint. The PoDs were human estimates derived from physiologically based pharmacokinetic-pharmacodynamic (PBPK-PD) modeling of 10% AChE inhibition in red blood cells. It was in the December 2015 draft that the potential human exposure to spray drift (via inhalation or deposition) first became a concern. As such, chlorpyrifos entered the formal process to evaluate the scientific evidence for listing as a pesticide Toxic Air Contaminant (TAC) (CA Food & Agricultural Code §14021-14027). The first draft TAC evaluation was published by DPR in August 2017 (DPR, 2017a). A subsequent revision was published in December 2017 (DPR, 2017b), which has been reviewed by the Scientific Review Panel (SRP) on Toxic Air Contaminants.

Findings from the December 2017 Analysis of the Acetylcholinesterase Inhibition Endpoint

In the December 2017 Draft Evaluation of Chlorpyrifos as a Toxic Air Contaminant,[1] the critical no-observed-effect level (NOEL) for evaluating oral, dermal, and inhalation exposure to chlorpyrifos was a point of departure (PoD) based on inhibition of AChE in red blood cells. The classical mechanism of chlorpyrifos-mediated toxicity is associated with binding and inhibition of the enzyme AChE. As detailed in the December 2017 draft, the PoDs were originally adopted from the US EPA 2014 Revised Human Health Risk Assessment for Chlorpyrifos and are physiologically-based pharmacokinetic-pharmacodynamic (PBPK-PD) model derived human equivalent doses based on 10% inhibition of AChE activity after acute (single day, 24 hr) or steady-state (21-day) exposure. The PBPK-PD model includes parameters that account for human-specific physiology and metabolism and can be used to derive age, exposure duration, and route specific PoDs. Risks were calculated as margins of exposure (MOE) for infants, children, youths, and non-pregnant adults. The MOE equals the critical PoD divided by the estimated human exposure level. DPR considers a MOE of 100 to be protective of human health for all exposure scenarios. The target of 100 included uncertainty factors (UF) of 1x for

[1] The December 2017 Draft Evaluation of Chlorpyrifos as a Toxic Air Contaminant may be found in full at either https://www.cdpr.ca.gov/docs/whs/pdf/chlorpyrifos_draft_evaluation_as_tac.pdf or in Appendix 6 of this document.

interspecies sensitivity, 10x for intraspecies variability, and 10x for potential neurodevelopmental effects. Exposures resulting in MOEs lower than the target of 100 are considered to be of potential health risk to humans. Using the 10% AChE inhibition endpoint and exposures estimated from spray drift following aerial applications of chlorpyrifos, human health risks were identified from hand-to-mouth exposure to children, from inhalation exposure to children and women of childbearing age, and from various aggregate exposures. However, the air component of the exposure contributed up to 95% of the total aggregate exposure risk.

Refinements to the Acetylcholinesterase Inhibition Endpoint

HHA subsequently revised its PBPK-PD modeling outputs for the steady-state (21 day) PoDs for inhalation exposure for children 1-2 years old. HHA initiated the review of the modeling outputs as published in the August 2017 draft TAC evaluation (DPR, 2017a) following receipt of comments from Dow AgroSciences LLC (DAS). In those comments (available at https://www.cdpr.ca.gov/docs/whs/pdf/chlorpyrifos_comments_dow_draft_eval_tac.pdf), DAS commented that the steady state (21 day) inhalation PoD for children 1-2 years old presented in the US EPA 2014 Revised Human Health Risk Assessment (2.37 mg/m^3), and on which HHA initially based the PBPK-PD derived PoDs, would not achieve a 10% reduction in RBC AChE. In a separate analysis requested by HHA, DAS used the HHA default physiological parameters for children 1-2 years old (e.g., 13 kg; Andrews and Patterson, 2000) and an estimated air concentration of 3.0 mg/m^3 that will result in 10% RBC AChE inhibition at 1 hour per day for 21 days (Poet, 2017a). Given that HHA adopted all PoD values from the US EPA 2014 risk assessment into the August 2017 DPR draft risk assessment, the updated inhalation PoD value needs to be consistent with the physiological parameters US EPA used for generating other PoD values (e.g., dietary) for children 1-2 years old (e.g., 11 kg rather than 13 kg used previously). Therefore, HHA re-estimated a separate 21-day (steady state) PoD value for inhalation using the latest version of the CPF PBPK/PD model (Poet et al., 2017b) and the model input parameters as specified in the US EPA 2014 Revised Human Health Risk Assessment (US EPA 2014). The resulting PoD was 2.85 mg/m^3, which is similar to that generated by DAS but slightly higher than the 2014 US EPA PoD value (Table1). **Note**: The complete set of revised PoDs and MOEs not previously published and that reflect these PBPK-PD modeling refinement are found herein.

Table 1. Comparison of PBPK Modeled 21-Day PoD for Inhalation Exposure of Children (1-2 years old) by US EPA, DAS, and DPR

Inhalation Concentration (mg/m^3)	Exposure Hours per Day for 21 Days	Percent Control RBC AChE Activity	Source
2.37	1	<<10%	US EPA (2014) and DPR (August 2017)
3.0	1	~10%	DAS
2.85	1	~10%	DPR (December 2017)

Using the Acetylcholinesterase Inhibition Endpoint to Protect Against Developmental Neurotoxicity

Identification of a rigorous neurodevelopmental point of departure for chlorpyrifos would be strengthened by elucidation of a potential mechanism. Mammalian neurodevelopment is

multifactorial and there are likely multiple pathways involved, some of which may be mediated via the classical cholinesterase toxicity pathway of binding and inhibiting AChE. Other potential mechanisms maybe covariates of this pathway, or may involve other key events at the molecular, cellular, and tissue level. While an adverse outcome pathway has not been elucidated at this time, with further investigation it may be revealed that AChE inhibition plays a direct or indirect role in the pathway of chlorpyrifos-mediated developmental neurotoxicity. For the AChE inhibition endpoint, a target MOE of 100 was considered protective of human health for all exposure scenarios. The target of 100 included uncertainty factors (UF) of 1 for interspecies sensitivity and 10 for intraspecies variability. Because of the unknowns in the adverse outcome pathway of chlorpyrifos-induced developmental neurotoxicity, HHA set an uncertainty factor (UF) of 10 to protect against developmental neurotoxicity. This was intended to protect human populations from potential impacts on neurological or neurodevelopmental parameters that are not easily measured and may occur at doses lower than those necessary to elicit AChE inhibition. The magnitude of the UF was well supported by recent in vivo animal data that showed developmental neurotoxic effects occurring at doses approximately 10-fold lower than those known to inhibition red blood cell AChE.

After further review of the PBPK-PD model, and in consultation with the SRP, DPR revised the interspecies UF from 1 to 3, thus increasing the target MOE from 100 to 300 for the PBPK-PD derived AChE inhibition PoD. By increasing the total UF to 300, the protection factor and the conservativeness inherent in the chlorpyrifos proposed target RfCs and RfDs is further increased. The summary of PoDs and RfCs/RfDs from a total UF of 100 and 300 is summarized in Table 2.

Table 2. Points of Departure, Reference Doses, or Concentrations used to evaluate the Risk from Exposure to Chlorpyrifos in Selected Population Subgroups for Acetylcholinesterase Inhibition

Route	10% Acetylcholinesterase Inhibition[b]		
	PBPK-PD PoD[a]	RfD or RfC[c] (PoD/UF of 100)	RfD or RfC (PoD/UF of 300)
Uncertainty Factors (UF)		**1 interspecies 10 intraspecies 10 DNT**	**3 interspecies 10 intraspecies 10 DNT**
Acute Oral [mg/kg/day]			
Infants	0.600	0.006	0.002
Children 1-2	0.581	0.006	0.002
Children 6-12	0.530	0.005	0.002
Females 13-49	0.469	0.005	0.002
Acute Dermal [mg/kg/day]			
Children 1-2	134.3	1.34	0.448
Females 13-49	23.6	0.24	0.079
Acute Inhalation [mg/m^3]			
Children 1-2	2.85	0.0285	0.0095
Females 13-49	6.15	0.0615	0.0205

[a] PoD, Point of Departure (PoD): a starting dose point for low-dose extrapolation.
[b] The PoDs are Physiologically-Based Pharmacokinetic-Pharmacodynamic (PBPK-PD) model derived human equivalent doses based on 10% inhibition of acetylcholinesterase (AChE) in red blood cells after an acute (single day, 24 hr) or steady-state (21-day) exposure to chlorpyrifos. PBPK-derived PoDs were used in the DPR December 2017 Draft Evaluation of Chlorpyrifos as a Toxic Air Contaminant to derive RfDs/RfCs and to calculate risk from exposure to chlorpyrifos.

[c] RfD, Reference Dose or Reference Concentration (RfC): As defined by US EPA, RfC or RfD is an estimate of the concentration or dose of a substance to which a human populations can be exposed (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime; derived by dividing the appropriate PoD by the product of all uncertainty factors (UF).

Conclusion

DPR applied an uncertainty factor of 10X to the AChE inhibition endpoint to account for the possibility of developmental neurotoxicity effects, thus increasing the protection factor of the estimated reference concentrations / reference doses (RfCs, RfDs) for chlorpyrifos. In addition, in the final TAC evaluation of chlorpyrifos and based on the recommendation of the SRP, DPR added an additional 3x uncertainty factor for PBPK-PD model insufficiencies which further increased the protectiveness in the proposed target RfCs and RfDs. The database is robust, covering many hundreds of research papers over several decades, with consistency across laboratories and studies for the level of chlorpyrifos that inhibits AChE in red blood cells in both animals and humans. Additionally, the magnitude of the 10x UF to account for possible developmental effects is well supported by existing data that demonstrate effects occurring at levels below those that inhibit AChE.

References

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EAS EXPOSURE ESTIMATES AND REVISED MOEs FOR AChE INHIBITION
Aerial Estimates - Children 1 - 2 y.o.

Drift-Modeling AirCraft	Drift-Modeling AppVolume	Drift-Modeling AppRate (lb-ai/A)	Buffer Distance Buffer Distance (feet)	Dermal MOE	H-to-M MOE	O-to-Mouth MOE	Soil MOE	Combined-MOE Deposit-ALL	Inhalation MOE	CD + I Combined-MOE Deposit-ALL-Inhalation	CD + I + D Combined MOE Deposit-Inhalation-Food (Children)	CD + I + D + DW-EMON Combined MOE DIF-DW (PDP)-Children	CD + I + D + DW-EMON Combined MOE DIF-DW (DPR)-Children
AT 802A	2	1	25	4440	161	5230	21515	149	98	59	57	57	53
AT 802A	2	1	50	5641	204	6645	27335	190	108	69	66	65	61
AT 802A	2	1	100	8374	303	9864	40578	282	130	89	83	83	76
AT 802A	2	1	250	16063	581	18922	77842	541	177	133	122	121	107
AT 802A	2	1	500	26951	975	31747	130601	907	244	192	168	168	142
AT 802A	2	1	1000	50532	1827	59526	244877	1701	438	349	278	276	212
AT 802A	2	1	1320	77411	2799	91188	375131	2606	621	501	367	363	261
AT 802A	2	1	2608	428039	15479	504218	2074252	14408	1770	1576	734	717	404
Bell 205 Helicopter	2	1	25	4686	169	5519	22706	158	85	55	53	53	50
Bell 205 Helicopter	2	1	50	7652	277	9013	37079	258	104	74	70	70	65
Bell 205 Helicopter	2	1	100	12589	455	14830	61007	424	130	100	93	93	84
Bell 205 Helicopter	2	1	250	19720	713	23230	95562	664	186	145	132	131	115
Bell 205 Helicopter	2	1	500	33227	1202	39140	161015	1118	279	224	192	191	158
Bell 205 Helicopter	2	1	1000	68006	2459	80109	329554	2289	491	405	313	309	232
Bell 205 Helicopter	2	1	1320	97022	3509	114289	470164	3266	636	532	384	379	269
Bell 205 Helicopter	2	1	2608	606389	21928	714309	2938524	20411	1397	1308	670	656	384
AT 802A	2	2	25	2218	80	2613	10751	75	58	33	32	32	31
AT 802A	2	2	50	2829	102	3333	13710	95	65	39	38	38	36
AT 802A	2	2	75	3456	125	4071	16747	116	72	44	43	43	41
AT 802A	2	2	100	4236	153	4989	20525	143	81	52	50	50	47
AT 802A	2	2	150	5663	205	6671	27444	191	92	62	59	59	56
AT 802A	2	2	200	7253	262	8544	35147	244	105	73	70	70	65
AT 802A	2	2	250	8461	306	9967	41003	285	120	85	80	79	73
AT 802A	2	2	300	10614	384	12503	51437	357	134	97	91	91	83
AT 802A	2	2	500	15548	562	18316	75347	523	186	137	125	124	110
AT 802A	2	2	1000	39547	1430	46585	191643	1331	396	305	250	248	195
AT 802A	2	2	1320	67377	2436	79368	326503	2268	579	461	345	342	250
AT 802A	2	2	2608	363833	13157	428585	1763114	12247	1748	1530	724	708	401
Bell 205 Helicopter	2	2	25	2312	84	2723	11201	78	49	30	29	29	29
Bell 205 Helicopter	2	2	50	3755	136	4423	18195	126	62	42	40	40	39
Bell 205 Helicopter	2	2	75	4707	170	5545	22810	158	72	50	48	48	45
Bell 205 Helicopter	2	2	100	6034	218	7108	29239	203	83	59	56	56	53
Bell 205 Helicopter	2	2	150	7541	273	8884	36545	254	98	71	67	67	63
Bell 205 Helicopter	2	2	200	9365	339	11032	45384	315	114	84	79	79	73
Bell 205 Helicopter	2	2	250	10893	394	12832	52788	367	133	97	91	91	83
Bell 205 Helicopter	2	2	300	13133	475	15471	63643	442	147	110	102	102	92
Bell 205 Helicopter	2	2	500	21277	769	25063	103106	716	219	168	150	149	128
Bell 205 Helicopter	2	2	1000	48511	1754	57145	235082	1633	419	334	268	266	207
Bell 205 Helicopter	2	2	1320	75799	2741	89289	367315	2551	571	467	348	345	251
Bell 205 Helicopter	2	2	2608	454791	16446	535732	2203893	15309	1301	1199	640	628	374

EAS EXPOSURE ESTIMATES AND REVISED MOEs FOR AChE INHIBITION
Aerial Estimates - Chldren 1 - 2 y.o.

Drift-Modeling AirCraft	Drift-Modeling AppVolume	Drift-Modeling AppRate (lb-ai/A)	Buffer Distance Buffer Distance (feet)	Dermal MOE	H-to-M MOE	O-to-Mouth MOE	Soil MOE	Combined-MOE Deposit-ALL	Inhalation MOE	CD + I Combined-MOE Deposit-ALL-Inhalation	CD + I + D Combined MOE Deposit-Inhalation-Food (Children)	CD + I + D + DW-EMON Combined MOE DIF-DW (PDP)-Children	CD + I + D + DW-EMON Combined MOE DIF-DW (DPR)-Children
AT 802A	2	2.3	25	1930	70	2274	9354	65	54	30	29	29	28
AT 802A	2	2.3	50	2464	89	2903	11940	83	61	35	34	34	33
AT 802A	2	2.3	100	3696	134	4354	17911	124	77	47	46	46	44
AT 802A	2	2.3	250	7392	267	8708	35821	249	114	78	74	74	68
AT 802A	2	2.3	500	13937	504	16418	67539	469	180	130	119	118	105
AT 802A	2	2.3	1000	35952	1300	42350	174221	1210	382	290	240	238	189
AT 802A	2	2.3	1320	63275	2288	74537	306629	2130	559	443	335	331	244
AT 802A	2	2.3	2608	287615	10401	338803	1393766	9681	1696	1443	704	689	395
Bell 205 Helicopter	2	2.3	25	2009	73	2366	9734	68	47	28	27	27	26
Bell 205 Helicopter	2	2.3	50	3262	118	3842	15806	110	59	38	37	37	36
Bell 205 Helicopter	2	2.3	100	5229	189	6160	25341	176	79	54	52	52	49
Bell 205 Helicopter	2	2.3	250	9646	349	11362	46742	325	128	92	86	86	79
Bell 205 Helicopter	2	2.3	500	19174	693	22587	92918	645	214	161	144	143	124
Bell 205 Helicopter	2	2.3	1000	44560	1611	52491	215936	1500	415	325	263	261	203
Bell 205 Helicopter	2	2.3	1320	70306	2542	82818	340698	2367	565	456	343	339	248
Bell 205 Helicopter	2	2.3	2608	351530	12712	414092	1703492	11833	1267	1144	624	612	368
AT 802A	15	1	25	5164	187	6084	25026	174	69	49	48	48	45
AT 802A	15	1	50	6457	233	7606	31289	217	73	55	53	52	50
AT 802A	15	1	100	9651	349	11368	46767	325	82	65	62	62	58
AT 802A	15	1	250	18803	680	22149	91117	633	99	85	80	80	74
AT 802A	15	1	500	30319	1096	35715	146926	1021	117	105	98	97	88
AT 802A	15	1	1000	40652	1470	47887	196996	1368	150	135	123	123	108
AT 802A	15	1	1320	44918	1624	52912	217668	1512	174	156	140	139	121
AT 802A	15	1	2608	151597	5482	178577	734631	5103	317	299	245	244	193
Bell 205 Helicopter	15	1	25	5187	188	6110	25133	175	48	38	37	37	35
Bell 205 Helicopter	15	1	50	8939	323	10530	43320	301	55	47	45	45	43
Bell 205 Helicopter	15	1	100	15417	558	18160	74708	519	64	57	54	54	51
Bell 205 Helicopter	15	1	250	22185	802	26133	107507	747	78	70	67	67	62
Bell 205 Helicopter	15	1	500	29580	1070	34844	143343	996	99	90	84	84	77
Bell 205 Helicopter	15	1	1000	45197	1634	53240	219020	1521	141	129	118	117	104
Bell 205 Helicopter	15	1	1320	56408	2040	66447	273351	1899	191	173	154	153	131
Bell 205 Helicopter	15	1	2608	346508	12531	408177	1679156	11664	356	345	276	274	211

EAS EXPOSURE ESTIMATES AND REVISED MOEs FOR AChE INHIBITION
Aerial Estimates - Children 1 - 2 y.o.

Drift-Modeling AirCraft	Drift-Modeling AppVolume	Drift-Modeling AppRate (lb-ai/A)	Buffer Distance Buffer Distance (feet)	Dermal MOE	H-to-M MOE	O-to-Mouth MOE	Soil MOE	Combined-MOE Deposit-ALL	Inhalation MOE	CD + I Combined-MOE Deposit-ALL-Inhalation	CD + I + D Combined MOE Deposit-Inhalation-Food (Children)	CD + I + D + DW-EMON Combined MOE DIF-DW (PDP)-Children	CD + I + D + DW-EMON Combined MOE DIF-DW (DPR)-Children
AT 802A	15	2	25	2472	89	2912	11978	83	41	27	27	27	26
AT 802A	15	2	50	3068	111	3614	14866	103	43	30	30	30	29
AT 802A	15	2	100	4503	163	5304	21821	152	49	37	36	36	35
AT 802A	15	2	250	8561	310	10084	41485	288	61	50	49	48	46
AT 802A	15	2	500	13426	486	15815	65060	452	75	64	61	61	57
AT 802A	15	2	1000	18469	668	21756	89498	622	102	88	83	82	76
AT 802A	15	2	1320	21277	769	25063	103106	716	125	107	99	99	89
AT 802A	15	2	2608	88740	3209	104533	430028	2987	276	253	214	212	173
Bell 205 Helicopter	15	2	25	2490	90	2934	12068	84	34	24	24	24	23
Bell 205 Helicopter	15	2	50	4182	151	4926	20266	141	40	31	30	30	29
Bell 205 Helicopter	15	2	100	7065	255	8322	34235	238	47	39	38	38	36
Bell 205 Helicopter	15	2	250	10106	365	11905	48975	340	58	50	48	48	46
Bell 205 Helicopter	15	2	500	14212	514	16742	68872	478	76	66	63	63	59
Bell 205 Helicopter	15	2	1000	23473	849	27651	113749	790	113	99	92	92	84
Bell 205 Helicopter	15	2	1320	30833	1115	36321	149416	1038	138	122	112	111	99
Bell 205 Helicopter	15	2	2608	173254	6265	204088	839578	5832	248	238	203	202	166
AT 802A	15	2.3	25	2138	77	2518	10359	72	37	24	24	24	23
AT 802A	15	2.3	50	2650	96	3121	12840	89	39	27	27	27	26
AT 802A	15	2.3	100	3891	141	4584	18858	131	45	33	33	33	31
AT 802A	15	2.3	250	7375	267	8687	35738	248	56	45	44	44	42
AT 802A	15	2.3	500	11589	419	13651	56159	390	69	58	56	56	53
AT 802A	15	2.3	1000	15979	578	18822	77431	538	95	81	77	76	71
AT 802A	15	2.3	1320	18945	685	22316	91805	638	118	100	93	93	84
AT 802A	15	2.3	2608	77165	2790	90898	373937	2597	268	243	206	205	168
Bell 205 Helicopter	15	2.3	25	2149	78	2532	10415	72	31	22	21	21	21
Bell 205 Helicopter	15	2.3	50	3599	130	4240	17442	121	36	28	27	27	26
Bell 205 Helicopter	15	2.3	100	6061	219	7140	29371	204	42	35	34	34	33
Bell 205 Helicopter	15	2.3	250	8740	316	10295	42352	294	54	45	44	44	42
Bell 205 Helicopter	15	2.3	500	12456	450	14673	60360	419	71	61	58	58	55
Bell 205 Helicopter	15	2.3	1000	20544	743	24200	99555	692	106	92	86	86	79
Bell 205 Helicopter	15	2.3	1320	27041	978	31853	131038	910	130	114	105	105	94
Bell 205 Helicopter	15	2.3	2608	150656	5448	177468	730068	5071	225	215	186	185	154

EAS EXPOSURE ESTIMATES AND REVISED MOEs FOR AChE INHIBITION
Aerial Estimates - Females 13 - 49 y.o.

Drift-Modeling Groundboom	Drift-Modeling AirCraft	Drift-Modeling AppRate (lb-ai/A)	Buffer Distance (feet)	Dermal MOE	Inhalation MOE	Combined-MOE Deposit-ALL-Inhalation	Combined MOE Dermal-Inhalation-Food (Females)	Combined MOE DIF-DW (PDP)-Females	Combined MOE DIF-DW (DPR)-Females
Aircraft	GPA	AppRate (lb-ai/A)	Buffer Distance (feet	Dermal-MOE	Inhalation-MO	MOE-Deposit-Inhalation	MOE-D-I-Food-Females	MOE-DIF-DW(PDP)-Females	MOE-DIF-DW(DPR)-Females
AT 802A	2	1	25	1173	282	227	212	211	177
AT 802A	2	1	50	1491	317	261	241	240	197
AT 802A	2	1	100	2213	377	322	292	290	230
AT 802A	2	1	250	4246	521	464	404	400	294
AT 802A	2	1	500	7123	724	657	542	536	362
AT 802A	2	1	1000	13356	1309	1192	862	845	480
AT 802A	2	1	1320	20460	1864	1708	1103	1075	547
AT 802A	2	1	2608	113132	5125	4903	1904	1824	691
Bell 205 Helicopter	2	1	25	1238	256	212	199	198	168
Bell 205 Helicopter	2	1	50	2022	312	270	249	247	202
Bell 205 Helicopter	2	1	100	3327	389	348	313	311	243
Bell 205 Helicopter	2	1	250	5212	554	501	431	427	309
Bell 205 Helicopter	2	1	500	8782	831	759	610	602	391
Bell 205 Helicopter	2	1	1000	17974	1464	1354	944	923	505
Bell 205 Helicopter	2	1	1320	25643	1922	1788	1136	1107	555
Bell 205 Helicopter	2	1	2608	160270	4100	3998	1750	1682	670
AT 802A	2	2	25	586	168	130	125	125	112
AT 802A	2	2	50	748	192	153	146	145	128
AT 802A	2	2	100	1119	237	196	184	184	158
AT 802A	2	2	250	2236	353	305	278	276	221
AT 802A	2	2	500	4109	554	488	422	418	304
AT 802A	2	2	1000	10452	1183	1062	792	778	458
AT 802A	2	2	1320	17808	1708	1559	1039	1014	531
AT 802A	2	2	2608	96162	5125	4866	1899	1818	691
Bell 205 Helicopter	2	2	25	611	152	122	117	117	106
Bell 205 Helicopter	2	2	50	992	191	160	152	152	134
Bell 205 Helicopter	2	2	100	1595	250	216	202	201	170
Bell 205 Helicopter	2	2	250	2879	399	351	315	313	244
Bell 205 Helicopter	2	2	500	5624	661	592	497	492	341
Bell 205 Helicopter	2	2	1000	12822	1255	1143	836	820	472
Bell 205 Helicopter	2	2	1320	20034	1704	1570	1044	1019	532
Bell 205 Helicopter	2	2	2608	120203	3868	3747	1701	1636	663

EAS EXPOSURE ESTIMATES AND REVISED MOEs FOR AChE INHIBITION
Aerial Estimates - Females 13 - 49 y.o.

Drift-Modeling Groundboom	Drift-Modeling AirCraft	Drift-Modeling AppRate (lb-ai/A)	Buffer Distance (feet)	Dermal MOE	Inhalation MOE	Combined-MOE Deposit-ALL-Inhalation	Combined MOE Dermal-Inhalation-Food (Females)	Combined MOE DIF-DW (PDP)-Females	Combined MOE DIF-DW (DPR)-Females
Aircraft	GPA	AppRate (lb-ai/A)	Buffer Distance (feet	Dermal-MOE	Inhalation-MO	MOE-Deposit-Inhalation	MOE-D-I-Food-Females	MOE-DIF-DW(PDP)-Females	MOE-DIF-DW(DPR)-Females
AT 802A	2	2.3	25	510	156	120	115	115	104
AT 802A	2	2.3	50	651	180	141	135	135	120
AT 802A	2	2.3	100	977	224	182	172	171	148
AT 802A	2	2.3	250	1954	336	287	263	261	211
AT 802A	2	2.3	500	3684	535	467	406	402	296
AT 802A	2	2.3	1000	9502	1139	1017	767	753	449
AT 802A	2	2.3	1320	16724	1662	1512	1018	994	525
AT 802A	2	2.3	2608	76018	5125	4801	1889	1809	689
Bell 205 Helicopter	2	2.3	25	531	141	112	108	108	98
Bell 205 Helicopter	2	2.3	50	862	178	148	141	141	125
Bell 205 Helicopter	2	2.3	100	1382	237	202	190	189	161
Bell 205 Helicopter	2	2.3	250	2549	384	334	302	300	236
Bell 205 Helicopter	2	2.3	500	5068	641	569	481	476	333
Bell 205 Helicopter	2	2.3	1000	11777	1230	1114	820	805	467
Bell 205 Helicopter	2	2.3	1320	18582	1662	1526	1024	1000	527
Bell 205 Helicopter	2	2.3	2608	92910	3844	3691	1689	1625	661
AT 802A	15	1	25	1365	201	175	166	165	144
AT 802A	15	1	50	1707	214	190	179	179	154
AT 802A	15	1	100	2551	240	220	205	204	173
AT 802A	15	1	250	4970	290	274	252	250	204
AT 802A	15	1	500	8014	347	333	301	299	236
AT 802A	15	1	1000	10744	446	428	376	373	279
AT 802A	15	1	1320	11872	517	495	427	423	307
AT 802A	15	1	2608	40068	946	924	713	701	430
Bell 205 Helicopter	15	1	25	1371	144	131	125	125	112
Bell 205 Helicopter	15	1	50	2363	165	154	147	146	129
Bell 205 Helicopter	15	1	100	4075	189	181	171	170	148
Bell 205 Helicopter	15	1	250	5864	231	222	208	207	174
Bell 205 Helicopter	15	1	500	7818	294	284	260	258	210
Bell 205 Helicopter	15	1	1000	11946	418	404	358	355	269
Bell 205 Helicopter	15	1	1320	14909	569	548	466	461	326
Bell 205 Helicopter	15	1	2608	91583	961	951	728	716	436

EAS EXPOSURE ESTIMATES AND REVISED MOEs FOR AChE INHIBITION
Aerial Estimates - Females 13 - 49 y.o.

Drift-Modeling Groundboom	Drift-Modeling AirCraft	Drift-Modeling AppRate (lb-ai/A)	Buffer Distance (feet)	Dermal MOE	Inhalation MOE	Combined-MOE Deposit-ALL-Inhalation	Combined MOE Dermal-Inhalation-Food (Females)	Combined MOE DIF-DW (PDP)-Females	Combined MOE DIF-DW (DPR)-Females
Aircraft	GPA	AppRate (lb-ai/A)	Buffer Distance (feet	Dermal-MOE	Inhalation-MO	MOE-Deposit-Inhalation	MOE-D-I-Food-Females	MOE-DIF-DW(PDP)-Females	MOE-DIF-DW(DPR)-Females
AT 802A	15	2	25	653	118	100	97	96	89
AT 802A	15	2	50	811	127	110	106	106	97
AT 802A	15	2	100	1190	144	129	124	123	111
AT 802A	15	2	250	2263	180	167	158	158	138
AT 802A	15	2	500	3548	221	208	195	194	165
AT 802A	15	2	1000	4881	304	287	262	261	211
AT 802A	15	2	1320	5624	373	350	314	312	244
AT 802A	15	2	2608	23454	820	792	632	622	399
Bell 205 Helicopter	15	2	25	658	103	89	87	87	80
Bell 205 Helicopter	15	2	50	1105	119	108	104	104	95
Bell 205 Helicopter	15	2	100	1867	139	129	124	124	111
Bell 205 Helicopter	15	2	250	2671	174	164	155	155	136
Bell 205 Helicopter	15	2	500	3756	228	215	201	200	170
Bell 205 Helicopter	15	2	1000	6204	336	319	289	287	228
Bell 205 Helicopter	15	2	1320	8149	410	390	347	344	263
Bell 205 Helicopter	15	2	2608	45792	741	729	591	583	383
AT 802A	15	2.3	25	565	106	89	87	87	80
AT 802A	15	2.3	50	700	115	99	96	95	88
AT 802A	15	2.3	100	1029	131	116	112	112	102
AT 802A	15	2.3	250	1949	164	151	144	144	127
AT 802A	15	2.3	500	3063	203	190	179	179	154
AT 802A	15	2.3	1000	4223	283	266	245	243	200
AT 802A	15	2.3	1320	5007	351	328	297	295	233
AT 802A	15	2.3	2608	20395	799	769	616	608	393
Bell 205 Helicopter	15	2.3	25	568	93	80	78	78	73
Bell 205 Helicopter	15	2.3	50	951	108	97	94	94	87
Bell 205 Helicopter	15	2.3	100	1602	127	118	113	113	103
Bell 205 Helicopter	15	2.3	250	2310	160	149	143	142	126
Bell 205 Helicopter	15	2.3	500	3292	211	199	187	186	159
Bell 205 Helicopter	15	2.3	1000	5430	315	298	272	270	218
Bell 205 Helicopter	15	2.3	1320	7147	387	367	328	326	252
Bell 205 Helicopter	15	2.3	2608	39819	668	657	543	536	362

EAS EXPOSURE ESTIMATES AND REVISED MOEs FOR AChE INHIBITION
Airblast Estimates - Children 1 - 2 y.o.

Orchard Airblast - Dormant Apples - 60 Swath	Drift-Modeling	Drift-Modeling	Buffer Distance	Dermal	H-to-M	O-to-Mouth	Soil	Combined-MOE	Inhalation	Combined-MOE	Combined MOE	Combined MOE	Combined MOE
AirCraft used for Air Conc 1 lb/ac ai	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)	MOE	MOE	MOE	MOE	Deposit-ALL	MOE	Deposit-ALL-Inhalation	Deposit-Inhalation-Food (Children)	DIF-DW (PDP)-Children	DIF-DW (DPR)-Children
AT 802A	2	1	25	13147	475	15486	63708	443	98	80	76	75	70
AT 802A	2	1	50	34552	1249	40701	167437	1163	108	99	92	92	84
AT 802A	2	1	100	123964	4483	146026	600720	4173	130	126	115	115	102
AT 802A	2	1	250	921096	33309	1085027	4463580	31005	177	176	156	155	133
AT 802A	2	1	500	5197616	187958	6122650	25187346	174955	244	243	207	205	168
AT 802A	2	1	1000	28294133	1023185	33329716	137111735	952399	438	438	332	329	243
AT 802A	2	1	1320	56593576	2046561	66665687	274249203	1904977	620	620	427	421	289
AT 802A	2	1	2608	310315816	11221775	365543555	1503772517	10445432	1781	1781	776	757	416
AirCraft used for Air Conc 2 lb/ac ai	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)	Dermal-MOE	H-to-M-MOE	O-to-Mouth-MOE	Soil-MOE	Deposit-ALL-MOE	Inhalation-MOE	MOE-Deposit-Inhalation	MOE-DI-Food-Child		MOE-DI-F-DW(DPR)-Child
AT 802A	2	2	25	6573	238	7743	31854	221	58	46	44	44	42
AT 802A	2	2	75	35221	1274	41489	170679	1186	74	70	66	56	62
AT 802A	2	2	100	61982	2241	73013	300360	2086	81	78	74	74	68
AT 802A	2	2	250	460548	16655	542513	2231790	15502	120	119	110	109	98
AT 802A	2	2	500	2598808	93979	3061325	12593673	87478	186	186	164	163	138
AT 802A	2	2	1000	14147067	511592	16664858	68555868	476199	396	396	307	304	229
AT 802A	2	2	1320	28296788	1023281	33332844	137124601	952488	582	582	409	403	281
AT 802A	2	2	2608	155157908	5610888	182771777	751886259	5222716	1781	1781	776	757	416
AirCraft used for Air Conc 4 lb/ac ai	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)	Dermal-MOE	H-to-M-MOE	O-to-Mouth-MOE	Soil-MOE	Deposit-ALL-MOE	Inhalation-MOE	MOE-Deposit-Inhalation	MOE-DI-Food-Child		MOE-DI-F-DW(DPR)-Child
AT 802A	2	4	25	3287	119	3872	15927	111	36	27	27	27	26
AT 802A	2	4	50	8638	312	10175	41859	291	41	36	35	35	34
AT 802A	2	4	100	30991	1121	36506	150180	1043	54	52	50	50	47
AT 802A	2	4	250	230274	8327	271257	1115895	7751	91	89	84	84	77
AT 802A	2	4	500	1299404	46990	1530662	6296837	43739	162	162	145	144	125
AT 802A	2	4	1000	7073533	255796	8332429	34277934	238100	373	372	293	290	221
AT 802A	2	4	1320	14148394	511640	16666422	68562301	476244	557	557	396	391	275
AT 802A	2	4	2608	77578954	2805444	91385889	375943129	2611358	1524	1524	722	706	401
AirCraft used for Air Conc 6 lb/ac ai	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)	Dermal-MOE	H-to-M-MOE	O-to-Mouth-MOE	Soil-MOE	Deposit-ALL-MOE	Inhalation-MOE	MOE-Deposit-Inhalation	MOE-DI-Food-Child		MOE-DI-F-DW(DPR)-Child
AT 802A	2	6	25	2191	79	2581	10618	74	27	20	20	20	19
AT 802A	2	6	50	5759	208	6784	27906	194	32	28	27	27	26
AT 802A	2	6	100	20661	747	24338	100120	695	44	41	40	40	38
AT 802A	2	6	250	153516	5552	180838	743930	5167	82	81	76	76	70
AT 802A	2	6	500	866269	31326	1020442	4197891	29159	159	158	142	141	123
AT 802A	2	6	1000	4715689	170531	5554953	22851956	158733	370	369	291	288	220
AT 802A	2	6	1320	9432263	341094	11110948	45708200	317496	548	548	392	387	273
AT 802A	2	6	2608	51719303	1870296	60923926	250628753	1740905	1425	1425	699	684	393

EAS EXPOSURE ESTIMATES AND REVISED MOEs FOR AChE INHIBITION

Airblast Estimates - Children 1 - 2 y.o.

Orchard Airblast - Sparse Orchard - 60 Swath	Drift-Modeling	Drift-Modeling	Buffer Distance	Dermal	H-to-M	O-to-Mouth	Soil	Combined-MOE	Inhalation	Combined-MOE	Combined MOE	Combined MOE
AirCraft used for Air Conc 1 lb/ac ai	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)	MOE	MOE	MOE	MOE	Deposit-ALL	MOE	Deposit-ALL-Inhalation	Deposit-Inhalation-Food (Children)	DIF-DW (DPR)-Children
AT 802A	2	1	25	16214	586	19099	78570	546	98	83	78	78	72
AT 802A	2	1	50	35600	1287	41936	172516	1198	108	99	92	92	84
AT 802A	2	1	100	99272	3590	116940	481068	3342	130	125	114	114	101
AT 802A	2	1	250	481898	17427	567663	2335251	16221	177	175	155	155	132
AT 802A	2	1	500	1837605	66452	2164648	8904928	61855	244	243	206	205	168
AT 802A	2	1	1000	8854701	320208	10430596	42909371	298055	438	438	332	329	242
AT 802A	2	1	1320	18978636	686314	22356314	91969372	638833	620	620	427	421	289
AT 802A	2	1	2608	356180069	12880338	419570392	1726028038	11989252	1781	1781	776	757	416
AirCraft used for Air Conc 2 lb/ac ai	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)	Dermal-MOE	H-to-M-MOE	O-to-Mouth-MOE	Soil-MOE	Deposit-ALL-MOE	Inhalation-MOE	MOE-Deposit-Inhalation	MOE-DI-Food-Child	MOE-DI-F-DW(DPR)-Child
AT 802A	2	2	25	8107	293	9550	39285	273	58	48	46	46	44
AT 802A	2	2	50	17800	644	20968	86258	599	65	59	56	56	53
AT 802A	2	2	100	49636	1795	58470	240534	1671	81	78	73	73	68
AT 802A	2	2	250	240949	8713	283831	1167625	8111	120	118	109	109	97
AT 802A	2	2	500	918802	33226	1082324	4452464	30927	186	185	163	162	138
AT 802A	2	2	1000	4427351	160104	5215298	21454685	149027	396	395	307	304	229
AT 802A	2	2	1320	9489318	343157	11178157	45984686	319417	582	582	409	403	281
AT 802A	2	2	2608	178090034	6440169	209785196	863014019	5994626	1781	1781	776	757	416
AirCraft used for Air Conc 4 lb/ac ai	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)	Dermal-MOE	H-to-M-MOE	O-to-Mouth-MOE	Soil-MOE	Deposit-ALL-MOE	Inhalation-MOE	MOE-Deposit-Inhalation	MOE-DI-Food-Child	MOE-DI-F-DW(DPR)-Child
AT 802A	2	4	25	4053	147	4775	19643	136	36	28	28	28	27
AT 802A	2	4	50	8900	322	10484	43129	300	41	36	35	35	34
AT 802A	2	4	100	24818	897	29235	120267	835	54	51	49	49	47
AT 802A	2	4	250	120475	4357	141916	583813	4055	91	89	83	83	76
AT 802A	2	4	500	459401	16613	541162	2226232	15464	162	160	144	143	124
AT 802A	2	4	1000	2213675	80052	2607649	10727343	74514	373	371	292	290	221
AT 802A	2	4	1320	4744659	171578	5589079	22992343	159708	557	557	396	390	275
AT 802A	2	4	2608	89045017	3220085	104892598	431507010	2997313	1524	1524	722	706	401
AirCraft used for Air Conc 6 lb/ac ai	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)	Dermal-MOE	H-to-M-MOE	O-to-Mouth-MOE	Soil-MOE	Deposit-ALL-MOE	Inhalation-MOE	MOE-Deposit-Inhalation	MOE-DI-Food-Child	MOE-DI-F-DW(DPR)-Child
AT 802A	2	6	25	2702	98	3183	13095	91	27	21	21	21	20
AT 802A	2	6	50	5933	215	6989	28753	200	32	28	27	27	26
AT 802A	2	6	100	16545	598	19490	80178	557	44	41	39	39	38
AT 802A	2	6	250	80316	2904	94610	389208	2704	82	79	75	75	69
AT 802A	2	6	500	306267	11075	360775	1484155	10309	159	157	141	140	122
AT 802A	2	6	1000	1475784	53368	1738433	7151562	49676	370	367	290	287	219
AT 802A	2	6	1320	3163106	114386	3726052	15328229	106472	548	548	392	386	273
AT 802A	2	6	2608	59363345	2146723	69928399	287671340	1998209	1425	1425	699	684	393

EAS EXPOSURE ESTIMATES AND REVISED MOEs FOR AChE INHIBITION
Airblast Estimates - Females 13 - 49 y.o.

Drift-Modeling Orchard Airblast - Dormant Apples - 60 Swath	Drift-Modeling	Drift-Modeling	Buffer Distance	Dermal MOE	Inhalation MOE	Combined-MOE Deposit-ALL-Inhalation	Combined MOE D-I-food (Females)	Combined MOE D-F-DW (PDP)-Females	Combined MOE D-I-F-DW (DPR)-Females
AirCraft used for Air Conc 1 lb/ac ai	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)						
AT 802A	2	1	25	3475	282	261	241	239	197
AT 802A	2	1	50	9132	317	306	279	277	222
AT 802A	2	1	100	32764	377	373	333	331	255
AT 802A	2	1	250	243449	521	520	446	441	316
AT 802A	2	1	500	1373746	724	723	587	579	381
AT 802A	2	1	1000	7478229	1309	1308	921	902	498
AT 802A	2	1	1320	14957862	1852	1852	1161	1131	561
AT 802A	2	1	2608	82017454	5302	5301	1961	1876	699
AirCraft used for Air Conc 2 lb/ac ai	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)						
AT 802A	2	2	25	1737	168	153	146	145	128
AT 802A	2	2	50	4566	192	184	174	173	150
AT 802A	2	2	100	16382	237	234	218	217	181
AT 802A	2	2	250	121724	353	352	317	314	245
AT 802A	2	2	500	686873	554	554	470	465	328
AT 802A	2	2	1000	3739115	1183	1182	857	840	479
AT 802A	2	2	1320	7478931	1708	1708	1103	1075	547
AT 802A	2	2	2608	41008727	5125	5124	1937	1853	696
AirCraft used for Air Conc 4 lb/ac ai	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)						
AT 802A	2	4	25	869	103	92	90	89	83
AT 802A	2	4	50	2283	122	116	112	112	101
AT 802A	2	4	100	8191	158	155	148	147	130
AT 802A	2	4	250	60862	267	266	245	244	200
AT 802A	2	4	500	343437	482	481	417	413	301
AT 802A	2	4	1000	1869557	1114	1113	820	805	467
AT 802A	2	4	1320	3739465	1662	1661	1083	1057	542
AT 802A	2	4	2608	20504364	4556	4555	1849	1773	684
AirCraft used for Air Conc 6 lb/ac ai	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)						
AT 802A	2	6	25	579	79	69	68	68	64
AT 802A	2	6	50	1522	96	90	87	87	81
AT 802A	2	6	100	5461	128	125	121	120	109
AT 802A	2	6	250	40575	243	242	224	223	186
AT 802A	2	6	500	228958	473	472	410	406	298
AT 802A	2	6	1000	1246372	1118	1117	822	807	468
AT 802A	2	6	1320	2492977	1618	1617	1064	1039	537
AT 802A	2	6	2608	13669576	4393	4391	1822	1748	680

EAS EXPOSURE ESTIMATES AND REVISED MOEs FOR AChE INHIBITION
Airblast Estimates - Females 13 - 49 y.o.

Orchard Airblast - Sparse Orchard - 60 Swath	Drift-Modeling	Drift-Modeling	Buffer Distance	Dermal MOE	Inhalation MOE	Combined-MOE Deposit-ALL-Inhalation	Combined MOE D-I-food (Females)	Combined MOE D-I-F-DW (DPR)-Females	
AirCraft used for Air Conc 1 lb/ac ai	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)						
AT 802A	2	1	25	4285	282	265	244	243	199
AT 802A	2	1	50	9409	317	307	279	277	222
AT 802A	2	1	100	26238	377	372	332	330	254
AT 802A	2	1	250	127367	521	519	445	440	316
AT 802A	2	1	500	485685	724	722	586	579	381
AT 802A	2	1	1000	2340326	1309	1308	921	902	498
AT 802A	2	1	1320	5016114	1852	1852	1161	1131	561
AT 802A	2	1	2608	94139522	5302	5301	1961	1876	699
AirCraft used for Air Conc 2 lb/ac ai	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)						
AT 802A	2	2	25	2143	168	155	148	148	130
AT 802A	2	2	50	4705	192	185	174	174	150
AT 802A	2	2	100	13119	237	233	217	216	181
AT 802A	2	2	250	63684	353	351	316	314	245
AT 802A	2	2	500	242842	554	553	469	464	328
AT 802A	2	2	1000	1170163	1183	1181	856	840	479
AT 802A	2	2	1320	2508057	1708	1707	1103	1075	547
AT 802A	2	2	2608	47069761	5125	5124	1937	1853	696
AirCraft used for Air Conc 4 lb/ac ai	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)						
AT 802A	2	4	25	1071	103	94	91	91	84
AT 802A	2	4	50	2352	122	116	112	112	102
AT 802A	2	4	100	6559	158	154	147	147	129
AT 802A	2	4	250	31842	267	265	244	243	199
AT 802A	2	4	500	121421	482	480	416	412	301
AT 802A	2	4	1000	585081	1114	1112	819	804	467
AT 802A	2	4	1320	1254028	1662	1660	1083	1056	542
AT 802A	2	4	2608	23534880	4556	4555	1849	1773	684
AirCraft used for Air Conc 6 lb/ac ai	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)						
AT 802A	2	6	25	714	79	71	69	69	65
AT 802A	2	6	50	1568	96	90	88	87	81
AT 802A	2	6	100	4373	128	125	120	120	108
AT 802A	2	6	250	21228	243	240	223	222	185
AT 802A	2	6	500	80947	473	470	409	405	297
AT 802A	2	6	1000	390054	1118	1115	821	806	467
AT 802A	2	6	1320	836019	1618	1615	1064	1038	537
AT 802A	2	6	2608	15689920	4393	4392	1822	1748	680

EAS EXPOSURE ESTIMATES AND REVISED MOEs FOR AChE INHIBITION
Ground Boom Estimates - Children 1 - 2 y.o.

Ground Boom - High Boom 40 swath/50th Percentile	Drift-Modeling	Drift-Modeling	Buffer Distance	Dermal	H-to-M	O-to-Mouth	Soil	Combined-MOE	Inhalation	Combined-MOE	Combined MOE	Combined MOE	Combined MOE
AirCraft used for Air Conc 1 lb/ac ai	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)	MOE	MOE	MOE	MOE	Deposit-ALL	MOE	Deposit-ALL-Inhalation	Deposit-Inhalation-Food (Children)	DIF-DW (PDP)-Children	DIF-DW (DPR)-Children
AT 802A	2	1	25	76596	2770	90229	371182	2578	98	94	88	88	80
AT 802A	2	1	50	115503	4177	136059	559719	3888	108	105	98	97	88
AT 802A	2	1	100	196667	7112	231668	953035	6620	130	127	116	116	103
AT 802A	2	1	250	428039	15479	504218	2074252	14408	177	175	155	154	132
AT 802A	2	1	500	1001662	36223	1179931	4853998	33717	244	242	206	204	167
AT 802A	2	1	1000	3328948	120383	3921410	16131890	112055	438	437	331	328	242
AT 802A	2	1	1320	6130433	221691	7221483	29707725	206354	620	620	427	420	289
AT 802A	2	1	2608	41436008	1498427	48810485	200796500	1394763	1781	1781	776	757	416
AirCraft used for Air Conc 2 lb/ac ai	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)	Dermal-MOE	H-to-M-MOE	O-to-Mouth-MOE	Soil-MOE	Deposit-ALL-MOE	Inhalation-MOE	MOE-Deposit-Inhalation	MOE-DI-Food-Child		MOE-DI-F-DW(DPR)-Child
AT 802A	2	2	25	38298	1385	45114	185591	1289	58	55	53	53	50
AT 802A	2	2	50	57751	2088	68029	279859	1944	65	63	60	60	57
AT 802A	2	2	100	98333	3556	115834	476517	3310	81	79	75	75	69
AT 802A	2	2	250	214019	7739	252109	1037126	7204	120	118	109	87	97
AT 802A	2	2	500	500831	18111	589965	2426999	16858	186	184	162	162	138
AT 802A	2	2	1000	1664474	60191	1960705	8065945	56027	396	393	306	303	228
AT 802A	2	2	1320	3065217	110846	3610741	14853862	103177	582	582	409	402	281
AT 802A	2	2	2608	20718004	749213	24405243	100398250	697381	1781	1781	776	756	416
AirCraft used for Air Conc 4 lb/ac ai	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)	Dermal-MOE	H-to-M-MOE	O-to-Mouth-MOE	Soil-MOE	Deposit-ALL-MOE	Inhalation-MOE	MOE-Deposit-Inhalation	MOE-DI-Food-Child		MOE-DI-F-DW(DPR)-Child
AT 802A	2	4	25	19149	692	22557	92795	645	36	34	33	33	32
AT 802A	2	4	50	28876	1044	34015	139930	972	41	40	39	39	37
AT 802A	2	4	100	49167	1778	57917	238259	1655	54	52	51	50	48
AT 802A	2	4	250	107010	3870	126055	518563	3602	91	88	83	83	76
AT 802A	2	4	500	250416	9056	294983	1213500	8429	162	159	143	142	123
AT 802A	2	4	1000	832237	30096	980352	4032972	28014	373	368	290	288	219
AT 802A	2	4	1320	1532608	55423	1805371	7426931	51589	557	557	396	388	275
AT 802A	2	4	2608	10359002	374607	12202621	50199125	348691	1524	1524	722	705	401
AirCraft used for Air Conc 6 lb/ac ai	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)	Dermal-MOE	H-to-M-MOE	O-to-Mouth-MOE	Soil-MOE	Deposit-ALL-MOE	Inhalation-MOE	MOE-Deposit-Inhalation	MOE-DI-Food-Child		MOE-DI-F-DW(DPR)-Child
AT 802A	2	6	25	12766	462	15038	61864	430	27	26	25	25	25
AT 802A	2	6	50	19250	696	22676	93286	648	32	31	30	30	29
AT 802A	2	6	100	32778	1185	38611	158839	1103	44	42	41	41	39
AT 802A	2	6	250	71340	2580	84036	345709	2401	82	79	75	75	69
AT 802A	2	6	500	166944	6037	196655	809000	5619	159	155	139	138	120
AT 802A	2	6	1000	554825	20064	653568	2688648	18676	372	364	288	285	218
AT 802A	2	6	1320	1021739	36949	1203580	4951287	34392	546	546	391	382	272
AT 802A	2	6	2608	6906001	249738	8135081	33466083	232460	1451	1451	706	688	395

EAS EXPOSURE ESTIMATES AND REVISED MOEs FOR AChE INHIBITION
Ground Boom Estimates - Children 1 - 2 y.o.

Ground Boom - Low Boom 40 swath/50th Percentile	Drift-Modeling	Drift-Modeling	Buffer Distance	Dermal	H-to-M	O-to-Mouth	Soil	Combined-MOE	Inhalation	Combined-MOE	Combined MOE	Combined MOE	Combined MOE
AirCraft used for Air Conc 1 lb/ac ai	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)	MOE	MOE	MOE	MOE	Deposit-ALL	MOE	Deposit-ALL-Inhalation	Deposit-Inhalation-Food (Children)	DIF-DW (PDP)-Children	DIF-DW (DPR)-Children
AT 802A	2	1	25	145533	5263	171434	705246	4899	98	96	89	89	81
AT 802A	2	1	50	214019	7739	252109	1037126	7204	108	106	99	98	89
AT 802A	2	1	100	363833	13157	428585	1763114	12247	130	128	117	117	104
AT 802A	2	1	250	727666	26314	857171	3526229	24494	177	176	156	155	133
AT 802A	2	1	500	1412875	51093	1664329	6846713	47558	244	242	206	205	168
AT 802A	2	1	1000	3729404	134864	4393136	18072474	125534	438	437	331	328	242
AT 802A	2	1	1320	6108803	220909	7196003	29602905	205626	620	620	427	420	289
AT 802A	2	1	2608	28619013	1034933	33712416	138686085	963335	1781	1781	776	756	416
AirCraft used for Air Conc 2 lb/ac ai	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)	Dermal-MOE	H-to-M-MOE	O-to-Mouth-MOE	Soil-MOE	Deposit-ALL-MOE	Inhalation-MOE	MOE-Deposit-Inhalation	MOE-DI-Food-Child		MOE-DI-F-DW(DPR)-Child
AT 802A	2	2	25	72767	2631	85717	352623	2449	58	56	54	54	51
AT 802A	2	2	50	107010	3870	126055	518563	3602	65	64	61	61	57
AT 802A	2	2	100	181917	6579	214293	881557	6123	81	80	76	76	70
AT 802A	2	2	250	363833	13157	428585	1763114	12247	120	119	110	109	98
AT 802A	2	2	500	706438	25547	832164	3423356	23779	186	185	163	162	138
AT 802A	2	2	1000	1864702	67432	2196568	9036237	62767	396	393	306	303	228
AT 802A	2	2	1320	3054401	110455	3598001	14801453	102813	582	582	409	402	281
AT 802A	2	2	2608	14309507	517467	16856208	69343042	481667	1781	1781	776	756	416
AirCraft used for Air Conc 4 lb/ac ai	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)	Dermal-MOE	H-to-M-MOE	O-to-Mouth-MOE	Soil-MOE	Deposit-ALL-MOE	Inhalation-MOE	MOE-Deposit-Inhalation	MOE-DI-Food-Child		MOE-DI-F-DW(DPR)-Child
AT 802A	2	4	25	36383	1316	42859	176311	1225	36	35	34	34	33
AT 802A	2	4	50	53505	1935	63027	259282	1801	41	40	39	39	38
AT 802A	2	4	100	90958	3289	107146	440779	3062	54	53	51	51	49
AT 802A	2	4	250	181917	6579	214293	881557	6123	91	89	84	84	77
AT 802A	2	4	500	353219	12773	416082	1711678	11890	162	160	143	143	124
AT 802A	2	4	1000	932351	33716	1098284	4518119	31384	373	369	291	288	220
AT 802A	2	4	1320	1527201	55227	1799001	7400726	51407	557	557	396	388	275
AT 802A	2	4	2608	7154753	258733	8428104	34671521	240834	1524	1524	722	704	401
AirCraft used for Air Conc 6 lb/ac ai	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)	Dermal-MOE	H-to-M-MOE	O-to-Mouth-MOE	Soil-MOE	Deposit-ALL-MOE	Inhalation-MOE	MOE-Deposit-Inhalation	MOE-DI-Food-Child		MOE-DI-F-DW(DPR)-Child
AT 802A	2	6	25	24256	877	28572	117541	816	27	26	26	26	25
AT 802A	2	6	50	35670	1290	42018	172854	1201	32	31	31	31	30
AT 802A	2	6	100	60639	2193	71431	293852	2041	44	43	42	42	40
AT 802A	2	6	250	121278	4386	142862	587705	4082	82	80	76	76	70
AT 802A	2	6	500	235479	8516	277388	1141119	7926	159	156	140	139	121
AT 802A	2	6	1000	621567	22477	732189	3012079	20922	372	365	289	286	218
AT 802A	2	6	1320	1018134	36818	1199334	4933818	34271	546	546	391	382	272
AT 802A	2	6	2608	4769836	172489	5618736	23114347	160556	1451	1451	706	687	395

EAS EXPOSURE ESTIMATES AND REVISED MOEs FOR AChE INHIBITION
Ground Boom Estimates - Children 1 - 2 y.o.

Ground Boom - High Boom 40 swath/90th Percentile	Drift-Modeling	Drift-Modeling	Buffer Distance	Dermal	H-to-M	O-to-Mouth	Soil	Combined-MOE	Inhalation	Combined-MOE	Combined MOE	Combined MOE	Combined MOE
AirCraft used for Air Conc 1 lb/ac ai	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)	MOE	MOE	MOE	MOE	Deposit-ALL	MOE	Deposit-ALL-Inhalation	Deposit-Inhalation-Food (Children)	DIF-DW (PDP)-Children	DIF-DW (DPR)-Children
AT 802A	2	1	25	53901	1949	63494	261202	1814	98	93	87	87	79
AT 802A	2	1	50	75017	2713	88368	363529	2525	108	104	96	96	87
AT 802A	2	1	100	121278	4386	142862	587705	4082	130	126	115	115	102
AT 802A	2	1	250	242555	8771	285724	1175410	8165	177	173	154	153	131
AT 802A	2	1	500	425916	15402	501717	2063963	14337	244	240	204	203	166
AT 802A	2	1	1000	762324	27567	897997	3694177	25660	438	431	328	325	240
AT 802A	2	1	1320	966030	34934	1137957	4681325	32517	620	620	427	416	289
AT 802A	2	1	2608	1739360	62899	2048918	8428836	58548	1781	1781	776	747	416
AirCraft used for Air Conc 2 lb/ac ai	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)	Dermal-MOE	H-to-M-MOE	O-to-Mouth-MOE	Soil-MOE	Deposit-ALL-MOE	Inhalation-MOE	MOE-Deposit-Inhalation	MOE-DI-Food-Child		MOE-DI-F-DW(DPR)-Child
AT 802A	2	2	25	26951	975	31747	130601	907	58	54	52	52	49
AT 802A	2	2	50	37509	1356	44184	181764	1263	65	62	59	59	56
AT 802A	2	2	100	60639	2193	71431	293852	2041	81	78	74	74	68
AT 802A	2	2	250	121278	4386	142862	587705	4082	120	117	108	107	96
AT 802A	2	2	500	212958	7701	250859	1031981	7168	186	182	160	160	136
AT 802A	2	2	1000	381162	13784	448998	1847089	12830	396	384	300	297	225
AT 802A	2	2	1320	483015	17467	568978	2340663	16259	582	582	409	394	281
AT 802A	2	2	2608	869680	31450	1024459	4214418	29274	1781	1781	776	738	416
AirCraft used for Air Conc 4 lb/ac ai	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)	Dermal-MOE	H-to-M-MOE	O-to-Mouth-MOE	Soil-MOE	Deposit-ALL-MOE	Inhalation-MOE	MOE-Deposit-Inhalation	MOE-DI-Food-Child		MOE-DI-F-DW(DPR)-Child
AT 802A	2	4	25	13475	487	15874	65301	454	36	33	32	32	31
AT 802A	2	4	50	18754	678	22092	90882	631	41	39	38	38	36
AT 802A	2	4	100	30319	1096	35715	146926	1021	54	51	50	50	47
AT 802A	2	4	250	60639	2193	71431	293852	2041	91	87	82	81	75
AT 802A	2	4	500	106479	3851	125429	515991	3584	162	155	139	139	121
AT 802A	2	4	1000	190581	6892	224499	923544	6415	373	353	281	278	214
AT 802A	2	4	1320	241507	8733	284489	1170331	8129	557	557	396	373	275
AT 802A	2	4	2608	434840	15725	512230	2107209	14637	1524	1524	722	674	401
AirCraft used for Air Conc 6 lb/ac ai	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)	Dermal-MOE	H-to-M-MOE	O-to-Mouth-MOE	Soil-MOE	Deposit-ALL-MOE	Inhalation-MOE	MOE-Deposit-Inhalation	MOE-DI-Food-Child		MOE-DI-F-DW(DPR)-Child
AT 802A	2	6	25	8984	325	10582	43534	302	27	25	25	25	24
AT 802A	2	6	50	12503	452	14728	60588	421	32	30	29	29	28
AT 802A	2	6	100	20213	731	23810	97951	680	44	41	40	40	38
AT 802A	2	6	250	40426	1462	47621	195902	1361	82	77	73	73	68
AT 802A	2	6	500	70986	2567	83620	343994	2389	159	149	135	134	117
AT 802A	2	6	1000	127054	4595	149666	615696	4277	370	341	273	271	209
AT 802A	2	6	1320	161005	5822	189659	780221	5420	548	548	392	361	273
AT 802A	2	6	2608	289893	10483	341486	1404806	9758	1425	1425	699	640	393

EAS EXPOSURE ESTIMATES AND REVISED MOEs FOR AChE INHIBITION
Ground Boom Estimates - Children 1 - 2 y.o.

Ground Boom - Low Boom 40 swath/90th Percentile	Drift-Modeling	Drift-Modeling	Buffer Distance	Dermal	H-to-M	O-to-Mouth	Soil	Combined-MOE	Inhalation	Combined-MOE	Combined MOE		Combined MOE
AirCraft used for Air Conc 1 lb/ac ai	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)	MOE	MOE	MOE	MOE	Deposit-ALL	MOE	Deposit-ALL-Inhalation	Deposit-Inhalation-Food (Children)		DIF-DW (DPR)-Children
AT 802A	2	1	25	85608	3096	100844	414850	2882	98	94	88	88	80
AT 802A	2	1	50	117366	4244	138253	568747	3951	108	105	98	97	88
AT 802A	2	1	100	186581	6747	219787	904161	6280	130	127	116	116	103
AT 802A	2	1	250	363833	13157	428585	1763114	12247	177	174	155	154	132
AT 802A	2	1	500	602535	21789	709770	2919851	20282	244	241	205	203	167
AT 802A	2	1	1000	1050319	37982	1237247	5089785	35354	438	433	329	326	241
AT 802A	2	1	1320	1321467	47787	1556652	6403752	44481	620	620	427	417	289
AT 802A	2	1	2608	2350825	85012	2769208	11391964	79130	1781	1781	776	750	416
AirCraft used for Air Conc 2 lb/ac ai	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)	Dermal-MOE	H-to-M-MOE	O-to-Mouth-MOE	Soil-MOE	Deposit-ALL-MOE	Inhalation-MOE	MOE-Deposit-Inhalation	MOE-DI-Food-Child		MOE-DI-F-DW(DPR)-Child
AT 802A	2	2	25	42804	1548	50422	207425	1441	58	56	53	53	50
AT 802A	2	2	50	58683	2122	69127	284373	1975	65	63	60	60	57
AT 802A	2	2	100	93291	3374	109894	452081	3140	81	79	75	75	69
AT 802A	2	2	250	181917	6579	214293	881557	6123	120	118	109	108	97
AT 802A	2	2	500	301268	10895	354885	1459925	10141	186	183	161	161	137
AT 802A	2	2	1000	525160	18991	618624	2544893	17677	396	387	302	299	226
AT 802A	2	2	1320	660733	23894	778326	3201876	22241	582	582	409	396	281
AT 802A	2	2	2608	1175413	42506	1384604	5695982	39565	1781	1781	776	743	416
AirCraft used for Air Conc 4 lb/ac ai	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)	Dermal-MOE	H-to-M-MOE	O-to-Mouth-MOE	Soil-MOE	Deposit-ALL-MOE	Inhalation-MOE	MOE-Deposit-Inhalation	MOE-DI-Food-Child		MOE-DI-F-DW(DPR)-Child
AT 802A	2	4	25	21402	774	25211	103713	720	36	34	33	33	32
AT 802A	2	4	50	29341	1061	34563	142187	988	41	40	39	39	37
AT 802A	2	4	100	46645	1687	54947	226040	1570	54	52	50	50	48
AT 802A	2	4	250	90958	3289	107146	440779	3062	91	88	83	82	76
AT 802A	2	4	500	150634	5447	177442	729963	5070	162	157	141	140	122
AT 802A	2	4	1000	262580	9496	309312	1272446	8839	373	358	284	281	216
AT 802A	2	4	1320	330367	11947	389163	1600938	11120	557	557	396	378	275
AT 802A	2	4	2608	587706	21253	692302	2847991	19783	1524	1524	722	682	401
AirCraft used for Air Conc 6 lb/ac ai	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)	Dermal-MOE	H-to-M-MOE	O-to-Mouth-MOE	Soil-MOE	Deposit-ALL-MOE	Inhalation-MOE	MOE-Deposit-Inhalation	MOE-DI-Food-Child		MOE-DI-F-DW(DPR)-Child
AT 802A	2	6	25	14268	516	16807	69142	480	27	26	25	25	25
AT 802A	2	6	50	19561	707	23042	94791	658	32	31	30	30	29
AT 802A	2	6	200	50532	1827	59526	244877	1701	69	66	63	41	59
AT 802A	2	6	250	60639	2193	71431	293852	2041	82	79	74	74	69
AT 802A	2	6	500	100423	3632	118295	486642	3380	159	152	137	136	119
AT 802A	2	6	1000	175053	6330	206208	848298	5892	370	348	278	275	212
AT 802A	2	6	1320	220244	7965	259442	1067292	7414	548	548	392	368	273
AT 802A	2	6	2608	391804	14169	461535	1898661	13188	1425	1425	699	651	393

EAS EXPOSURE ESTIMATES AND REVISED MOEs FOR AChE INHIBITION
Ground Boom Estimates - Females 13-49 y.o.

Drift-Modeling

Ground Boom - High Boom 40 swath/50th Percentile	Drift-Modeling	Drift-Modeling	Buffer Distance	Dermal MOE	Inhalation MOE	Combined-MOE MOE-Deposit-Inhalation	Combined MOE MOE-D-I-Food-Females	Combined MOE MOE-DIF-DW(PDP)-Females	Combined MOE MOE-DIF-DW(DPR)-Females
AirCraft used for Air Conc	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)						
1 lb/ac ai									
AT 802A	2	1	25	20245	282	278	255	254	207
AT 802A	2	1	50	30528	317	314	285	283	226
AT 802A	2	1	100	51980	377	375	334	332	256
AT 802A	2	1	250	113132	521	519	445	440	315
AT 802A	2	1	500	264743	724	722	586	578	380
AT 802A	2	1	1000	879852	1309	1307	920	901	498
AT 802A	2	1	1320	1620293	1852	1850	1161	1130	561
AT 802A	2	1	2608	10951668	5302	5299	1961	1876	699
AirCraft used for Air Conc	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)						
2 lb/ac ai									
AT 802A	2	2	25	10122	168	165	157	156	137
AT 802A	2	2	50	15264	192	190	179	178	154
AT 802A	2	2	100	25990	237	235	219	218	182
AT 802A	2	2	250	56566	353	351	316	313	245
AT 802A	2	2	500	132371	554	552	469	464	327
AT 802A	2	2	1000	439926	1183	1180	855	839	478
AT 802A	2	2	1320	810146	1708	1705	1102	1074	547
AT 802A	2	2	2608	5475834	5125	5120	1936	1853	696
AirCraft used for Air Conc	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)						
4 lb/ac ai									
AT 802A	2	4	25	5061	103	101	98	98	90
AT 802A	2	4	50	7632	122	120	116	116	105
AT 802A	2	4	100	12995	158	156	149	148	131
AT 802A	2	4	250	28283	267	265	244	243	199
AT 802A	2	4	500	66186	482	478	415	411	300
AT 802A	2	4	1000	219963	1114	1109	817	802	466
AT 802A	2	4	1320	405073	1662	1655	1081	1054	542
AT 802A	2	4	2608	2737917	4556	4548	1848	1772	684
AirCraft used for Air Conc	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)						
6 lb/ac ai									
AT 802A	2	6	25	3374	79	77	75	75	70
AT 802A	2	6	50	5088	96	94	91	91	84
AT 802A	2	6	100	8663	128	127	122	121	109
AT 802A	2	6	250	18855	243	240	223	222	185
AT 802A	2	6	500	44124	473	468	407	403	296
AT 802A	2	6	1000	146642	1118	1110	818	803	467
AT 802A	2	6	1320	270049	1618	1609	1061	1035	537
AT 802A	2	6	2608	1825278	4393	4382	1820	1746	680

EAS EXPOSURE ESTIMATES AND REVISED MOEs FOR AChE INHIBITION
Ground Boom Estimates - Females 13-49 y.o.

Ground Boom - Low Boom 40 swath/50th Percentile	Drift-Modeling	Drift-Modeling	Buffer Distance	Dermal MOE	Inhalation MOE	Combined-MOE MOE-Deposit-Inhalation	Combined MOE MOE-D-I-Food-Females	Combined MOE MOE-DIF-DW(PDP)-Females	Combined MOE MOE-DIF-DW(DPR)-Females
AirCraft used for Air Conc	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)						
1 lb/ac ai									
AT 802A	2	1	25	38465	282	280	257	255	208
AT 802A	2	1	50	56566	317	315	286	284	227
AT 802A	2	1	100	96162	377	376	335	333	256
AT 802A	2	1	250	192324	521	520	445	441	316
AT 802A	2	1	500	373427	724	722	586	578	381
AT 802A	2	1	1000	985693	1309	1307	920	901	498
AT 802A	2	1	1320	1614576	1852	1850	1161	1130	561
AT 802A	2	1	2608	7564096	5302	5298	1961	1876	699
AirCraft used for Air Conc	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)						
2 lb/ac ai									
AT 802A	2	2	25	19232	168	166	158	157	138
AT 802A	2	2	50	28283	192	191	180	179	154
AT 802A	2	2	100	48081	237	236	220	219	183
AT 802A	2	2	250	96162	353	352	316	314	245
AT 802A	2	2	500	186714	554	552	469	464	328
AT 802A	2	2	1000	492847	1183	1180	856	839	479
AT 802A	2	2	1320	807288	1708	1705	1102	1074	547
AT 802A	2	2	2608	3782048	5125	5118	1936	1853	696
AirCraft used for Air Conc	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)						
4 lb/ac ai									
AT 802A	2	4	25	9616	103	102	99	99	91
AT 802A	2	4	50	14142	122	121	117	116	105
AT 802A	2	4	100	24041	158	157	149	149	131
AT 802A	2	4	250	48081	267	266	245	244	200
AT 802A	2	4	500	93357	482	479	416	412	301
AT 802A	2	4	1000	246423	1114	1109	818	803	466
AT 802A	2	4	1320	403644	1662	1655	1081	1054	542
AT 802A	2	4	2608	1891024	4556	4545	1848	1772	684
AirCraft used for Air Conc	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)						
6 lb/ac ai									
AT 802A	2	6	25	6411	79	78	76	76	71
AT 802A	2	6	50	9428	96	95	92	92	85
AT 802A	2	6	100	16027	128	127	122	122	110
AT 802A	2	6	250	32054	243	241	224	223	186
AT 802A	2	6	500	62238	473	470	408	404	297
AT 802A	2	6	1000	164282	1118	1111	819	803	467
AT 802A	2	6	1320	269096	1618	1609	1061	1035	537
AT 802A	2	6	2608	1260683	4393	4378	1819	1746	680

EAS EXPOSURE ESTIMATES AND REVISED MOEs FOR AChE INHIBITION
Ground Boom Estimates - Females 13-49 y.o.

Ground Boom - High Boom 40 swath/90th Percentile	Drift-Modeling	Drift-Modeling	Buffer Distance	Dermal MOE	Inhalation MOE	Combined-MOE MOE-Deposit-Inhalation	Combined MOE MOE-D-I-Food-Females	Combined MOE MOE-DIF-DW(PDP)-Females	Combined MOE MOE-DIF-DW(DPR)-Females
AirCraft used for Air Conc	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)						
1 lb/ac ai									
AT 802A	2	1	25	14246	282	277	254	253	206
AT 802A	2	1	50	19827	317	312	284	282	225
AT 802A	2	1	100	32054	377	373	333	330	255
AT 802A	2	1	250	64108	521	517	443	439	315
AT 802A	2	1	500	112571	724	719	584	576	380
AT 802A	2	1	1000	201485	1309	1300	917	898	497
AT 802A	2	1	1320	255325	1852	1839	1156	1126	560
AT 802A	2	1	2608	459718	5302	5241	1953	1868	698
AirCraft used for Air Conc	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)						
2 lb/ac ai									
AT 802A	2	2	25	7123	168	164	156	155	136
AT 802A	2	2	50	9914	192	189	178	177	153
AT 802A	2	2	100	16027	237	234	218	217	181
AT 802A	2	2	250	32054	353	350	314	312	244
AT 802A	2	2	500	56285	554	549	466	461	326
AT 802A	2	2	1000	100742	1183	1169	850	833	477
AT 802A	2	2	1320	127662	1708	1686	1094	1067	545
AT 802A	2	2	2608	229859	5125	5013	1921	1839	694
AirCraft used for Air Conc	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)						
4 lb/ac ai									
AT 802A	2	4	25	3562	103	100	97	97	89
AT 802A	2	4	50	4957	122	119	115	115	104
AT 802A	2	4	100	8014	158	155	148	147	130
AT 802A	2	4	250	16027	267	263	242	241	198
AT 802A	2	4	500	28143	482	474	411	407	298
AT 802A	2	4	1000	50371	1114	1090	807	792	463
AT 802A	2	4	1320	63831	1662	1620	1066	1040	538
AT 802A	2	4	2608	114930	4556	4382	1820	1746	680
AirCraft used for Air Conc	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)						
6 lb/ac ai									
AT 802A	2	6	25	2374	79	76	74	74	70
AT 802A	2	6	50	3305	96	93	90	90	83
AT 802A	2	6	100	5342	128	125	121	120	108
AT 802A	2	6	250	10685	243	238	221	220	183
AT 802A	2	6	500	18762	473	461	402	398	293
AT 802A	2	6	1000	33581	1118	1082	803	788	462
AT 802A	2	6	1320	42554	1618	1559	1039	1014	531
AT 802A	2	6	2608	76620	4393	4155	1780	1709	674

EAS EXPOSURE ESTIMATES AND REVISED MOEs FOR AChE INHIBITION
Ground Boom Estimates - Females 13-49 y.o.

Ground Boom - Low Boom 40 swath/90th Percentile	Drift-Modeling	Drift-Modeling	Buffer Distance	Dermal MOE	Inhalation MOE	Combined-MOE MOE-Deposit-Inhalation	Combined MOE MOE-D-I-Food-Females	Combined MOE MOE-DIF-DW(PDP)-Females	Combined MOE MOE-DIF-DW(DPR)-Females
AirCraft used for Air Conc	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)						
1 lb/ac ai									
AT 802A	2	1	25	22626	282	279	256	254	207
AT 802A	2	1	50	31020	317	314	285	283	226
AT 802A	2	1	100	49314	377	374	334	332	256
AT 802A	2	1	250	96162	521	518	444	440	315
AT 802A	2	1	500	159252	724	720	585	577	380
AT 802A	2	1	1000	277603	1309	1302	918	899	497
AT 802A	2	1	1320	349268	1852	1843	1158	1127	560
AT 802A	2	1	2608	621331	5302	5257	1955	1870	698
AirCraft used for Air Conc	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)						
2 lb/ac ai									
AT 802A	2	2	25	11313	168	165	157	156	137
AT 802A	2	2	50	15510	192	190	179	178	154
AT 802A	2	2	100	24657	237	235	219	218	182
AT 802A	2	2	250	48081	353	351	315	313	244
AT 802A	2	2	500	79626	554	550	468	463	327
AT 802A	2	2	1000	138801	1183	1173	852	835	477
AT 802A	2	2	1320	174634	1708	1692	1096	1069	545
AT 802A	2	2	2608	310665	5125	5042	1925	1842	694
AirCraft used for Air Conc	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)						
4 lb/ac ai									
AT 802A	2	4	25	5657	103	101	98	98	90
AT 802A	2	4	50	7755	122	120	116	116	105
AT 802A	2	4	100	12328	158	156	149	148	131
AT 802A	2	4	250	24041	267	264	244	242	199
AT 802A	2	4	500	39813	482	476	413	409	299
AT 802A	2	4	1000	69401	1114	1097	811	796	464
AT 802A	2	4	1320	87317	1662	1631	1070	1044	539
AT 802A	2	4	2608	155333	4556	4426	1828	1753	681
AirCraft used for Air Conc	GPA (gal/arce)	AppRate (lb-ai/A)	Buffer Distance (feet)						
6 lb/ac ai									
AT 802A	2	6	25	3771	79	77	75	75	70
AT 802A	2	6	50	5170	96	94	91	91	84
AT 802A	2	6	200	8219	128	126	121	121	109
AT 802A	2	6	250	16027	243	239	222	221	185
AT 802A	2	6	500	26542	473	465	404	401	295
AT 802A	2	6	1000	46267	1118	1092	808	793	463
AT 802A	2	6	1320	58211	1618	1575	1046	1021	533
AT 802A	2	6	2608	103555	4393	4214	1791	1719	676

APPENDIX 4.

INTERIM GUIDANCE FOR SELECTING DEFAULT INHALATION RATES FOR CHILDREN AND ADULTS

DEPARTMENT OF PESTICIDE REGULATION MEMORANDUM

CHUCK ANDREWS (WORKER HEALTH & SAFETY BRANCH) AND GARY PATTERSON (MEDICAL TOXICOLOGY BRANCH)

MEMO NO. HSM-00010

DECEMBER 1, 2000

Paul E. Helliker
Director

Department of Pesticide Regulation

Gray Davis
Governor
Winston H. Hickox
Secretary, California Environmental Protection Agency

M E M O R A N D U M

TO: Worker Health and Safety Branch Staff **HSM-00010**
Medical Toxicology Branch Staff

FROM: Chuck Andrews, Chief
Worker Health and Safety Branch
445-4260
445-4261

Gary Patterson, Chief
Medical Toxicology Branch
445-4233

[Original signed by C Andrews and G Patterson]

DATE: December 1, 2000

SUBJECT: Interim Guidance for Selecting Default Inhalation Rates for Children and Adults

The Worker Health and Safety and Medical Toxicology Branch jointly developed the attached document entitled "Interim Guidance for Selecting Daily Inhalation Rates for Children and Adults." This document supercedes Branch policies regarding the selection of default inhalation rates for children and adults to estimate acute and chronic exposures. The default rates in the document should be used when estimating inhalation exposures in exposure assessment and risk characterization documents when actual data are unavailable. These inhalation rates should be used for any documents currently under development and any future documents to be developed. If a document has gone through Branch or DPR peer review, the author should discuss with his or her supervisor whether revisions should be made. Authors do not need to revise completed documents.

If you have any questions, please contact your supervisor.

Attachment

cc: Dr. Tobi Jones, Assistant Director

Interim Guidance for Selecting Default Inhalation Rates for Children and Adults

(December 1, 2000)

Purpose

This Guidance Document addresses the selection of default daily inhalation rates (in term of m^3/kg/day) for adults and children for both acute and chronic exposures. These values should be considered to calculate exposures, regulatory limits, and other values which require inhalation rate measurements and when actual data are not available. These rates are interim values until more detailed analyses are conducted to determine the appropriate rates for different age groups, gender, and duration of exposure (*i.e.,* acute and chronic exposures).

Background

Daily inhalation exposure is calculated from the air concentration (amount of chemical/m^3 of air) and inhalation rate (e.g., m^3/kg/day). Since inhalation rate is generally not measured in exposure or toxicity studies, default values have been adopted based on available data. Historically, the Medical Toxicology (MT) Branch and Worker Health and Safety (WH&S) Branch have used different default inhalation rates because of different application needs and the resources and references used. For adult daily inhalation rates, the values used by the Branches were similar. The MT Branch used 0.26 m^3/kg/day and the WH&S Branch used 0.28 m^3/kg/day. The default daily inhalation rates for children were significantly different. WH&S Branch used a value of 0.74 m^3/kg/day for a 6-year old child to represent all children. This value was based on an U.S. EPA 1985 analysis (U.S. EPA, 1997). MT Branch used a mean value of 0.46 m^3/kg/day for 1-10 year old children based on the analyses by the International Commission of Radiological Protection (ICRP) (Snyder *et al.,* 1975).

In 1997, U.S.EPA presented recommendations for short-term activity-based and long-term inhalation rates in the revised Exposure Factors Handbook (U.S. EPA, 1997; Table 5-23). These rates were based on more recent analyses of studies (Adams, 1993; Layton, 1993; Linn *et al.*, 1992 and 1993; Spier *et al.*, 1992) of California only residents (except Layton, 1993).

MT Branch and WH&S Branch discussed the U.S. EPA recommendation and available databases. To ensure consistency between the Branches, staff agreed to develop one set of default daily inhalation rates for adults and children. The recommended interim values are presented in this Document.

Recommendations

1. For adults and children, when the duration of activity and activity pattern are specified or known, use recommended short-term rates for the appropriate population in U.S. EPA Exposure Factors Handbook (Table 5-23 in U.S. EPA, 1997) (Attachment 1 and 2).

2. For children, when duration of activity and activity pattern are **not** specified, use the default value of **0.59 m^3/kg/day** for infants since infants have the highest value among all children group when body weight is considered (Attachment 1).

Basis for default value: This rate is based on the inhalation rates (m^3/day) and body weights determined by Layton (1993). These rates were estimated from the food-energy intakes of individuals sampled in the 1977-1978 National Food Consumption Survey data. The rationale is that energy expenditures associated with basic metabolic requirements and physical activities equals food energy intake. Therefore, the energy content of a person's diet can be used to estimate his or her energy expenditures and related respiratory requirements.

The U.S. EPA adopted these as recommended long-term inhalation rates (m^3/day) for children in the Exposure Factors Handbook (U.S. EPA, 1997). When these rates are expressed in terms of body weights, the infants have the highest daily inhalation rate (0.59 m^3/kg/day for 4.5 m^3/day and 7.6 kg body weight). Therefore, DPR is selecting the infant inhalation rate as the default value to represent all children.

3. For adults, when the duration of activity and activity pattern are **not** specified, use the default value of **0.28 m^3/kg/day** for both genders.

   Basis for default value: These default inhalation rates are based on the activity pattern, inhalation rate per activity, and default body weights (Attachment 2). The activity pattern was based on specific activities reported for persons 18 years old and older in a survey conducted by the California Air Resources Board (Table 4.1; Wiley *et al., 1991*). The time spent in the activity categories were: 8.5 hours rest, 13.2 hours light, 1.4 hours moderate, and 0.27 hours of heavy activity (Attachment 3). The inhalation rates per activity were the mean of rates determined by Adams (1993) and Layton (1993). These rates were recommended in the U.S. EPA Exposure Factor Handbook for age's 19-65 years (U.S. EPA, 1997). These rates were: 0.4 m^3/hr (rest), 1.0 m^3/hr (light), 1.6 m^3/hr (moderate), and 3.2 m^3/hr (heavy). The default body weight was 71.8 kg as the mean body weight for ages 18<75 (Table 7-2 in U.S. EPA, 1997).

   The recommended long-term rates for adults, based on the analysis of the 1977-1978 NFCS data by Layton (1993), were not selected as default values. The rates of 12-17 m^3/day are lower than the 20 m^3/day default commonly used by regulatory agencies, including the U.S. EPA. Also, the direct measurement of activity patterns and inhalation rates are available for adults (*i.e.* Wiley et al., 1991 and Adams, 1993).

4. For both children and adult exposures, inhalation rates for specific age groups should be considered whenever it is appropriate. For example, a specific age group may be selected in an aggregate exposure assessment to ensure an age-correspondence across multiple routes or pathways.

5. When the long-term inhalation rates are used to estimate acute exposure, it should be explicitly stated in the risk characterization document that they contribute toward an under-estimation of exposure. Short-term high-end inhalation rates are likely to be higher than the amortized average value for long-term exposure.

6. In the future, the MT and WH&S Branches will conduct a more detailed analysis of the database using distributional methodology. This will require time and commitment from the staff of both Branches. Building a reliable database not only will lend support to a default point estimate of inhalation rate, but also facilitate a distributional analysis in the future.

7. Staff should consult their respective Branch Chief on the implementation of these recommended values. This Guidance Document is subject to revisions for the incorporation of new data and approaches.

References

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Attachment 1: Daily Inhalation Rates for Children.

When activity pattern is specified:			
Activity	Inhalation rate (m^3/ hour)[a]	Daily inhalation rate (m^3/kg/day)	
Rest	0.3	Depends on body weights and activity pattern selected for the age group of interest	
Sedentary	0.4		
Light	1.0		
Moderate	1.2		
Heavy	1.9		
When activity pattern is not specified:			
Age years	Mean body weight (kg)[b]	Inhalation rate (m^3/day)[b]	Daily Inhalation rate (m^3/kg/day)
Infants male/female	7.6	4.5	**0.59**
1-2 male/female	13	6.8	0.52
3-5 male/female	18	8.3	0.46
6-8 male/female	26	10	0.38
9-11 male 9-11 female	36 36	14 13	0.39 0.36
12-14 male 12-14 female	50 49	15 12	0.30 0.24
15-18 male 15-18 female	66 56	17 12	0.26 0.21

a/ Data from U.S. EPA (1997, Table 5-23) for short-term exposures and were based on analyses by Spier *et al*., 1992; Layton, 1993; Linn *et al*., 1992, and Adam, 1993.

b/ Data from Layton, 1993 (Tables 3 and 5) and recommended by U.S. EPA (1997) for long-term exposures.

Attachment 2: Daily Inhalation Rates for Adults.[a]

When activity pattern is specified:		
Activity	Inhalation rate (m^3/ hour)[a]	Daily inhalation rate (m^3/kg/day)
Rest	0.4	Depends on body weights and activity pattern selected for the age group of interest
Sedentary	0.5	
Light	1.0	
Moderate	1.6	
Heavy	3.2	

When activity pattern is not specified:			
Activity	Hours/day[b]	Inhalation rate (m^3/ hour)[a]	Inhalation rate (m^3/day)
Rest	8.5	0.4	20 m^3/day
Light	13.2	1.0	
Moderate	1.4	1.6	
Heavy	0.27	3.2	

Age years	Mean Body weight (kg)[c]	Inhalation rate (m^3/day)	Daily Inhalation rate (m^3/kg/day)
Both	71.8	20	**0.28**

a/ Data from U.S. EPA (1997, Table 5-23) for short-term exposures and were based on analyses by Layton, 1993 and Adam, 1993.

b/ Data from Wily *et al.,* (1991) and categorization of activities from OEHHA (2000).

c/ Mean body weight for ages 18<75 for both genders (Table 7-2 (U.S. EPA, 1997).

Attachment 3: Categorization of Specific Activities[a]

Rest (8.5 hours)	Light (13.2 hours)		Moderate (1.4 hours)	Heavy (0.27 hours)
Breaks	Main job	travel during work	cleaning house	active sports
night sleep	Travel to/from work	eating	outdoor cleaning	outdoor
naps/day	Food preparation	meal cleanup	car repair/	walking or
sleep	Clothes care	plant care	maintenance	hiking
think, relax	Animal care	other household work	other repairs	
	Helping/teaching	talking/reading	baby care	
	Other child care	at dry cleaners	child care	
	Travel, child care	personal services	indoor playing	
	Medical appointments	govt./financial services	outdoor playing	
	car repair services	other repair services	everyday shopping	
	other services	errands	durable/house shop	
	travel, goods/services	washing	music/drama/dance	
	medical care	help and care		
	meals at home	meals out		
	dressing	N.A. activities		
	travel, personal care	students' classes		
	other classes	homework		
	other education	travel, education		
	volunteer/helping	religious group		
	religious practice	child/youth/family		
	other organizations	travel, organizations		
	sports events	entertainment, events		
	movies	theatre		
	museums	visiting		
	parties	bars/lounges		
	other social activities	travel, events/social		
	hobbies	domestic crafts		
	games	computer use		
	travel, recreation	radio		
	TV	records/tapes		
	Read books	reading magazine/other		
	Reading newspaper	conversations		
	Writing	travel, communication		

a/ Based on activity (minutes/day) analyses of Wiley *et al.,* (1991) and categorization of activities of OEHHA (2000).

APPENDIX 5.

MECHANISTIC STUDIES OF

CHLORPYRIFOS RELATED NEURODEVELOPMENTAL EFFECTS

INTRODUCTION

Identification of a rigorous neurodevelopmental point of departure for chlorpyrifos (CPF) would be strengthened by elucidation of the possible mechanistic underpinnings for its effects. While the studies reviewed in the preceding sections shed some light on the question of mechanism, the following paragraphs summarize studies that were designed to approach it directly. Investigations into CPF-induced neuroinflammation, as well as into its effects on neurotransmission in the endocannabinoid, dopaminergic, serotonergic and glutamatergic systems have been carried out by several laboratories recently and are given special attention in this section.

Mechanisms Associated with CPF-Related Disruption of Serine Hydrolases that Degrade Endocannabinoids after Perinatal Treatment

Recent research has shown that organophosphate (OP) pesticides, including CPF, block 30–50 % of all serine hydrolase activities in vivo in the brain beyond acetylcholinesterase (AChE) (Medina-Cleghorn et al. 2014). These included the serine hydrolases monoacylglycerol lipase (MAGL) and fatty acid amide hydrolase (FAAH) that are responsible for the breakdown of endogenous cannabinoid signaling lipids 2-arachidonylglycerol and anandamide (2-AG and AEA). Blockade of MAGL and FAAH and disruption of signaling in the brain during the development can lead to cannabinoid receptor (CB1)-mediated behaviors result in long term behavioral deficits. CPF has been shown to inhibit MAGL and FAAH in to rat pups treated by gavage from postnatal day (PND) 10 to PND 16. Importantly, MAGL and FAHH inhibitions occur at doses lower than those inhibiting brain AChE (R.L. Carr et al. 2011; R. L. Carr et al. 2013).

CPF and its major metabolite, CPF-oxon, have both been shown to inhibit the CB1 receptor of male Swiss-Webster mouse whole brain membranes in vitro (Quistad et al. 2002). CPF -oxon inhibition was 2500 times more potent than CPF ethyl based on the concentration of inhibitor displacing 50% specific binding (IC_{50}) (IC_{50} mean ± S.E: 14±4 versus 35000 ± 6000 nM, respectively). In vivo, these mice showed CPF -oxon (3 mg/kg) and CPF (30 mg/kg) inhibited CB1 receptor at 24 (±7) and 35 (±6) percent, respectively. Since CPF is highly lipophilic it is also possible that it could diffuse into cells, circumventing the CB1 receptor (Smith et al. 2011; Smith et al. 2014). Calcium influx and K^+ efflux are necessary for neurotransmitter release (Elphick and Egertova 2001; Guo and Ikeda 2004; Twitchell et al. 1997); however, pre-synaptic agonist activation of CB1 leads to inhibition of adenylyl cyclase (AC) and inhibition of the conversion of ATP to cyclic AMP, resulting in direct stimulation of K+ channel opening (efflux) and inhibition of Ca^{+2} influx (Di Marzo 2008; Elphick and Egertova 2001; Howlett et al. 2002; Pertwee 2008).

CPF also inhibits the normal reabsorption and pre-synaptic breakdown of 2-AG by MAGL and FAAH degradation of AEA post-synaptically (Di Marzo 2011; Ohno-Shosaku and Kano 2014). When MAGL and FAAH are inhibited, the normal metabolic breakdown of 2-AG and anandamide is disrupted and endocannabinoids accumulate (R.L. Carr et al. 2011; R. L. Carr et al. 2013; R. L. Carr et al. 2014; R.L. Carr et al. 2015) resulting in inhibition of neurotransmitter release (i.e., GABA, glutamate, dopamine, norepinephrine, and acetylcholine). Depending on

dose, treatment regimen, tests performed, etc., both excitatory and inhibitory effects on behavior (anxiety and motor activity) may be detected after CPF treatment (R.L. Carr et al. 2017a; Lee et al. 2015; Silva et al. 2017). Continuous stimulation of the CB1 receptor and/or inhibition of FAAH and MAGL have been shown to have long term developmental effects in animals (Buntyn et al. 2017; R.L. Carr et al. 2015; Russell L Carr et al. 2017b; Mohammed et al. 2015).

Oxidative-reduction (redox) potential alterations occur during neurogenesis and mitochondrial respiration in differentiated neurons. Redox signaling regulates hippocampal neuroprogenitor cell proliferation, differentiation and function (Hebert-Chatelain et al. 2016; Le Belle et al. 2011). Neural stem cells have a higher oxidative state with reactive oxygen species (ROS: e.g., hydrogen peroxide) than adult cells because high ROS levels are necessary for self-renewal and neurogenesis. Low doses of CPF can result in oxidative stress in rodent models (Kopjar et al. 2018). Post-weaning male Wistar rats treated with CPF at 0 (ethanol), 0.01, 0.015 and 0.16 mg/kg/d for 28 days showed no effects on plasma, RBC or brain ChE however there was an increase in superoxide dismutase in the brain at 0.16 mg/kg/d, indicating that CPF was inducing oxidative stress in developing animals at very low doses.

Control of many neuronal processes is initiated by CB1-receptor agonist activation of mitochondrial CB1 receptors (mtCB1) on the mitochondrial membranes. Mitochondria regulate normal cell function through ATP production, generation of reactive oxygen species (ROS), calcium buffering and metabolism of neurotransmitters in the CNS (Djeungoue-Petga and Hebert-Chatelain 2017). When mtCB1 are activated, cAMP is decreased and adenylyl cyclase and protein kinase A are inhibited which results in decreased complex I phosphorylation (NADH dehydrogenase (Hebert-Chatelain et al. 2016). Complex I is the first enzyme of the mitochondrial electron transport chain for the production of ATP and when it is decreased, the result is decreased energy production and disruption of mitochondrial Ca^{2+}inner membrane potential (Bénard et al. 2012; Djeungoue-Petga and Hebert-Chatelain 2017). MtCB1 directly increases the closure of N- and P/Q-type voltage activated Ca^{2+} channels in neurons, preventing Ca^{2+} release, preventing release of neurotransmitters at GABAergic synapses in the hippocampus and glutamatergic synapses in the dorsal striatum (Pankratov et al. 2002). Exposure to the active metabolite of CPF-oxon, results in over-expression of gene sets involved in mitochondrial dysfunction and oxidative stress in the rat cerebellum (Cole et al. 2011); and the antioxidant vitamin E has been shown to meditate the anti-proliferative effect of CPF in PC12 cells (Slotkin et al. 2007).

CPF effects on neuronal pathway development and differentiation, as well as synaptogenesis and dendritogenesis that are stimulated by various growth factors (neurotropins). CPF inhibits neurite outgrowth in vitro by affecting the cAMP pathway and nerve growth factor (NGF) (Eaton et al. 2008). NGF binds to and activates tropomyosin receptor kinase A (TrkA) and the PI3 Kinase Sl to stimulate neurogenesis, plasticity, and axonal growth (Dalton and Howlett 2012; Keimpema et al. 2013). TrkA can also increase expression of diacyglycerol lipases (DAGL), MAGL, and the CB1 receptor (Berghuis 2007; Keimpema et al. 2013).

Fibroblast growth factor (FGF) in the CNS functions as a regulator of neural stem cell proliferation, in addition to neurogenesis, axon growth, and differentiation (Rash et al. 2011; Rash et al. 2013). Postnatal exposure of Sprague-Dawley rats to 1 mg/kg/d CPF on post-natal

days 1-4 altered expression of the neurotropin fibroblast growth factor (FGF) (Slotkin et al. 2007; Slotkin et al. 2008). The FGF receptor signal activates phospholipase Cγ pathway to produce diacylglycerol (DAG) post-synaptically (Williams et al. 2003). In early development, diacylglycerol lipase-β (DAGL) catalyzes DAG to produce 2-AG (Figure 3) (Ahn et al. 2008; Jung et al. 2011). Depending on the cell-state-specific developmental stage, 2-AG (DAGL-dependent) synthesis and subsequent interaction with CB1 receptor signal transduction has been shown to be regulated by FGF signaling cascades (Maison et al. 2009). Disruption of FGF by CPF can adversely affect 2-AG synthesis as well as cellular differentiation into neural pathways (Keimpema et al. 2010).

The expression of CB1, MAGL, FAAH, and DAGL has been reported in neuroprogenitor cells (Berghuis 2007). CB1 activation promotes progenitor cell proliferation, while genetic deletion of CB1 decreases cortical progenitor proliferation in the embryonic brain. Deletion of FAAH increases neural progenitor proliferation. A DAGL antagonist inhibits the *in vitro* proliferation of neural stem cells, and the proliferation of neuroprogenitor cells is impaired in DAGL knockout mice (Gao et al. 2010).

Several lines of evidence suggest a potential CPF effect on proliferation, differentiation, and migration in neuroprogenitor cells. CPF was found to alter the proliferation, differentiation, and histone modifications of human neuroprogenitor cells (Kim et al. 2016). In the hippocampus, most of the CB1-expressing neurons are cholecystokinin-expressing interneurons (CCK- INTs) (Antypa et al. 2011; Morozov et al. 2009). Exposure to CPF evoked a robust upregulation of cholecystokinin in PC12 cells (Slotkin and Seidler 2010). CPF and CPF oxon can directly bind to muscarinic cholinergic receptors (mAChR) M2 at concentrations below those that result in AChE inhibition (Huff et al. 1994; Ward et al. 1993). This supports a potential developmental neurotoxicity mechanism associated with the morphogenetic roles of acetylcholine (Borodinsky and Belgacem 2016; Lauder and Schambra 1999)
The endocannabinoid system controls the guidance of axonal growth in connecting the thalamus and cerebral cortex (Keimpema et al. 2010). Corticofugal axons are CB1 positive, whereas thalamocortical axons are CB1 negative but MAGL positive. The autocrine 2-AG signaling in corticofugal axons promotes their elongation, while MAGL guides the axonal growth by limiting the spatial spread of 2-AG. After synapses are formed, MAGL is overexpressed to provide a 'stop' signal at the pre-synapses. CPF and CPF-oxon were shown to alter cell and axonal growth in a mouse neuroblastoma × rat glioma hybrid cell line and zebrafish, respectively (Campanha et al. 2014; Yang et al. 2011).

Perinatal disruption of synaptogenesis by CPF can result in detrimental consequences in later life. Several published reviews report the association of various adverse developmental health outcomes and potential, estimated, or quantified exposure to CPF during pregnancy (see Epidemiology Epidemiological Studies Related to Neurodevelopmental Effects for an in depth presentation of effects on humans).

Other CPF Mechanisms for Developmental Neurotoxicity Related to Disruption of the Adenylyl Cyclase, Serotonergic Pathways

CPF has been shown to disrupt the serotonergic and dopaminergic systems; however, the low doses used in the above studies were at the threshold of RBC AChE inhibition. 5HT is critical to the control of neural differentiation and organization of the developing brain (Dreyfus 1998; Lauder 1985; Levitt et al. 1997; Turlejski 1996; Weiss and Wagner 1998; Whitaker-Azmitia 1991, 2001). A possible mechanism for developmental neurotoxicity may be via disruption of cell signaling through the serotoninergic system. One of the most potent effects noted for CPF is the ability to control cAMP-dependent cell differentiation through inhibition of adenylyl cyclase (AC) (Crumpton et al. 2000; Garcia et al. 2001; Schuh et al. 2002).

1. AC was inhibited in during gestational neurulation (GD9-12 and GD 17-21) which may lead to later effects on 5HT receptor signaling.
2. CPF treatment in the immediate perinatal period (PND1-4: neuronal differentiation and synaptogenesis) is the most sensitive for detecting decreases in 5HT receptors and 5HTT that persist into adulthood (PND60).
3. Degree of effects on 5HT receptors and 5HTT is dependent on period of treatment and brain region.
4. The 5HT and 5HTT decrements from CPF treatment in the immediate post-natal period were associated with deficits in learning, memory and signs of depression, based on anhedonia, in adulthood (Aldridge et al. 2005b).

The critical effects occurring from CPF exposure were altered neuronal development of 5HT receptor subtypes, 5HTT as well as AC at 1.0 mg/kg/d (lowest dose tested). Severity of effects differed by brain region. However, 1.0 mg/kg/day is also the threshold for AChE inhibition, so it is difficult to separate non-cholinergic from cholinergic effects. The Aldridge et al. studies did not co-examine AChE for comparison and they used the subcutaneous (s.c.) route of exposure which is not a representative route in humans. The results suggest that gestational and neonatal CPF exposures can cause persistent changes in brain synaptic activity based on observed changes to 5-HT levels and turnover. The greatest sensitivity to the above affects occurs prior to the second postnatal week. These effects had gender selectivity and were observed below the threshold for cholinergic symptoms.

The dopaminergic system was disrupted in pups exposed perinatally to CPF as shown by Mohammed et al. (2015) and Aldridge et al. (2005a). At 0.5 mg/kg/d CPF administered by gavage in corn oil, male and female Sprague-Dawley rats showed increased DA metabolism in the amygdala that was associated with decreased anxiety (Mohammed et al., 2015). Aldridge et al. (2005a) showed DA levels and turnover at PND60 were either increased or decreased depending on brain region when pups were treated by s.c. injection PND1-4 at 1.0 mg/kg/d CPF. DA levels and turnover in the cerebral cortex but were increased in the striatum and only turnover was increased in the midbrain. Effects in Mohammed et al. (2015) occurred below the general threshold for RBC AChE inhibition (1 mg/kg/day) when CPF was administered by gavage, although it should be noted that the former study used an atypical route of administration.

Included in Appendix 5, Table 1, below, is an evaluation of studies reporting age-dependent, serotonergic effects of CPF based on published evidence for this MOA. All of the reported serotonergic effects occurred at the lowest dose levels of their corresponding studies and at dose-levels where cholinergic effects were either seen or expected.

Appendix 5. Table 1. Individual End-point Data from Published Studies Reviewed to Evaluate Potential Age Susceptibility to Serotonergic Effects Related to Exposures to CPF

Reference	Test System	Route/Dose Levels (mg/kg/day)	Treatment Period	Endpoint Type	Endpoint	Endpoint Timing	Effects of CPF Treatment	Conclusion(s)
(Mohammed et al. 2015)	Rat Pups	Oral Gavage; 0, 0.5, 0.75, 1; m/f: 17-18/12-16	PND10-16 (pre-adolescence)	Changes to emergence behavior as emotional reactivity (ER) or anxiety	Time-to-emergence from cup	PND16	M and F: ↓ER	The results suggest that CPF targets the endocannabinoid system of the developing brain by disrupting endocannabinoid-mediated dopaminergic signaling. Effects were observed at doses ≥ 0.5 mg/kg/day.
(Mohammed et al. 2015)	Rat Pups	Oral Gavage; 0, 0.5, 0.75, 1; m/f: 17-18/12-16	PND10-16 (pre-adolescence)	Changes to brain monoamine neurotransmitter (MNT) signaling related to emotional behavior	MNT levels in the hippocampus and amygdala. MNTs included dopamine, serotonin, and metabolites	PND16	Hippocampus: ↑ NE, 5-HT, and 5-HIAA levels Amygdala: ↑DOPAC and HVA	
(Aldridge et al. 2003)	Rats: pregnant dams and pups	Subcutaneous injection; 0, 1, 2, and 5	GD9-12 (neurulation)	Changes to the levels of 5-HTRs (1A and 2) and 5-HTT in the brains of pups.	5-HT binding to *ex-vivo* 5-HTRs (1A and 2) and 5-HTT	GD17 and 21	Whole Brain: ↓5-HTR and 5-HTT binding (GD17). Brainstem: ↑5-HTR and 5-HTT binding (GD21).	The results suggest that CPF targets the 5-HT system of the developing brain at the level of the cell. CPF likely targets the development and function of signaling molecules (5-HTRs and

(Aldridge et al. 2003)	Rats: pregnant dams and pups	Subcutaneous injection: 0, 1, 2, and 5	GD9-12 (neurulation)	Changes to the Adenylyl cyclase (AC) response to 5HT in the brains of pups.	Ratio of AC activity +/- 5-HT and +/- forskolin	GD17 and 21	↓5-HT-mediated stimulation. ↑5-HT-mediated inhibition (+forskolin).	5-HTTs). The critical window for CPF effects ranged from the neural tube stage to the stages of terminal differentiation and synaptogenesis. These effects had gender specificity and were observed below the threshold for cholinergic symptoms. Effects were observed at doses ≥ 1.0 mg/kg/day.
(Aldridge et al. 2003)	Rats: pregnant dams and pups	Subcutaneous injection: 0, 1, 2, 5, 10, 20, 40	GD17-20 (late gestation)	Changes to the levels of 5-HTRs (1A and 2) and 5-HTT in the brains of pups.	5-HT binding to *ex-vivo* 5-HTRs (1A and 2) and 5-HTT	GD21	Brainstem: ↑5-HTR and 5-HTT binding. Forebrain: ↑5-HTR and ↑↓5-HTT binding.	
(Aldridge et al. 2003)	Rats: pregnant dams and pups	Subcutaneous injection: 0, 1, 2, 5, 10, 20, 40	GD17-20 (late gestation)	Changes to the Adenylyl cyclase (AC) response to 5HT in the brains of pups.	Ratio of AC activity +/- 5-HT and +/- forskolin	GD21	↑5-HT-mediated stimulation. ↑5-HT-mediated inhibition (+forskolin).	
(Aldridge et al. 2003)	Rat pups	Subcutaneous injection: 0 and 1	PND1-4	Changes to the levels of 5-HTRs (1A and 2) in the brains of pups.	5-HT binding to *ex-vivo* 5-HTRs (1A and 2)	PND5 and 10	PND5 Brainstem (M/F): ↑5-HTR binding. Forebrain (M/F): ↑5-HTR binding. PND10 Brainstem (M/F): ↑/↓5-HTR binding Forebrain (M/F): ↑/↓ and ↑5-HTR binding.	

(Aldridge et al. 2003)	Rat pups	Subcutaneous injection: 0 and 5	PND11-14	Changes to the levels of 5-HTRs (1A and 2) in the brains of pups.	5-HT binding to *ex-vivo* 5-HTRs (1A and 2)	PND15 and 20	PND15 Brainstem (M/F): ↓/↑ 5-HTR binding. Forebrain (M/F): ↑ and ↓/↑ 5-HTR binding. PND20 Brainstem (M/F): ↓5-HTR binding Forebrain (M/F): ↓5-HTR binding.	
(Aldridge et al. 2004)	Rats: pregnant dams and adult progeny	Subcutaneous injection; 0, 1, and 5	GD9-12 (neurulation)	Changes to the levels of 5-HTRs (1A and 2) and 5-HTT in the brains of adult rats.	5-HT binding to *ex-vivo* 5-HTRs (1A and 2) and 5-HTT	PND60 (adulthood)	Cerebral Cortex, Midbrain, and Brainstem (M/F): ↑5-HTR and 5-HTT binding.	The results suggest that CPF acts to alter the development program for 5-HT innervation in specific synaptic populations. The period of greatest sensitivity was from late gestation to early post-natal corresponding the second trimester of

(Aldridge et al. 2004)	Rats: pregnant dams and adult progeny	Subcutaneous injection; 0, 1, and 5	GD17-20 (late gestation)	Changes to the levels of 5-HTRs (1A and 2) and 5-HTT in the brains of adult rats.	5-HT binding to *ex-vivo* 5-HTRs (1A and 2) and 5-HTT	PND60 (adulthood)	Cerebral Cortex, Hippocampus, Striatum, Midbrain, and Brainstem (M/F): ↑↓5-HTR and 5-HTT binding. Effects were greater for males than females.	human fetal development. These effects had gender specificity and were observed below the threshold for cholinergic symptoms.
(Aldridge et al. 2004)	Rats: pregnant dams and adult progeny	Subcutaneous injection: 0 and 1	PND1-4	Changes to the levels of 5-HTRs (1A and 2) and 5-HTT in the brains of adult rats.	5-HT binding to *ex-vivo* 5-HTRs (1A and 2) and 5-HTT	PND60 (adulthood)	Cerebral Cortex, Hippocampus, Striatum, Midbrain, and Brainstem (M/F): ↑↓5-HTR and 5-HTT binding. Effects were greater for males than females.	Effects were observed at doses ≥ 1.0 mg/kg/day.
(Aldridge et al. 2004)	Rats: pregnant dams and adult progeny	Subcutaneous injection: 0 and 5	PND11-14	Changes to the levels of 5-HTRs (1A and 2) and 5-HTT in the brains of adult rats.	5-HT binding to *ex-vivo* 5-HTRs (1A and 2) and 5-HTT	PND60 (adulthood)	Cerebral Cortex, Hippocampus, Striatum, Midbrain, and Brainstem (M/F): ↑↓5-HTR and 5-HTT binding.	

(Aldridge et al. 2004)	Rats: pregnant dams and adult progeny	Subcutaneous injection; 0, 1, and 5	GD9-12 (neurulation)	Changes to the Adenylyl cyclase (AC) response to 5HT in the brains of pups.	Ratio of AC activity +/- 5-HT	PND60 (adulthood)	Gender-specific changes in basal AC activity.	
(Aldridge et al. 2004)	Rats: pregnant dams and adult progeny	Subcutaneous injection; 0, 1, and 5	GD17-20 (late gestation)	Changes to the Adenylyl cyclase (AC) response to 5HT in the brains of pups.	Ratio of AC activity +/- 5-HT	PND60 (adulthood)	↓Forskolin-stimulated AC activity.	
(Aldridge et al. 2004)	Rat pups	Subcutaneous injection; 0, 1, and 5	PND1-4	Changes to the Adenylyl cyclase (AC) response to 5HT in the brains of pups.	Ratio of AC activity +/- 5-HT (+/- forskolin)	PND60 (adulthood)	Gender-specific changes in basal AC activity.	
(Aldridge et al. 2004)	Rat pups	Subcutaneous injection; 0, 1, and 5	PND11-14	Changes to the Adenylyl cyclase (AC) response to 5HT in the brains of pups.	Ratio of AC activity +/- 5-HT (+/- forskolin)	PND60 (adulthood)	↓Basal AC activity. ↓Forskolin-stimulated AC activity.	

(Aldridge et al. 2005b)	Rat pups	Subcutaneous injection; CPF: 0 and 1	PND1-4	Changes to elevated plus maze navigation parameters to test for depression-like behaviors known to be mediated by 5-HT deficiencies.	Percentage of time spent in open arms and locomotive activity (center crossings).	PND52-53	M: ↑Time in open-arms. M: ↑Activity.	The results suggest that neonatal CPF exposures can cause persistent behavioral effects associated with rodent models of depression likely mediated by changes in 5-HT signaling. These effects had gender selectivity but not specificity and were observed below the threshold for cholinergic symptoms. Effects were observed at doses ≥ 1.0 mg/kg/day.
(Aldridge et al. 2005b)	Rat pups	Subcutaneous injection; CPF: 0 and 1	PND1-4	Changes to chocolate milk consumption preference to test for anhedonia known to be mediated by 5-HT deficiencies.	Milk:Water preference ratio.	PND54	M and F: ↓Preference for chocolate milk.	
(Aldridge et al. 2005b)	Rat pups	Subcutaneous injection; CPF: 0 and 1	PND1-4	Changes to radial-arm maze navigation parameters to test working and reference memory.	Working and reference memory error rates in locating food.	PND64	Working and Reference Memory: M: ↑ error rate. F: ↓ error rate. Effects eliminated characteristic sex differences observed in controls	

(Aldridge et al. 2005b)	Rat pups	Subcutaneous injection; CPF: 0 and 1 Ketanserin: 0, 0.5, 1 and 2	PND1-4	Changes to radial-arm maze navigation parameters to test working and reference memory and the role played by 5-HT.	Working and reference memory error rates in locating food.	PND64	M and F (combined): ↑Error rate. F: ↓Error rate. Effects in working memory > reference memory.	
(Aldridge et al. 2005a)	Rats: pregnant dams and adult progeny	Subcutaneous injection; CPF: 0, 1 and 5	GD17-20	Changes to brain 5-HT and DA signaling (synaptic activity) and its relationship to observed behaviors similar to those for rodent models of depression.	5-HT levels and turnover in the brain. Turnover is the ratio parent MNT to its metabolites. MNTs included dopamine, serotonin, and metabolites	PND60	M and F: Net ↓5-HT content Net ↑5-HT turnover Net - DA content Net ↑DA turnover	The results suggest that gestational and neonatal CPF exposures can cause persistent changes in brain synaptic activity based on observed changes to 5-HT levels and turnover. The greatest sensitivity to the above affects occurs prior to the second postnatal week.

(Aldridge et al. 2005a)	Rats: pregnant dams and adult progeny	Subcutaneous injection; CPF: 0 and 1	PND1-4	Changes to brain 5-HT signaling and its relationship to observed behaviors similar to those for rodent models of depression.	5-HT levels and turnover in the brain. Turnover was the ratio parent MNT to its metabolites. MNTs included dopamine, serotonin, and metabolites	PND60	M: Net -5-HT content Net ↑5-HT turnover F: Net ↓5-HT content Net ↑5-HT turnover	These effects had gender selectivity and were observed below the threshold for cholinergic symptoms. Effects were observed at doses ≥ 1.0 mg/kg/day.
(Aldridge et al. 2005a)	Rats: pregnant dams and adult progeny	Subcutaneous injection; CPF: 0 and 5	PND11-14	Changes to brain 5-HT signaling and its relationship to observed behaviors similar to those for rodent models of depression.	5-HT levels and turnover in the brain. Turnover was the ratio parent MNT to its metabolites. MNTs included dopamine, serotonin, and metabolites	PND60	M and F: Net -5-HT content Net -5-HT turnover	

APPENDIX 5. REFERENCES

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APPENDIX 6.

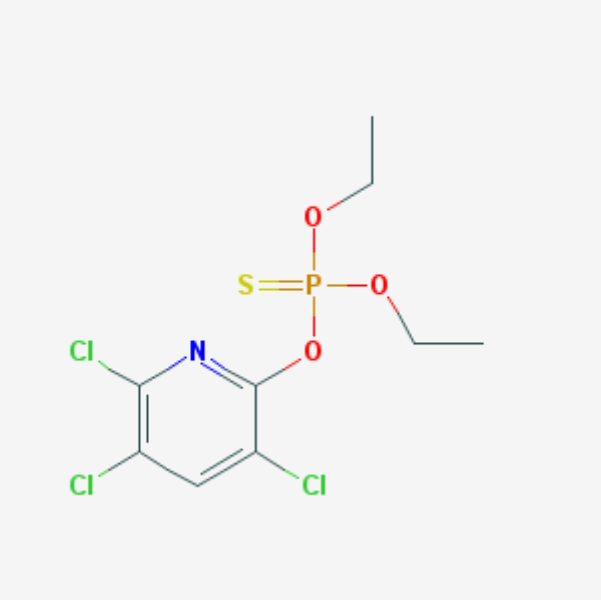
Draft Evaluation of Chlorpyrifos as a Toxic Air Contaminant:

Risk Characterization of Spray Drift, Dietary, and Aggregate Exposures to Residential Bystanders

Revised December 11, 2017

Draft Evaluation of Chlorpyrifos as a Toxic Air Contaminant:

Risk Characterization of Spray Drift, Dietary, and Aggregate Exposures to Residential Bystanders



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List of Abbreviations

AADD	Annual average daily dose
AC	Adenylcyclase
AC_{50}	Active concentration resulting in activity of 50% of group
ACh	Acetylcholine
AChE	Acetylcholinesterase
ADD	Absorbed daily dose
AEA	Anandamide
2-AG	2-Arachidonoylglycerol
AI	Active ingredient
BMD	Benchmark dose
BMDL	Benchmark dose lower limit (95^{th} percentile)
BuChE	Butyryl/plasma/pseudo-ChE or B-esterase
CalEPA	California Environmental Protection Agency
cAMP	Cyclic AMP
CCCEH	Columbia Center for Children's Environmental Health
CES	Carboxyesterase
CNS	Central nervous system
CPF	Chlorpyrifos
CPF-oxon	Chlorpyrifos oxon
DA	Dopamine
DAP	Dialkylphosphate
DPR	California Department of Pesticide Regulation
DOPAC	3,4-Dihydroxyphenylacetic acid
EMON	Environmental Monitoring Branch
FAAH	Fatty acid amide hydrolase
FIFRA	Federal Insecticide, Fungicide & Rodenticide Act
FQPA	Food Quality Protection Act
GABA	ɣ-aminobutyric acid
GD	Gestation day
GnRH	Gonadotrophin releasing hormone
HHA	Human Health Assessment Branch
HDT	Highest dose tested
5HT	Serotonin
IARC	International Agency for Research on Cancer
i.p.	Intraperitoneal
IRED	Interim Reregistration Eligibility Decision
IVIVE	*In vitro* to *in vivo* extrapolation
LADD	Lifetime average daily dose
LD	Lactation day
LDT	Lowest dose tested
LOAEL	Lowest observed adverse effect level

LOEL	Lowest observed effect level
LOD/LOQ	Limit of detection/limit of quantitation
MAGL	Monoacylglycerol lipase
MCL	Maximum contaminant level
MDL	Minimal detection limit
MOA	Mode of action
MOE	Margin of exposure
MTD	Maximum tolerated dose
NE	Norepinephrine
NOAEL	No observed adverse effect level
NOEL	No observed effect level
NRDC	National Resources Defense Fund
OP	Organophosphate
P450/CYP	Cytochrome P450s
PAD	Population adjusted dose
PBPK-PD	Physiologically-based pharmacokinetic-pharmacodynamic
PDP	Pesticide Data Program
PISP	Pesticide Illness Surveillance Program
PND	Postnatal day
PoD	Point of departure
PON1	Paraoxonase 1 or A-esterase
PPE	Personal protection equipment
ppm, ppb	Parts per million; parts per billion
PUR	Pesticide use report
PNS	Peripheral nervous system
RAC	Raw agricultural commodity
RAS	Risk Assessment Section
RBC	Red blood cell
RED	Reregistration eligibility decision
RfD	Reference dose
SADD	Seasonal absorbed daily dose
SAP	Scientific Advisory Panel
s.c.	Subcutaneous
SF	Safety factor
TCPy	3,5,6-trichloro-2-pyridinol
ToxCast	US EPA Toxicity ForeCaster
ToxPi	Toxicological Priority Index
UF	Uncertainty factor
US EPA	US Environmental Protection Agency

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EXECUTIVE SUMMARY

Chlorpyrifos (CPF) is a chlorinated organophosphorus (OP) ester used as an insecticide, acaricide, and miticide. The toxicity of CPF is associated with binding and inhibition of the enzyme acetylcholinesterase (AChE) in insects and mammals. CPF requires metabolic activation to CPF-oxon to yield anticholinesterase activity. CPF may cause developmental neurotoxicity at exposure levels that do not induce overt toxicity or inhibit cholinesterase (ChE) activity.

CPF has major uses in California as an insecticide for nut trees, fruit, vegetable, and grain crops as well as non-food crop uses (e.g., golf course turf, industrial sites, greenhouse and nursery production, sod farms, and wood products). Major use areas include the Central Valley, Central Coast region, and Imperial County. Use occurs year-round, with peak use during the summer. There are several dozen chlorpyrifos products, registered by approximately 20 different companies. Methods of application allowed by labels include aerial, airblast, ground boom, chemigation, and others.

This risk assessment addresses potential human effects arising from exposure to CPF from food, drinking water, air and skin contact, incidental ingestion contact, as well as aggregate exposures from various combined scenarios. The health risk assessment was carried out for 4 sentinel subgroups of the general population: infants (<1 year old), children 1-2 years old, children 6-12 years old, and females of childbearing age (13-49 years old). The critical toxicological points of departure (PoDs) used to characterize the risk from exposure to CPF were human equivalent doses estimated by physiologically based pharmacokinetic and pharmacodynamic modeling. Risks were calculated as margin of exposure (MOE), which was equal to the critical PoD divided by the anticipated human exposure level. The Department of Pesticide Regulation (DPR) based its PoDs on the 2014 US EPA Revised Human Health Risk Assessment for CPF. A MOE of 100 was considered protective of human health for all exposure scenarios. The target of 100 included uncertainty factors (UF) of 1 for interspecies sensitivity, 10 for intraspecies variability, and 10 for potential neurodevelopmental effects. Exposures resulting in MOEs lower than the target of 100 are considered to be of potential health risk to humans. DPR's Human Health Assessment Branch (HHA) used the PoDs and the target UF of 100 to estimate reference doses or reference concentrations for chlorpyrifos (Executive Summary Table 1).

Executive Summary Table 1. Points of Departure, Reference Doses, or Concentrations used to Evaluate the Risk from Various Single and Aggregate Routes of Exposure to Selected Population Subgroups

Routes and Duration	Exposure Scenario[a]	10% RBC AChE Inhibition	
		PoD[b]	RfD[c] or RfC[c] (PoD/UF of 100)
Acute Oral [µg/kg/day]			
Infant <1	Dietary	600	6.00
Children 1-2	Dietary, Spray-Drift, Aggregate	581	5.81
Children 6-12	Dietary	530	5.30
Females 13-49	Dietary, Spray-Drift	467	4.67
Steady State Oral [µg/kg/day]			
Infant <1	Dietary	101	1.01
Children 1-2	Dietary, Spray-Drift, Aggregate	99	0.99
Children 6-12	Dietary	80	0.80
Females 13-49	Dietary, Spray-Drift	78	0.78
Steady State Dermal [µg/kg/day]			
Children 1-2	Spray-Drift, Aggregate	134250	1342.5
Females 13-49	Spray-Drift	23600	236
Steady State Inhalation [µg/m^3]			
Children 1-2	Spray-Drift, Aggregate	2370	23.7
Females 13-49	Spray-Drift	6150	61.5

a- **Exposure Scenarios**:
Diet: Oral exposure to CPF residues in food and drinking water for the four different population subgroups.
Spray-Drift: Non-occupational/residential bystanders' exposure to CPF due to off-site movement of the product from agricultural applications in California. Females of childbearing age (13-49 years old) and children 1-2 years old have been identified as the potential sensitive population subgroups due to their anticipated high exposures from treated turf and contaminated lawn via dermal contact and inhalation; and for children, mouthing activities such as hand-to-mouth, object-to-mouth, and incidental soil ingestion.
Aggregate: Combined exposures from dietary (food only) and drinking water plus spray drift exposures from inhalation and deposition (i.e., dermal contact for children and adults and mouthing activities for children: object-to-month, hand-to-mouth, and incidental ingestion)

b- **Point of Departure (PoD):** As defined by US EPA (2012), a point of departure is the dose-response point that marks the starting point for low-dose extrapolation, and the PoD generally corresponds to a selected estimated low-level of response. In this Toxic Air Contaminant (TAC) Evaluation, the critical response (PoD) for CPF is defined as 10% RBC AChE inhibition.

c- **Reference Dose (RfD) or reference concentration (RfC):** As defined by US EPA (2012), a RfC or RfD is an estimate of the concentration or dose of a substance (with uncertainty spanning perhaps an order of magnitude) to which a human population can be exposed (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. For CPF, the uncertainty factors (UF) employed are 10 for intraspecies variability based on 10% RBC AChE inhibition and 10 for database uncertainties for neurodevelopmental effects (Total UF = 100): RfD/RfC = (PoD ÷ UF of 100).

No risks were identified from exposures to children and females of childbearing age from dietary sources (food and drinking water) and dermal exposures resulting from spray drift. Potential health risks were identified as: hand-to-mouth exposure in children; inhalation exposure in children and women of childbearing age; and various aggregate exposures from combined media including dietary (food only), drinking water, and deposition and inhalation from spray-drift.

TECHNICAL SUMMARY

Chlorpyrifos (CPF) is a chlorinated organophosphorus (OP) ester used as an insecticide, acaricide, and miticide. The toxicity of CPF is associated with binding and inhibition of the enzyme acetylcholinesterase (AChE) in insects and mammals. CPF requires metabolic activation to CPF-oxon to yield anticholinesterase activity. CPF causes developmental neurotoxicity at exposure levels that do not induce overt toxicity or inhibit cholinesterase (ChE) activity.

The major uses of CPF in California are as an insecticide for nut trees, fruit, vegetable, and grain crops. There are also several registered non-production agricultural uses including uses on golf course turf, industrial sites, greenhouse and nursery production, seed treatments, sod farms, and wood products. Additional uses include cattle ear tags, roach bait (childproof) for use in homes and sewer manholes, and fire ant control in the utility industry. CPF is also used in the public health control of mosquitos. California is the only state that regulates CPF as a restricted use material (http://www.cdpr.ca.gov/docs/legbills/rulepkgs/14-002/final_text.pdf).

CPF was given a "High" priority status by the California Department of Pesticide Regulation (DPR) due to concerns regarding 1) potential neurodevelopmental/ neurobehavioral effects from exposure during vulnerable developmental windows in fetuses, infants, and children, 2) genotoxicity and reproductive toxicity in rats, 3) probable human exposure due to spray drift, 4) possible infant exposure from hand-to-mouth activities, and 5) exposure through food and drinking water. Based on its high priority status, CPF entered the DPR's process of comprehensive human health risk assessment in 2011 (http://www.cdpr.ca.gov/docs/risk/raprocess.pdf and http://www.cdpr.ca.gov/docs/dept/prec/2011/prec_letter_report_52_20110916.pdf).

This risk assessment addresses potential human effects arising from exposure to CPF from food, drinking water, air and skin contact, incidental ingestion contact, as well as aggregate exposures from various combined scenarios.

Chemical Identification and Technical/Product Formulation

CPF (Trade name- Dursban®, Lorsban®; O,O-diethyl O-3,5,6-trichloro-2-pyridyl phosphorothioate; CAS# 2921-88-2) is a crystalline broad-spectrum insecticide that was first manufactured by Dow AgroSciences LLC in 1965. In the 1990s, CPF was one of the top selling pesticides in the world. Over the last decade, concerns regarding toxicity to the developing nervous system have limited its use.

In December 2000, US EPA reached an agreement to halt the manufacture of chlorpyrifos for nearly all residential uses[1]. Registration was cancelled in March 2001 for indoor residential products except for containerized baits in child resistant packaging. Outdoor residential products

[1] Chlorpyrifos; Cancellation Order. A Notice by the Environmental Protection Agency on 12/06/2000. Federal Register, https://www.federalregister.gov/documents/2000/12/06/00-30917/chlorpyrifos-cancellation-order

were cancelled except for products specifically for fire ant mound treatment by licensed applicators or mosquito control by public health agencies. All retail sales were stopped in December 2002.

Uses in California

A query of the California Product/Label Database identified 48 products with active registrations in California. Among those, 24 products have labeling language that specifies aerial and/or ground-based application methods. Use fluctuates from year to year. However, the total yearly use of CPF between 2011 and 2015 has ranged from a low of 1.10 million pounds in 2012 to a high of 1.46 million pounds in 2013, with an average application of 1 lb/acre on 0.9 – 1.3 million acres. Almonds received the highest poundage of CPF compared to other crops (range: 192,482 in 2012 to 450,403 lb in 2013).

Illness and Exposure Reports

From 2004-2014, there were 246 associated cases of pesticide exposure stemming from 84 episodes involving chlorpyrifos. The average number of chlorpyrifos episodes per year was 2.9 and the average number of cases was 22.3 per year. The majority of illnesses were due to drift of pesticides (n=163, 66.2%), followed by residue (n=42, 17%). Ingestion accounted for 12 (5%) cases, eight of which resulted from improperly stored pesticides and/or pesticides that were easily accessible by children. Bystanders accounted for 217 (88.6%) of the reported illnesses and most were engaged in routine activities at the time of exposure (n=101, 41%).

Data available from the California Environmental Contaminant Biomonitoring Program (CECBP) gives an indication of background environmental exposure to chlorpyrifos and/or chlorpyrifos-methyl via the measurement of the urinary metabolite 3,5,6-trichloro-2-pyridinol (TCPy) in several study groups. In 112 male and female subjects from California's Central Valley, TCPy was detected in 81% of the urine specimens above the limit of detection (LOD). The geometric mean was 1.23 µg/L. In a group of 101 Orange County, CA firefighters, TCPy was detected in 89% of the samples, with a geometric mean of 1.78 µg/L. In a study conducted at the San Francisco General Hospital, 89 third-trimester maternal urine samples collected from mother-infant pairs had a geometric mean TCPy concentration of 0.52 µg/L (95% CI 0.41- 0.65 µg/L).

TOXICOLOGY PROFILE

The neurotransmitter acetylcholine (ACh) is hydrolyzed by cholinesterase enzymes (ChE), a type of serine hydrolase. AChE hydrolyzes ACh at synaptic clefts in the central nervous system at the neuromuscular or neuro-glandular junctions in the peripheral nervous system and in some non-neuronal cells such as erythrocytes (red blood cells, RBC). When AChE inhibition occurs in nerve and muscles, ACh accumulates and causes unremitting nerve impulses that lead to continuous muscle responses in the peripheral nervous system or neural stimulation in the central nervous system. Butyrylcholinesterases (BuChE/plasma ChE), which represent the majority of the ACh-hydrolyzing activity in human plasma, are also inhibited by CPF, though the toxicological consequences of this inhibition are not fully understood.

The active CPF metabolite, CPF-oxon, inhibits AChE by binding at the active site of the enzyme. CPF-oxon also inhibits the BuChE enzyme. AChE inhibition in red blood cells is commonly used as a surrogate of the inhibition in target tissues.

Metabolism

The estimated oral absorption of CPF is 70-99% in rats and humans. Dermal and inhalation absorption is mostly indicated from inhibition of ChE activities and urinary recovery of metabolites. In animals and humans, CPF is extensively metabolized by the liver cytochrome P450 enzymes (CYP1A2, 2B6, 2C19, 3A4, 3A5, and 3A7). Oxidative desulfuration results in CPF-oxon. Dearylation of CPF and CPF-oxon by CYP produces TCPy and diethyl thiophosphate (DETP). Hydrolysis of the CPF-oxon by B-esterases (BuChE and carboxylesterase, CES) and A-esterases (paraoxonases, PON1) detoxify CPF-oxon to the urinary metabolite TCPy, which is used as a biomarker for CPF exposure. CPF is detected in rat and human milk. In rats, transplacental transfer to the fetus is evidenced by ChE inhibition in fetal plasma and brain and by the presence of CPF in fetal liver, brain, placenta, umbilical cord, and amniotic fluid.

Acute and Short-Term Toxicity

CPF is classified by US EPA as a moderate oral toxicant (Category II). The acute oral LD_{50} is 32 mg/kg for hens and 82 to 504 mg/kg for rats, mice, and guinea pigs. The oral LD_{50} for CPF-oxon is > 100 mg/kg in male rats and 300 mg/kg in female rats. The dermal LD_{50} in rats is 202 mg/kg/d. The 4-hour inhalation LC_{50} in rats is > 2 mg/L. CPF is a Category IV skin and eye irritant, causing slight conjunctival and dermal irritation. Human deaths are reported due to accidental exposure or intentional ingestion. CPF doses > 300 mg/kg in humans have resulted in unconsciousness, convulsions, cyanosis, and uncontrolled urination.

The main target of CPF toxicity after short-term excessive oral exposure (not those expected from typical ambient, real-world exposure) is the nervous system of adult and developing organisms. Cholinergic syndromes resulting from the overstimulation of the muscarinic and nicotinic ACh receptors include hypersalivation, respiratory distress, miosis, muscular twitches, tremors, ataxia, diarrhea, and vomiting. Other effects include hematological and liver enzyme changes, chromodactyorrhea, tachycardia, renal effects, hypothermia, and body weight decreases. No delayed neuropathy was observed in hens.

As with other OPs, the critical no-observed effect levels (NOELs) for CPF are typically based on RBC or brain AChE inhibition, for which robust data in animals and humans are available. A Benchmark Dose (BMD) analysis performed by US EPA in 2011 calculated a BMDL (lower bound of BMD) of 0.36 mg/kg/d based on 10% RBC ChE inhibition in rat pups on postnatal day (PND) 11 after a single oral exposure. For acute CPF-oxon exposure, the similarly determined BMDL is 0.08 mg kg/day. In 2014, US EPA used a physiologically-based pharmacokinetic-pharmacodynamic (PBPK-PD) model to estimate the critical toxicological points of departure (PoDs) for CPF. These PoDs are human equivalent doses based on 10% inhibition of the RBC AChE activity after an acute (single day, 24 hr) or subchronic (steady-state, 21-days) exposure (Summary Table 1). The acute PoDs for children and females of childbearing age were 0.457-0.6 mg/kg/d and the steady state PoDs were 0.078-0.1 mg/kg/d.

Chronic Toxicity

Effects reported in workers chronically exposed to CPF included impaired memory, disorientation, speech difficulties, nausea, and weakness. The most sensitive effects observed after chronic dietary exposure to CPF in rats and mice were ChE inhibition, neurological signs, developmental neurotoxicity, and neurobehavioral effects. At higher doses, there was evidence of increased adrenal gland, brain and heart weight in rats, increased liver weight, and hepatocyte vacuolation in dogs and mice, and ocular opacity and hair loss in mice. In 2011, US EPA established a chronic BMDL of 0.03 mg/kg/d based on 10% RBC AChE inhibition in PND 11 male rats after 11 days of oral exposures.

Reproductive and Developmental Toxicity

The available two-generation reproductive toxicity studies in rats indicate that CPF is not teratogenic and does not adversely affect reproduction. In prenatal developmental toxicity studies in rats and mice, fetal growth retardation and developmental delays were observed in the presence of maternal toxicity.

Developmental Neurotoxicity

CPF may cause developmental neurotoxicity in rats and mice at doses that elicit minimal or no fetal brain AChE inhibition. Three major prospective cohort studies in humans evaluated pre- and post-natal pesticide exposure in mother-infant pairs and birth and developmental outcomes in neonates, infants, and children. One study from Columbia University in New York City Columbia Center for Children's Environmental Health (CCCEH) focused on CPF levels in the umbilical cord and maternal plasma as a direct biomarker for CPF *in utero* fetal exposure. The other two studies from Mount Sinai Hospital in New York City and from the University of California at Berkeley measured TCPy (a metabolite of CPF and CPF methyl) and non-specific OP metabolites in maternal urine. Collectively, the results from these studies have shown associations of indoor and outdoor exposure to CPF during pregnancy with adverse neurodevelopmental outcomes in children through age 11 years, including changes in brain morphology, delays in cognitive and motor functions, and problems with attention, and tremors.

Genotoxicity

CPF is negative for gene mutation (*Salmonella typhimurium*, *Escherichia coli*, Chinese hamster ovary cell) and chromosomal aberrations (rat lymphocytes, mouse bone marrow micronucleus). Assays for DNA damage were negative in mammalian cells, but positive in yeast and bacteria.

Carcinogenicity

CPF did not cause tumors in chronic oral studies with rats and mice. Currently CPF is not listed as a carcinogen (http://monographs.iarc.fr/ENG/Classification/List_of_Classifications.pdf; http://monographs.iarc.fr/ENG/Classification/index.php) by the International Agency for Research on Cancer (IARC), the US EPA Toxics Release Inventory Criteria (TRI), or California Proposition 65. The US EPA Office of Pesticide Programs states, "Chlorpyrifos is not likely to be carcinogenic to humans, based on the lack of evidence of carcinogenicity in studies in rats and

mice and the absence of a mutagenicity concern" (US EPA, 2011, Preliminary Human Health Risk Assessment for Chlorpyrifos, page 159.)

Immunotoxicity

Studies in rodents, cats, and dogs indicate that at doses causing ChE inhibition, CPF did not alter immune system function.

ToxCast™ Profiles and Tox21 HTS Profiles

The Toxicity ForeCaster (ToxCast™) and Tox21 high-throughput screening assays (HTS) were examined for indications of pathway disruptions that could lead to toxic effects. Zebrafish is a promising test model to examine the potential CPF neurobehavioral effects and compare active concentrations to those inhibiting ChE activity. Abnormal behaviors (increased "fish at rest," decreased swim speed, decrease in fish with a preference for being on the side or on the edge of their swim lane) occur at CPF levels 10-fold lower than those inhibiting AChE. This provides support for the use of UF of 10 to account for the potential neurodevelopmental effects.

ToxCast and Tox21 provide indications of CPF pathway disruptions in cell adhesion, cell cycle, and cell morphology assays. CPF is also a positive hit for molecular targets that regulate 1) induction and inhibition of CYP enzymes, 2) hormone levels in the brain, 3) endocrine receptor binding, and 4) inhibition of steroidogenesis. However, it is unclear if these impacted pathways are potential key noncholinergic molecular events responsible for the observed CPF neurodevelopmental toxicity *in vivo*.

RISK ASSESSMENT

A comprehensive human health risk assessment was conducted for 4 sentinel subgroups of the general population: infants (<1 year old), children 1-2 years old, children 6-12 years old, and females of childbearing age (13-49 years old).

Hazard Identification

The critical NOELs for evaluating oral, dermal, and inhalation exposure to CPF from diet and spray drift were toxicological PoDs based on inhibition of the RBC AChE activity. HHA used the PoDs from the US EPA 2014 Revised Human Health Risk Assessment as a starting point for this risk assessment. The PoDs are PBPK-PD model-derived human equivalent doses based on 10% inhibition of the RBC AChE activity after an acute (single day, 24 hr) or steady-state (21-days) exposure of CPF in humans (Summary Table 1). The PBPK-PD model includes parameters that account for human-specific physiology and metabolism for all age groups, as well as multi-route variations in RBC AChE inhibition that account for variation in the sensitivity within the human population (infants, children, youths, and non-pregnant adults).

Summary of Critical NOELs

Summary Table 1. Critical NOELs (PoDs) for CPF and CPF-Oxon

Exposure Route[a]	PBPK-PD PoDs (US EPA, 2014a)							
	Infants < 1 yr old		Children 1-2 yrs old		Child 6-12 yrs old		Females 13-49 yrs old	
	Acute	SS[b]	Acute	SS[b]	Acute	SS[b]	Acute	SS[b]
Dietary (food only) and Drinking Water Exposures								
Drinking H_2O (oxon ppb)	1,183	217	3,004	548	7,700	1,358	5,285	932
Food (mg/kg/d)	0.600	0.103	0.581	0.099	0.530	0.090	0.467	0.078
Non-Dietary Exposures								
Incidental Oral (mg/kg/d)	--	--	--	0.101	--	--	--	--
Dermal (mg/kg/d)	--	--	--	134.25	--	--	--	23.60
Inhalation (mg/m^3)	--	--	--	2.37	--	--	--	6.15

Abbreviation: PoD, point-of-departure; CPF, chlorpyrifos; CPF-Oxon, chlorpyrifos-oxon; PBPK/PD, physiological-based pharmacokinetic/pharmacodynamic model; SS, steady state

[a] PoDs are human equivalent doses derived from PBPK/PD model based on 10% inhibition of the RBC AChE activity after an acute (single day, 24 hr) or steady-state (21-day) exposure to CPF in humans (US EPA, 2014a). PoD from parent compound CPF was used for all exposure routes except for drinking water where the PoD from CPF-oxon was used.

[b] This assessment used SS oral (non-dietary), dermal, and inhalation PoDs to estimate the risk from spray drift and aggregate exposures.

[c] Acute PoDs for CPF-oxon in ppb (µg/L) were converted into internal doses (mg/kg/d) using default drinking water consumption and body weight values .

[d] Steady-state dermal PoDs for CPF were developed assuming exposure duration of 1.5 hours per day for 21 days (US EPA, 2014a).

[e] Steady-state inhalation PoDs were developed assuming exposure duration of 1 hour per day for 21 days (US EPA, 2014a).

EXPOSURE ASSESSMENT

Spray Drift Residue Exposure Estimates

Exposure associated with spray drift near an application site was evaluated for two of the sentinel population subgroups: children 1-2 years old and females of childbearing age (13-49 years old). In this exposure assessment, females 13-49 years old are a primary focus because of their potential increase in susceptibility to the toxicological effects of CPF during pregnancy. For children 1-2 years old, the US EPA Residential SOP (Addenda 1: Consideration of Spray Drift), indicates that children at this lifestage exhibit the highest exposure potential to pesticide contaminated lawn from spray drift due to dermal contact and different mouthing activities such as hand-to-mouth, object-to-mouth, and incidental soil ingestion. The SOP assumed that the duration of exposure for females 13-49 years old and children 1-2 years old near the application sites would be 1.5 hours.

Aerial Applications

Single application horizontal deposition exposure (in µg/kg/day) and inhalation exposure estimates (as 1 hour time-weighted average air concentrations in mg/m^3) of CPF were considered for two subpopulations: females 13-49 years old and children 1-2 years old and three application rates for two types of aircraft: fixed-wing (AT802A airplane) and rotary (Bell 205 helicopters). Increases in CPF application rate resulted in a corresponding increase in the horizontal deposition exposure estimates (regardless of exposure route) at different distances downwind from the edge of the treated field. Akin to the deposition estimates, the inhalation exposure estimates increase with the application rates.

For the aerial application, some CPF-containing products specify a minimum spray volume of not less than 2 gallons per acre. However, there appears to be no maximum spray volume specified. To evaluate the effect of spray volume on the horizontal deposition and inhalation exposure estimates, an additional AGricultural DISPersion (AGDISP) simulation was performed. As distance from the application edge increases, for a given application rate, both the horizontal deposition exposure estimates and the estimated 1 hour time-weighted average air concentrations increase with the spray volume.

Ground-Based Applications

Horizontal deposition exposure estimates (in µg/kg/day) of CPF were evaluated for the same two population subgroups at four application rates, up to the labeled maximum rate, with two ground-based application methods: ground boom and airblast. For ground boom, horizontal deposition estimates were derived using two swath percentiles: 50^{th} and 90^{th}. Horizontal deposition exposure estimates of CPF for children 1-2 years old after ground boom or airblast application showed that exposure increases with application rates of CPF. The higher horizontal deposition exposure estimates of the high-boom compared with the low-boom is consistent with the difference in the spray release height above the target between high- and low-boom (50 and 20 inches above the target, respectively). All other factors held constant, horizontal deposition increases as a function of boom height above the target. The higher near-field horizontal deposition exposure estimates shown by orchard airblast compared to ground boom are consistent with the much finer droplet spectrum of the airblast sprayer application method and the upward direction by the airblast sprayer of fine spray into the orchard canopy.

Dietary Exposure Assessment- Food and Drinking Water

CPF is used on a wide variety of food crops in California. Based on the most recent five years of use data (2011-2015), the top agricultural uses in the state were almond, alfalfa, walnut, orange, and cotton.

In 2014, US EPA conducted highly refined probabilistic acute and steady-state (21-day) dietary (food-only) exposure assessments of CPF. They evaluated the exposure to CPF from drinking water by estimating concentrations of CPF-oxon in surface and ground water (Estimated Drinking Water Concentrations, EDWC) and comparing the values to target concentrations expressed as DWLOC (Drinking Water Level of Comparison).

No new uses for CPF have been introduced since December 2014. Therefore, it was not necessary to conduct an independent dietary exposure assessment. Instead, HHA utilized the 2014 US EPA food-only exposure estimates to evaluate the risk from CPF exposure from food. HHA conducted an independent drinking water exposure assessment employing residue data from surface water in California and PDP monitoring data for drinking water in California.

Dietary (food-only) Exposure Assessment

Acute and subchronic (21-day steady-state) food-only exposures were calculated for four sentinel subpopulations identified in the US EPA risk assessment: infants (< 1 year old), children 1-2 years old, children 6-12 years old, and females of childbearing age (13-49 years

old). Children 1-2 years old were identified as the highest exposed population subgroup. At the 99.9th percentile, acute exposure was estimated to be 0.000423 mg/kg/d and steady-state exposure was estimated at 0.000242 mg/kg/d.

Drinking Water Exposure Assessment

CPF is rapidly oxidized to the oxon during the chlorination process. In this assessment, HHA assumed that 100% of CPF is converted to CPF-oxon during water treatment. HHA estimated drinking water probabilistic exposures using 1) Pesticide Data Program (PDP) drinking water residue data for CPF or 2) CPF residue data from the DPR Environmental Monitoring Branch (EMON) surface and ground water databases, and 3) drinking water consumption records in the Dietary Exposure Evaluation Model-Food Commodity Ingredient Database (DEEM-FCID™, version 2.036) for acute exposure. The analyses showed that exposures from residues in surface water in California could be as much as 4-fold higher than exposures based on the PDP CA-specific drinking water monitoring data.

Analysis of Drinking Water Exposure Using PDP Residue Data

PDP data from 2001 to 2013 were used in this analysis. A total of 706 post-treatment samples from municipal water treatment plants were analyzed for CPF-oxon. No residues were detected. Exposure to CPF-oxon in drinking water was estimated by assuming that each sample contained CPF-oxon at concentrations equivalent to the analytical limit of detection (LOD) for CPF. The 99.9th percentile exposure for all infants, the most highly exposed subpopulation, was 0.000108 mg/kg.

Analysis of Drinking Water Exposure Using DPR Surface and Ground Water Residue Data

Pesticide residues in water are monitored by the DPR surface and ground water programs. These programs are biased toward capturing higher concentrations that coincide with agricultural runoff, storm events, and pesticide use and applications. The DPR monitoring programs detected high residue levels in samples collected from various water sources including irrigation ponds, sloughs, and agricultural drains. DPR residue databases also contain analytical results reported by other California state and local agencies.

Between 2005 and 2014, a total of 7154 surface water samples were analyzed for CPF. The range of detected residues was 0.000572 to 3.7 ppb. For ground water, 2055 samples were analyzed from 2004 to 2013. Only two samples had detectible residues (0.006 and 0.008 ppb). Acute exposure to CPF-oxon in drinking water was estimated by conducting a probabilistic analysis of either the detected CPF residue in surface water or the detection limit (in the case of non-detects) together with all reported individual water consumption records for each subpopulation. The 99th percentile exposures for the most highly exposed subpopulation, all infants <1 years old, were 0.000419 mg/kg (surface water) and 0.000222 mg/kg (ground water).

RISK CHARACTERIZATION

The critical NOELs (PoDs) for characterizing the risk from exposure to CPF were PBPK-PD-estimated human equivalent doses. Risks were calculated as margin of exposure (MOE), a ratio of the NOEL to the human exposure level. A target MOE of 100 is generally considered protective against the CPF toxicity. This target takes into account uncertainty factors of 1 for interspecies sensitivity, 10 for intraspecies variability, and 10 for potential neurodevelopmental effects. When exposure occurs by more than one route, route-specific NOELs are used and combined MOE for all routes can be calculated.

Bystander Spray Drift MOEs

Spray drift exposure is of short-term duration (1 – 1.5 hours). Typically, acute PoDs would be used to estimate the risk associated with the short-term exposure. However, using acute PoDs may underestimate risks to individuals residing in areas of high CPF use because these values do not account for the reduced RBC AChE activities in such populations as a result of constant exposure that certainly occurs in high-CPF use areas. Indeed, data on RBC AChE levels in children residing in such areas show that their enzyme activities are decreased by about 30% compared to children who live in non- or low-use agricultural areas. Therefore, when evaluating the risk from a short term exposure in the presence of concurrent background exposures for populations in areas of high CPF use, we considered three critical factors: 1) AChE inhibition is cumulative in nature; 2) Studies in humans show that while CPF inhibits RBC AChE activity after a single dose, full recovery of enzyme activity is not attained even after 10 days; and, 3) AChE inhibition in repeated dosing studies in animals reaches steady state levels after ~2-3 weeks of exposure. In light of the reduced levels of AChE activity due to background exposure in high-use areas and the slow recovery of enzyme activity after CPF exposure, HHA concluded that the effect produced from short term drift exposures would be best characterized by the PoD derived from repeated (21-day) dosing.

MOEs for spray drift were estimated for females 13-49 years old and children 1-2 years old that were exposed at 10-1000 feet from CPF treated fields. Different exposure routes associated with spray drift were evaluated: 1) dermal exposure through skin contact; 2) inhalation exposure; and, 3) oral non-dietary exposure due to mouthing activities of young children such as hand-to-mouth, object-to-mouth, and incidental soil ingestion. The combined exposures included different portals of entry (dermal, oral, and inhalation) and exposure durations (1-1.5 hours near the application field and 1 day of food and drinking water consumption). Consequently, route-specific MOEs were used to characterize the risks associated with each route.

Females 13-49 years: The MOEs for dermal exposure near the application site were greater than the target of 100 for all evaluated scenarios: aerial application with the fixed-winged and rotor-wing aircrafts at the application rates of 1, 2, or 2.3 lb a.i./acre; and ground boom and airblast at the application rates of 1, 2, 4, or 6 lb a.i./acre. However, the MOEs for inhalation exposure near the application site were less than the target of 100 for some application scenarios: aerial application with the fixed-winged and rotor-wing aircrafts up to 10 ft for application rates of 2 or 2.3 lb a.i./acre; ground boom or airblast up to 50 ft for application rates at 4 or 6 lb a.i./acre.

Children 1-2 years: All MOEs for dermal or oral exposures (object-to-mouth and incidental soil ingestion) were greater than the target of 100 for both aerial and ground-based applications. The oral MOEs from hand-to-mouth exposure were greater than 100 at all distances using aerial or airblast equipment at an application rate of 1 lb a.i./acre. However, the oral MOEs from hand-to-mouth exposure were lower than 100 up to 50 feet from the aerial application starting at 2 lb a.i./acre and up to 25 feet of the airblast application at 6 lb a.i./acre. The inhalation MOEs were lower than the target of 100 for children up to 50 feet at 1 lb a.i./acre, 100 feet at 2 lb a.i./acre, and 250 feet at 2.3 lb a.i./acre from the edge of a treated field after applying CPF with aerial equipment. For ground boom and airblast the inhalation MOEs were less than the target of 100 for children up to 75 ft for 1 lb a.i./acre, 200 ft for 2 lb a.i./acre and 250 ft for 4 and 6 lb a.i./acre.

Dietary (food only) Exposure MOEs

At the 99.9th percentile, the acute dietary MOEs from exposure to CPF residues in food ranged from 1374 to 3127 for the four at risk subpopulations. At the 99.9th percentile, the steady state MOEs for these subpopulations ranged from 409 to 1040. All acute and steady state MOEs were greater than the target of 100.

Drinking Water Exposure MOEs

The acute MOEs for exposure to CPF-oxon in drinking water for the four at-risk subpopulations were based on drinking water residues from PDP or from the DPR surface and ground water programs. At the 99.9th percentile, the MOEs were highest for PDP (1571-3970) and lowest for the DPR surface water (405-1299). All MOEs for acute water-only exposure were greater than the target of 100.

Aggregate Exposure MOEs

For aggregate exposures, it was assumed that a child 1-2 years old would be exposed at 10-1000 feet from the CPF application site potentially through inhalation, skin contact with residues (spray drift deposition), ingestion of residues by object-to-mouth, hand-to-mouth, and incidental soil ingestion (oral exposure), and consumption of food and drinking water. An aggregate MOE approach was used because of different exposure routes and durations.

The PoD values used for the risk characterization of aggregate exposures to children 1-2 years old are shown in Summary Table 1. For the combined deposition, the risk was calculated using the steady state (21-day) dermal, inhalation, and oral PoDs for CPF and the short-term (1-1.5 hours) dermal, inhalation, and non-dietary oral exposures. The acute dietary risk from food-only or drinking water probabilistic 99.9th percentile exposures was calculated using the acute oral PoD for CPF and the acute oral PoD for CPF-oxon, respectively. Drinking water exposures were based on residues from PDP or the DPR surface water monitoring program.

The acute aggregate MOEs were estimated for all routes, including combined deposition:

$$\text{Aggregate MOE} = \frac{1}{\frac{1}{MOE_{CD}} + \frac{1}{MOE_{I}} + \frac{1}{MOE_{D}} + \frac{1}{MOE_{DW\ (PDP\ or\ EMON)}}}.$$

Abbreviations: CD [dermal + oral (object-to-mouth + hand-to-mouth + soil deposition)], inhalation (I), and oral from dietary sources (D: food only) and drinking water (DW).

The aggregate MOEs for a number of combined scenarios were below the target of 100 (Summary Table 2). The inhalation exposures made a substantial contribution to the aggregate exposure. Consequently, the combined MOEs were significantly reduced when inhalation exposures were added to the dermal, non-dietary oral, and dietary exposures. Therefore, inhalation exposure to CPF near the application site was the critical driver of the aggregate MOEs below the target value of 100 for children 1-2 years old (Summary Table 2).

RISK APPRAISAL

The main uncertainties associated with CPF toxicity and the use of 10% RBC AChE inhibition as toxicological PoDs were:

(i) Selection of 10% RBC AChE inhibition as the critical toxicity endpoint was intended to protect human populations from impacts on other endpoints that were not easily measured. However, collective results from epidemiology and animal toxicology studies indicate that CPF may be associated with neurodevelopmental and neurobehavioral effects at concentrations below those that cause AChE inhibition.

The main uncertainties in the exposure assessment were:

(i) Default physiological parameters and standard modeling and exposure computational methodologies were used to estimate bystanders' exposures (i.e., children 1-2 years old and adults only).

(ii) Illegal residues measured in fresh produce in California were not included in the dietary exposure assessment. PDP frequently detected CPF residues on crops that lack tolerances. In California, the DPR's Pesticide Residue Monitoring Program (CPRMP) monitors fresh produce collected throughout the channels of trade, including wholesale and retail outlets, distribution centers, and farmers markets (http://www.cdpr.ca.gov/docs/enforce/residue/rsmonmnu.htm). From 2015 to 2017, CPRMP detected CPF in 2547 samples of fresh produce, of which 269 (11%) were illegal. A high proportion of illegal detections were on litchi, orange, oriental pear, cactus and tangelo. Most of these foods were imported. Certain population ethnic subgroups (e.g., Hispanic and Asian) in California have higher consumption of these foods. HHA evaluations of these cases concluded that 23 were of potential health risk to consumers. HHA does not evaluate illegal residues on agricultural commodities in its dietary exposure assessments. Such residues come under the purview of DPR's Enforcement Branch, which has the authority to remove affected produce from channels of trade.

(iii) HHA estimated the exposure to CPF in drinking water using residue data from PDP or DPR surface and ground water monitoring programs. The analyses showed that exposures from residues in surface water in California could be up to 4-fold higher than exposures based on the PDP California-specific drinking water monitoring data, although those surface water sources are not necessarily drinking water sources. The use of PDP data may

lead to an underestimation of the drinking water exposure because PDP is not designed to detect peak concentrations of CPF-oxon in drinking water and the estimated exposures were based entirely on LODs. In contrast, drinking water exposure based on residues from the DPR surface and ground water programs would likely represent the "high-end" of the potential exposure, because these programs are biased toward capturing higher concentrations coinciding with runoff timing, storm events, and timing of pesticide use and applications. In addition, DPR monitoring programs detected high residue levels in samples collected from various water sources, including irrigation ponds, sloughs, and agricultural drains that may not be used for drinking water. Therefore, the drinking water exposure estimates in this risk assessment are considered highly conservative.

The main uncertainties in the risk characterization were:

(i) A default assumption of 10-fold was used due to database uncertainties in the PBPK-PD model. Predictions for variation in human sensitivity could not be used to reduce the default 10x intraspecies uncertainty factor because the model could not fully account for physiological, anatomical, and biochemical changes during pregnancy. Consequently, a default uncertainty factor of 10 instead of the pregnancy version of the PBPK/PD model was used to account for the sensitivity within the human population with respect to RBC AChE inhibition.

(ii) A default uncertainty factor of 10 was used to account for potentially more sensitive neurodevelopmental effects than AChE inhibition, the critical endpoint used to characterize the risk from CPF exposure. Effects on cognition, motor control and social behavior have been consistently reported in the CPF epidemiology and animal toxicology studies. However, these studies were not sufficient to derive critical points of departure for neurodevelopmental effects due to uncertainties associated with dose-response characteristics and exposure duration. Moreover, most animal studies were conducted with doses that also produced AChE inhibition at some time during the exposure. The document includes evidence for CPF-induced behavioral effects in young rats that may occur at doses up to 10-fold lower than the threshold established for RBC AChE inhibition, though as noted, precise quantification was not possible.

(iii) For spray drift, the risk from short-term (1-1.5 hour) dermal, inhalation, and non-dietary oral exposures was calculated using the steady-state (21-day) dermal, inhalation, and oral PoDs for CPF. Assuming the cumulative inhibitory effect of CPF on RBC AChE and the concurrent background exposure, acute PoDs may not be sufficient for characterizing the AChE inhibition from spray drift.

(iv) Drinking water exposure for children 1-2 years old was used for an aggregate MOE calculations even though infants <1 year old received the highest exposure to CPF-oxon in drinking water. This was done because the 99th percentile drinking water exposure for children 1-2 years old matches the population subgroup evaluated for exposure to food and spray drift. Had the drinking water exposure estimates for infants <1 year old been used, the drinking water MOEs would be 2-fold lower.

CONCLUSIONS

The health risk assessment of CPF was conducted for 4 sentinel subpopulations: infants (<1 year old), children 1-2 years old, children 6-12 years old, and females of childbearing age (13-49 years old).

Single-route exposure scenarios were evaluated for children 1-2 years old and females of childbearing age under short-term conditions associated with spray drift near the application site: dermal exposure through skin contact, inhalation exposure, and oral non-dietary exposure due to mouthing activities of young children (hand-to-mouth, object-to-mouth, and incidental soil ingestion). Dietary exposures from food for acute (1 day) or steady state (21-days) durations and acute (1 day) drinking water exposures were also calculated. Aggregate exposures involving multiple routes were calculated for females of childbearing age and children 1-2 years old at 10-1000 feet from the CPF application site. These routes included inhalation, skin contact with residues (horizontal deposition and aerosols associated with spray drift), ingestion of residues by object-to-mouth, hand-to-mouth and incidental soil ingestion (oral non-dietary exposure), and consumption of food and drinking water (oral, dietary exposure).

The critical NOELs or toxicological points of departure (PoDs) for CPF were PBPK-PD estimated human equivalent doses based on 10% RBC AChE inhibition. A MOE of 100 was considered protective against the CPF toxicity in humans. The target of 100 includes uncertainty factors of 1 for inter-species sensitivity, 10 for intra-species variability, and 10 for potential neurodevelopmental effects.

Spray Drift Exposure:

Females 13-49 years old: The MOEs for dermal and inhalation exposure near the application site were less than the target of 100 for some application scenarios: aerial application with the fixed-winged and rotor-wing aircrafts up to 10 ft for application rates of 2 or 2.3 lb a.i./acre; ground boom or airblast up to 50 ft for application rates at 4 or 6 lb a.i./acre.

Children 1-2 years old: All MOEs for dermal and oral exposures (object-to-mouth and incidental soil ingestion) were greater than the target of 100 for both air and ground-based applications. The oral MOEs from hand-to-mouth exposure were greater than 100 at all distances using aerial or airblast equipment at an application rate of 1 lb a.i./acre. However, the oral MOEs from hand-to-mouth exposure were lower than 100 up to 50 feet from the aerial application starting at 2 lb a.i./acre and up to 25 feet of the airblast application at 6 lb a.i./acre. The inhalation MOEs were lower than the target of 100 for children up to 50 feet at 1 lb a.i./acre, 100 feet at 2 lb a.i./acre, and 250 feet at 2.3 lb a.i./acre from the edge of a treated field after applying CPF with aerial equipment. For ground boom and airblast, the inhalation MOEs were less than the target of 100 for children up to 75 ft for 1 lb a.i./acre, 200 ft for 2 lb a.i./acre and 250 ft for 4 and 6 lb a.i./acre.

Dietary Exposure:

Food-only exposure: At the 99.9th percentile, the acute dietary MOEs from exposure to CPF residues in food ranged from 1374 to 3127 for the four evaluated sentinel population subgroups.

At the 99.9th percentile, the subchronic (21-day, steady state) MOEs for these subpopulations ranged from 409 to 1040. All acute and steady state MOEs were greater than the target of 100.

Drinking water exposure: The acute MOEs for exposure to CPF-oxon in drinking water for the four sentinel populations were based on drinking water residues from PDP or from the DPR's surface and ground water monitoring programs. At the 99.9th percentile, the MOEs were highest for PDP (1571 – 3970) and lowest for the DPR surface water (405 – 1299). All MOEs for acute water-only exposure were greater than the target of 100.

Aggregate Exposure: Dietary (food only), drinking water (PDP or DPR surface water) and spray drift

Children 1-2 year old: The acute aggregate MOEs were estimated for all routes, including combined deposition. For the combined deposition, the risk was calculated using the steady state (21-day) dermal, inhalation, and oral PoDs for CPF and the short-term (1.5 h) dermal, inhalation, and non-dietary oral exposures (Summary Table 1). The acute dietary risk at 99th percentile exposures was calculated using the acute oral PoD for CPF (food only) and the acute oral PoD for CPF-oxon (drinking water only), respectively. The drinking water exposures were based on residues from PDP or the DPR surface water monitoring program.

$$\text{Aggregate MOE} = \frac{1}{\frac{1}{MOE_{CD}} + \frac{1}{MOE_{I}} + \frac{1}{MOE_{D}} + \frac{1}{MOE_{DW\ (PDP\ or\ EMON)}}}.$$

CD [dermal + oral (object-to-mouth + hand-to-mouth + soil deposition)], inhalation (I), and oral from dietary sources (D: food only) and drinking water (DW). CPF-oxon residues in drinking water were from PDP or from DPR's surface water monitoring database.

The aggregate MOEs for a number of combined scenarios were below the target of 100 (Summary Table 2). The air component contributed up to 95% to the aggregate exposure. Consequently, the aggregate MOEs were significantly reduced when the inhalation MOE was added to the dermal, non-dietary oral, and dietary MOEs. In conclusion, the exposure to aerosols in the air near application sites was identified as the main driver when the aggregate MOEs fell below the target value of 100 for children 1-2 years old.

Summary Table 2. Aggregate MOEs for Children (1-2 years old) at Various Distances Downwind from Fields Treated with CPF by Fixed Wing Aircraft or Helicopter

Application Scenario	Appl. Vol. (gallon/acre)	Exposure Route	Appl. Rate (lb/acre)	MOE at Various Distances Downwind from the Treated Fields						
				10 feet	25 feet	50 feet	100 feet	250 feet	500 feet	1000 feet
Aircraft or Helicopter (Children 1-2 years old)										
AT802A Fixed Wing Aircraft	2	CD[a]	1	127	149	190	282	541	907	1701
			2	63	75	95	143	285	523	1331
			2.3	55	65	83	124	249	469	1210
		CD + I[b]	1	47	53	61	78	116	166	300
			2	26	29	35	46	74	120	264
			2.3	23	27	32	42	69	113	252
		CD + I + D[c]	1	45	51	58	74	107	148	246
			2	25	29	34	44	70	110	221
			2.3	23	26	31	41	65	105	213
		CD + I + D + DW-PDP[d]	1	45	51	58	74	106	147	244
			2	25	29	34	44	70	110	220

			2.3	23	26	31	41	65	104	211
		CD + I + D + DW-EMON[d]	1	43	48	55	68	95	127	193
			2	25	28	32	42	65	98	178
			2.3	22	25	30	39	61	94	172
Bell 205 Helicopter	2	CD	1	100	158	258	424	664	1118	2289
			2	50	78	126	203	367	716	1633
			2.3	43	68	110	176	325	645	1500
		CD + I	1	37	49	65	86	126	192	347
			2	20	27	37	51	85	145	287
			2.3	18	25	34	48	80	140	280
		CD + I + D	1	36	47	62	81	115	169	277
			2	19	26	36	49	80	131	238
			2.3	18	24	33	46	76	127	233
		CD + I + D + DW-PDP	1	36	47	62	81	115	168	274
			2	19	26	36	49	80	131	236
			2.3	18	24	33	46	76	126	231
		CD + I + D + DW-EMON	1	34	45	58	74	102	142	212
			2	19	26	34	47	73	115	188
			2.3	17	24	32	44	70	111	185
AT802A Fixed Wing Aircraft	15	CD	1	147	174	217	325	633	1021	1368
			2	70	83	103	152	288	452	622
			2.3	61	72	89	131	248	390	538
		CD + I	1	39	43	47	56	73	89	115
			2	22	24	27	32	43	55	75
			2.3	19	21	24	29	39	50	69
		CD + I + D	1	38	42	46	54	69	84	106
			2	21	24	26	32	42	53	71
			2.3	19	21	23	28	38	48	66
		CD + I + D + DW-PDP	1	38	42	46	54	69	83	105
			2	21	24	26	31	42	52	71
			2.3	19	21	23	28	38	48	66
		CD + I + D + DW-EMON	1	37	40	44	51	64	77	95
			2	21	23	25	30	40	50	66
			2.3	19	21	23	28	36	46	61
Bell 205 Helicopter	15	CD	1	107	175	301	519	747	996	1521
			2	52	84	141	238	340	478	790
			2.3	45	72	121	204	294	419	692
		CD + I	1	26	33	40	48	59	76	109
			2	17	21	27	33	42	56	84
			2.3	15	19	24	30	39	52	78
		CD + I + D	1	26	32	39	46	57	72	101
			2	16	21	26	33	41	54	79
			2.3	15	19	24	29	38	50	74
		CD + I + D + DW-PDP	1	26	32	39	46	57	72	100
			2	16	21	26	32	41	54	79
			2.3	15	19	24	29	38	50	74
		CD + I + D + DW-EMON	1	25	31	37	44	54	67	91
			2	16	21	26	31	39	51	73
			2.3	14	18	23	29	36	47	68

Source: US EPA (2014a) Dermal PoD-Steady-state = 134.25 mg/kg/d; For calculations, Dermal Absorption (0-1) = 1; Oral PoD Steady-state: 0.099 mg/kg/d. Target MOE = 100

[a] Combined Deposition (CD = Dermal + Object-to-Mouth + Hand-to-Mouth + Soil Ingestion)

[b] Combined Deposition (CD = Dermal + Object-to-Mouth + Hand-to-Mouth + Soil Ingestion; inhalation (I))

[c] Combined Deposition (CD = dermal + object-to-mouth + hand-to-mouth + soil deposition; inhalation (I); dietary (D: food only; PoD = 0.581 mg/kg/d).

[d] Combined Deposition (CD = dermal + object-to-mouth + hand-to-mouth + soil deposition; inhalation (I); dietary (D: food only; PoD = 0.581 mg/kg/d); drinking Water (CPF-oxon PoD = 0.159 mg/kg/d from DW-PDP or DW-EMON); inhalation PoD = 2.37 mg/m^3

I. INTRODUCTION

This Risk Characterization Document addresses potential human exposures from the use of chlorpyrifos (CPF) in California as an active ingredient (AI) in insecticide formulations for nut trees, fruit, vegetable, and grain crops, as well as for non-food crop uses (e.g., golf course turf, industrial sites, greenhouse and nursery production, sod farms, and wood products) for which there are tolerances. CPF was given a "High" priority status by DPR due to concerns regarding 1) potential neurodevelopmental/ neurobehavioral effects from exposures during vulnerable developmental windows in fetuses, infants, and children, 2) genotoxicity and reproductive toxicity in rats, 3) probable human exposure due to spray drift, 4) possible infant exposure from hand-to-mouth activities, and 5) exposure through food and drinking water in California. Based on its "High" priority status, in 2011 CPF entered the DPR's process of comprehensive human health risk assessment (http://www.cdpr.ca.gov/docs/risk/raprocess.pdf and http://www.cdpr.ca.gov/docs/dept/prec/2011/prec_letter_report_52_20110916.pdf).

An assessment of the relevance of the Physiologically-Based Pharmacokinetic-Pharmacodynamic (PBPK-PD) model utilized by US EPA (2014a) for California-specific exposure scenarios was performed. These data were compiled and evaluated in order to characterize risk from CPF in California.

I.A. Scope

This risk assessment focuses only on effects reported after exposure to CPF. The critical endpoint used throughout the risk characterization is acetylcholinesterase inhibition.

I.B. Regulatory Status

I.B.1. United States Environmental Protection Agency

Regulatory History for Chlorpyrifos:

1965: CPF was registered for residential use in 1965 as a crack and crevice treatment for ants, cockroaches and termites.

1997: The CPF technical registrants agreed to eliminate and phase out residential use due to US EPA concerns for effects to children and other sensitive subpopulations.

2000: All indoor residential CPF use as well as use for termite control in schools, hospitals and nursing homes was discontinued.

2004: CPF for termite control in new construction was discontinued.

2006: The US EPA CPF Reregistration Eligibility Decision (RED) was completed. Critical endpoints were established based on 10% RBC and plasma ChEI in adult rats.

2007-2008: Dow AgroSciences wrote commentaries rebutting fetal growth and developmental findings.

2007: National Resources Defense Council (NRDC) petitioned US EPA to ban CPF for all uses and also prepared a lawsuit.

2008: DOW AgroSciences petitioned US EPA to register CPF for additional agricultural uses.

2008: US EPA prepared a report for the FIFRA Scientific Advisory Panel (SAP) presenting the epidemiological evidence but left the then current safety standards intact. New science on infants, children, and pregnant women from experimental laboratory toxicology and epidemiology studies were examined.

2008: FIFRA SAP meeting to evaluate the Toxicology Profile for CPF.

2009-10: US EPA continued to gather epidemiological evidence data.

2010: Columbia researchers invited US EPA to a presentation of their 7 year findings from their CCCEH cohort (1998-2004).

2011: Preliminary human health risk assessment for registration review. In this document, US EPA stated that chlorpyrifos is not likely to be carcinogenic to humans based on the lack of evidence of carcinogenicity in studies in rats and mice and the absence of a mutagenicity concern. (US EPA, 2011a)

2011: Chlorpyrifos Physiologically Based Pharmacokinetic and Pharmacodynamic (PBPK/PD) Modeling Linked to Cumulative and Aggregate Risk Evaluation System (CARES)

2011: US EPA does not further restrict CPF uses; US EPA Preliminary Human Health Risk Assessment released (US EPA, 2011a) The critical endpoints were BMDLs for 10% RBC AChEI in pups (PND 11 pups) or pregnant dams.

2012: Federal Peer Review on reports of the MRI and neurobehavioral testing in children to further clarify results obtained by examination of the epidemiological cohorts.

2012: FIFRA SAP Additional analysis on science on infants, children, and pregnant women from experimental laboratory toxicology and epidemiology studies.

2012: US EPA released a mitigation decision for CPF based on potential excess risks from spray-drift to bystanders.

2014: US EPA Revised Human Health Risk Assessment for registration review released (US EPA, 2014a). The critical endpoints are PBPK-PD-estimated human equivalent doses based on 10% RBC AChEI These human PoDs are similar to the PoD values based animal data in the 2006 and 2011 US EPA risk assessments. There is much objection from academic institutions, the public, and other groups for the continued use of AChEI as the basis for regulatory standards.

2015: DPR released draft risk characterization document for CPF for external scientific review.

2016: US EPA utilized the PBPK portion of the PBPK-PD model from the 2014 US EPA Revised Human Health Risk Assessment to predict CPF blood levels in women based on the expected exposure from crack and crevice during the period of the Columbia CCEH study. These predicted blood levels were compared with measured blood levels of CCCEH that resulted in ~2% lower Working Memory Index. . This is the first time that US EPA proposed CPF PoDs that were not for RBC AChE inhibition, but rather for predicting risk of neurodevelopmental outcomes. These PoDs were drastically lower (approximately 1000-6400-fold) than the PoD in the US EPA 2014 Revised Human Health Risk Assessment. The results were presented at the SAP April 2016 meeting (US EPA, 2016a; US EPA/SAP, 2016). The SAP supported US EPA on the use of the PBPK model as a tool for assessing internal dosimetry following exposure to CPF, but did not support the approach of using the Columbia CCCEH cohort cord blood data for deriving PoDs.

2016: US EPA followed the SAP recommendation to estimate the time-weighted average (TWA) concentrations of CPF in fetal blood based on presumptive CPF residential use on crack and crevice/hard surface at the time of the CCCEH study (1998-2004). Using forward dosimetry, the concentration of CPF in human blood was calculated from the PBPK model (Figure 1) assuming a total exposure of 2 hours per day for 30 days and a 10% decrease in blood levels of CPF per day. The model used the TWA blood estimates as internal dose to back calculate external doses as points of departure (PoDs) for infants, children, and adults. These PoDs for were approximately 150-9000-fold lower than the PoDs based on 10% RBC AChE inhibition in the earlier US EPA risk assessments (US EPA, 2016b).

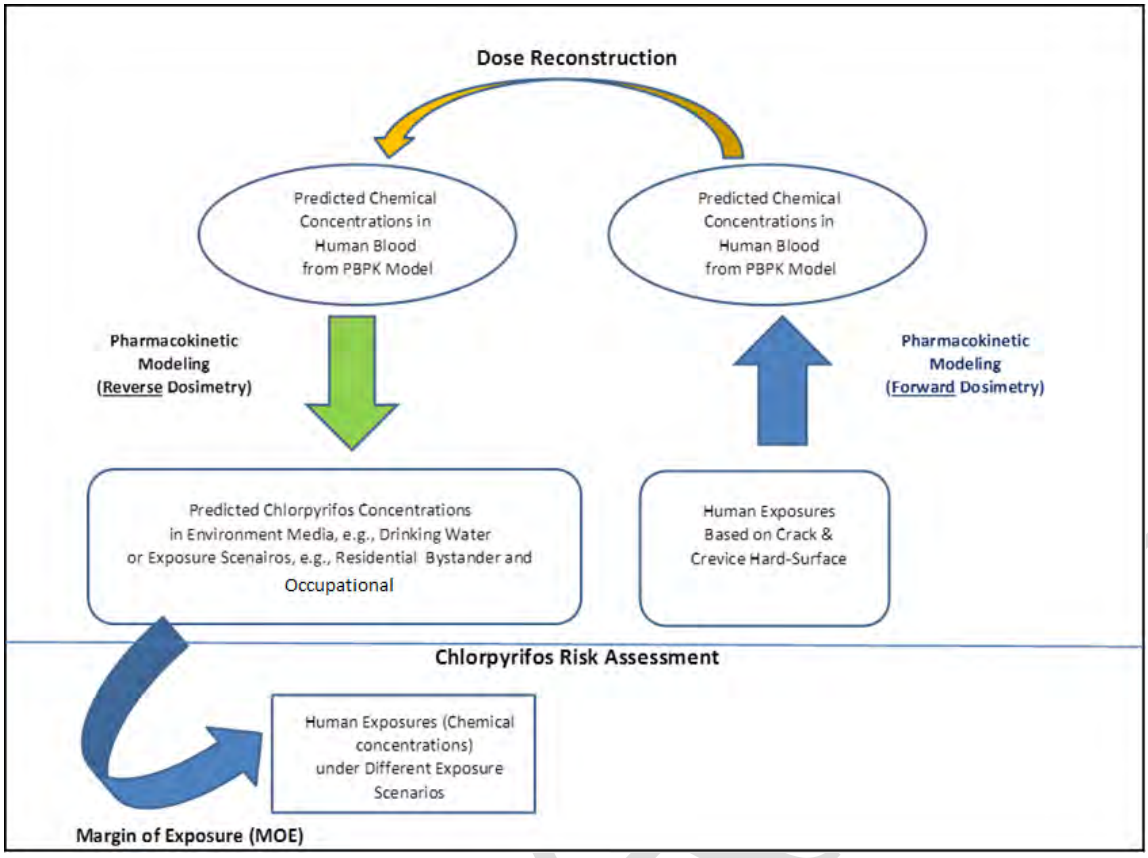


Figure 1. Depiction of the PBPK model incorporating estimation of CPF exposures

Based on Residential SOPs for crack and crevice and hard-surface exposures (www.epa.gov/sites/production/files/2015-08/documents/usepa-opp-hed_residential_sops_oct2012.pdf) from the same time-frame, predicted human blood CPF concentrations (dose reconstruction), and calculated exposures (reverse dosimetry) in the context of risk assessment (adapted and compiled utilizing the 2016 US EPA CPF PBPK model and exposure scenarios by Tan et al. (2007)

Scientific Advisory Panel

The FIFRA SAP convened several meetings to analyze the strengths and weaknesses of available data and to provide decision points on the incorporation of data for potential adverse neurodevelopmental effects in infants and children following prenatal CPF exposure. The first meeting in 2008 focused on a review of literature which reported associations of CPF exposure and adverse health outcomes in women and children (US EPA/SAP, 2008). Following this meeting, US EPA released a document detailing the aggregation of human data with other critical data and the determination of PoDs from human studies (Nolan et al., 1984; Rauh et al., 2006; US EPA/SAP, 2010; Rauh et al., 2011; Smith et al., 2011)

A proposal was made by Dow AgroSciences LLC to use a pharmacokinetic-pharmacodynamic model (PBPK-PD) developed for CPF PoD determination in risk assessment (Timchalk et al., 2002a; Timchalk et al., 2002b; Timchalk et al., 2005; Timchalk et al., 2006; Timchalk et al.,

2007; Timchalk and Poet, 2008). The SAP reviewed the model which was based on quantitative estimates of human AChE inhibition after oral, dermal, and inhalation exposure to CPF and CPF-oxon via dietary, water, occupational, and residential routes (US EPA/SAP, 2012). In its 2011 preliminary and 2014 revised CPF risk assessments, US EPA determined that AChE inhibition was the critical endpoint for CPF (US EPA, 2011a; US EPA, 2014a). This determination was based on the strength of the database as reflected by a statement by the SAP that:

> *"…AChE data provide the most appropriate endpoint and dose-response data for deriving PoDs for purposes of risk assessment. Moreover, because of the Agency's long experience with assessing the potential risk to CPF and other OPs, and because the dose response approaches based on AChE inhibition used in the 2011 preliminary assessment had been vetted by numerous SAPs, there was confidence in that approach*." (page 10)

Since 2012, the SAP has encouraged US EPA to evaluate both cholinergic (AChE) and non-cholinergic adverse endpoints, including developmental neurotoxicity and cognitive/behavioral alterations from CPF exposure (US EPA/SAP, 2012). Most notably, the revised 2014 US EPA risk assessment incorporated both a PBPK-PD model for deriving PoDs based on 10% RBC AChE inhibition, and evidence of neurodevelopmental effects in fetuses and children resulting from chlorpyrifos exposure as reported in epidemiological studies, particularly from the Columbia Center for Children's Environmental Health (CCCEH) cohort. At their April 2016 meeting, the SAP did not support using the cord blood data quantitatively for deriving PoDs. However, when considering the toxicological and epidemiological results, the panel concluded that there is evidence for adverse health outcomes associated with chlorpyrifos exposures below levels that result in 10% RBC AChE inhibition (US EPA/SAP, 2016).

California Proposition 65

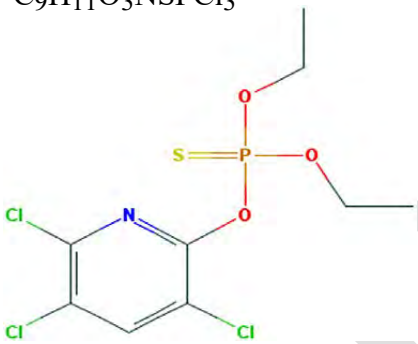
The Developmental and Reproductive Toxicant Identification Committee (DARTIC) agreed to consider whether chlorpyrifos should be listed under California Proposition 65 (the Safe Drinking Water and Toxic Enforcement Act of 1986) based on the developmental toxicity endpoint. At its meeting on November 29, 2017, the DARTIC agreed to list chlorpyrifos. Implementation is projected for 2018.

I.B.2. California Department of Pesticide Regulation (DPR)

CPF was given a "High" priority status by the California Department of Pesticide Regulation (DPR) due to concerns regarding 1) potential neurodevelopmental/ neurobehavioral effects from exposures during vulnerable developmental windows in fetuses, infants, and children, 2) genotoxicity and reproductive toxicity in rats, 3) probable human exposure due to spray drift, 4) possible infant exposure from hand-to-mouth activities, and 5) exposure through food and drinking water in California. Based on its "High" priority status, in 2011 CPF entered the DPR's process of comprehensive human health risk assessment (http://www.cdpr.ca.gov/docs/risk/raprocess.pdf and http://www.cdpr.ca.gov/docs/dept/prec/2011/prec_letter_report_52_20110916.pdf).

On July 1, 2015, CPF was designated as a restricted material when used as a pesticide product labeled for use in the production of an agricultural commodity.

I.C. Physical and Chemical Properties

Chemical Name:	O,O-diethyl O-3,5,6-trichloro-2-pyridyl phosphorothioate
CAS Number:	2921-88-2
Molecular Weight:	350.59 g/mol
Common Name:	Chlorpyrifos
Empirical Formula:	$C_9H_{11}O_3NSPCl_3$
Chemical Structure:	
Density:	1.51 ± 0.1 g cm^3 at 21 °C
Vapor Pressure:	2 x 10^{-5} mm Hg (0.003 Pa) at 25°C
Boiling Point:	> 320°C
Melting Point:	41–42°C
Flash Point:	> 200°F
Conversion Factor:	1 ppm = 14.31 ± 3 mg/m^3 at 25°C
Appearance:	Colorless to white, crystalline solid
Odor:	Mild mercaptan
Odor Threshold:	0.14 mg/m^3 (10 ppb)
Solubility in H_2O:	<2 mg/L solubility
Organic Solubility:	isooctane, methanol
Henry's Law Constant:	1 x 10^{-5} atm-m^3
Log Koc:	3.73
Kow:	4.8

I.D. Chemical Identification

CPF (Trade name- Dursban®, Lorsban®; O,O-diethyl O-3,5,6-trichloro-2-pyridyl phosphorothioate; CAS# 2921-88-2; DPR chemical code 253) is a crystalline broad-spectrum organophosphate (OP) insecticide that was first produced by Dow AgroSciences LLC in 1965. The toxic metabolite is CPF-oxon, generated by P450 activation and which inhibits acetylcholinesterase (AChE) in the nervous system (Meister and Sine, 2014; US EPA, 2014a).

I.E. Use and Product Formulations

I.E.1. Uses in California

Currently there are 48 actively registered product labels in California. Chlorpyrifos has been regulated in California as restricted use material since 2014

(http://www.cdpr.ca.gov/docs/legbills/rulepkgs/14-002/final_text.pdf and Table 1). By law, DPR requires the growers and pesticide applicators to report their pesticide use every year through their County Agricultural Commissioner. This pesticide use information can be found in the DPR Pesticide Use Reporting (PUR) database available at http://www.cdpr.ca.gov/docs/pur/purmain.htm. According to the most recent published data, total yearly use ranged from a low of 1.10 million pounds in 2012 to a high of 1.46 million pounds in 2013. The amount was applied over 0.9 – 1.3 million acres, with an average of 1 lb/acre, approximately the median application rate based on the label. There were no obvious trends in yearly use or acres treated. According to crop treatment data, the highest amount (in lbs) was compared to other crops (range: 192,482 in 2012 to 450,403 lb in 2013).

Table 1. Pesticide Use Data for CPF in California from 2011-2015

Year	Total yearly use (lb)	Total yearly treated (acre)	Top 5 crops treated	Yearly use for top 5 crops (lb)	Year	Total yearly use (lb)	Total yearly treated (acre)	Top 5 crops treated	Yearly use for top 5 crops (lb)
2011	1,296,074	1,186,979	Almond	231,067	2014	1,312,361	7,995,337	Almond	302,066
			Orange	205,595				Alfalfa	278,316
			Cotton	194,173				Walnut	187,152
			Alfalfa	185,879				Orange	162,986
			Walnut	163,097				Cotton	95,401
2012	1,100,873	1,051,292	Almond	192,482	2015	1,106,608	4,225,673	Almond	308,957
			Walnut	174,931				Orange	145,390
			Alfalfa	174,669				Walnut	133,242
			Orange	129,546				Alfalfa	123,748
			Cotton	97,769				Cotton	85,773
2013	1,465,115	9,889,464	Almond	450,403					
			Alfalfa	198,179					
			Walnut	166,340					
			Cotton	158,134					
			Orange	152,976					

I.E.2. Technical and Product Formulations

CPF is an AI in many registered products in various formulations, including emulsifiable concentrate, aqueous concentrate, flowable concentrate, ready-to-use liquid, wettable powder, pressurized liquid/fogger, paint/coatings, granular, microencapsulated, bait, and ear tag.

I.F. Human Illness and Exposure Reports

I.F.1. Reports of Human Illness

The California Pesticide Illness Surveillance Program (PISP) maintains a database of pesticide-related cases. An associated case is a record of one pesticide exposure and its apparent effects evaluated as definitely, probably, or possibly related to an exposure. A definite relationship indicates that both physical and medical evidence documents the exposure and consequent health effects. A probable relationship indicates that limited or circumstantial evidence supports a relationship to pesticide exposure. A possible relationship indicates that health effects correspond

generally to the reported exposure, but evidence is not available to support a stronger relationship. A case refers to a record of a pesticide exposure. An episode is an incident in which one or more people are exposed to the same source.

PISP receives reports of pesticide exposure from the California Pesticide Control System (CPCS), California Worker's Compensation, and from healthcare providers. PISP staff screen these reports and send the ones that meet program criteria to the County Agricultural Commissioners (CACs) for investigation. The CACs investigate the reports to determine if any violations of pesticide laws and regulations have occurred and collect information on the circumstances of exposure. The CACs send their reports to PISP for evaluation. PISP defines "agricultural" as pesticide use intended to contribute to production of an agricultural commodity including livestock. All other uses are considered "non-agricultural". PISP defines "occupational" as an individual who was on the job at the time of the incident and "non-occupational" as an individual who was not on the job at the time of the incident.

From 2004-2014, there were 246 associated cases of pesticide exposure stemming from 84 episodes involving chlorpyrifos. The number of illnesses varied throughout the 11 year period due to several multi-person episodes. Overall, the average number of chlorpyrifos episodes per year was 2.9. The average number of cases was 22.3 per year (Figure 2). The majority of illnesses were due to drift of pesticides (n=163, 66.2%), followed by residue (n=42, 17%). Ingestion accounted for 12 (5%) cases, eight of which resulted from improperly stored pesticides and/or those that were easily accessible to children (CDPR, 2017).

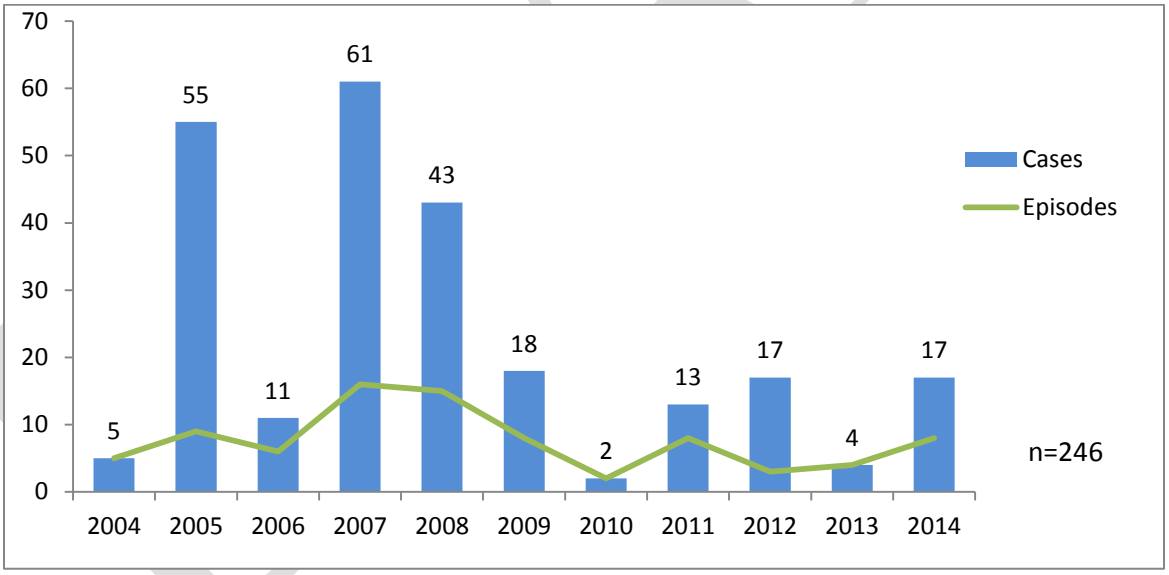


Figure 2. Cases and Episodes of Illness Due to Chlorpyrifos Exposure, 2004-2014

Bystanders accounted for 217 (88.6%) of the reported illnesses. Most bystanders were engaged in routine activities at the time of exposure (n=101, 41%), which meant they had minimal expectations of pesticide exposure. Fieldworkers followed with 82 cases (38%). Eighty-seven (35.6%) drift-related cases involved airblast sprayers, with the notable exception of 24 cases that involved chlorpyrifos used in combination with bensulfide applied by ground boom. Of the 246

cases involving chlorpyrifos in the years examined, 205 (83%) were agricultural and 40 (16%) were non-agricultural. Agricultural status could not be determined in one case. The majority of illness and injuries occurred while at work (n=171, 70%). Approximately, 60% (n=148) of the cases were both agricultural and occupational (Figure 3). Thirty-four cases involved children under the age of 18 (14%), 24 of which involved the agricultural use of chlorpyrifos (CDPR, 2017).

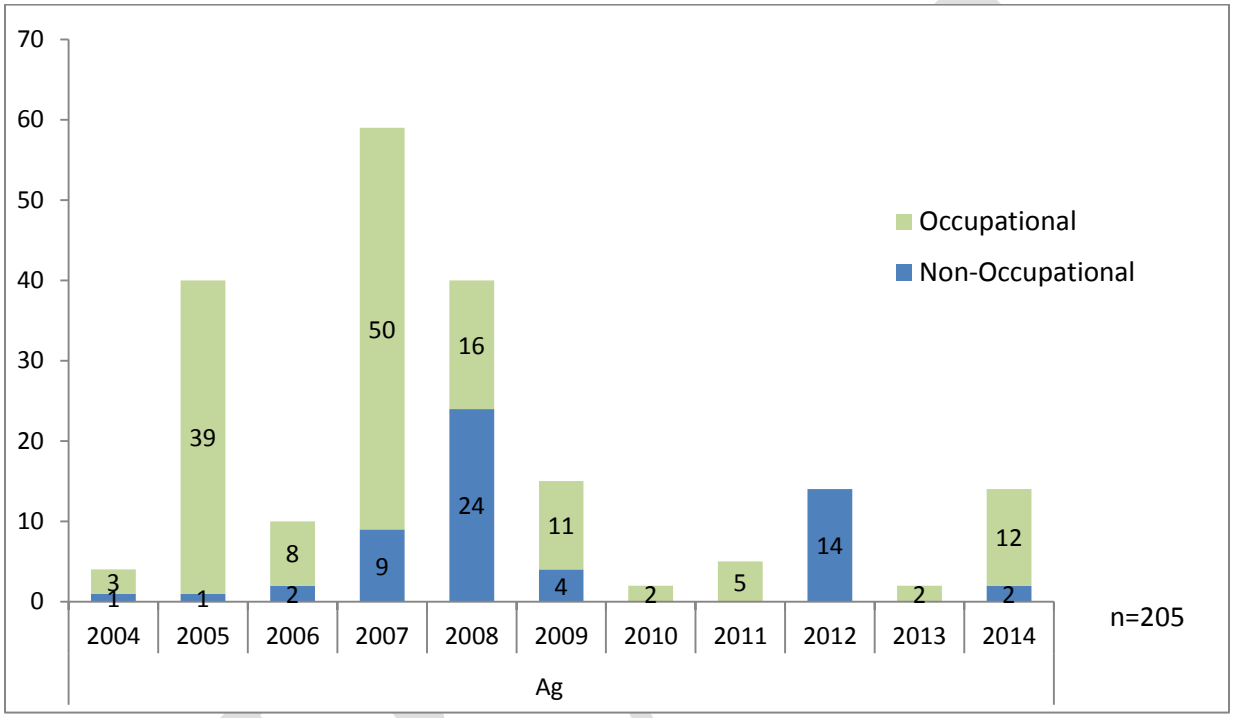


Figure 3. Chlorpyrifos Illnesses Caused by Agricultural Use, 2004-2014

Odor was also examined as a causal factor for reported symptoms. In agricultural drift episodes, the presence of an odor was the most frequently recorded contributing factor leading to illness, (n=147, 79%). Chlorpyrifos has a "skunky", rotten egg, garlic odor. Pesticides containing chlorpyrifos are often formulated with high percentages of petroleum based solvents, which can add to the odor. These solvents have a kerosene or gasoline-like smell. Unfortunately, most of the investigation reports did not provide a description of the odor in a way that would enable the distinction between the odor associated with chlorpyrifos and that of a petroleum-based solvent. The presence of an odor remains a significant concern, as it is suspected to potentially play a role in causation of symptoms experienced by people exposed to chlorpyrifos. Symptoms of exposure to these odorants include irritation to the eyes, nose and throat, dizziness, nausea, and headache. As such, it remains important to learn whether the odor from the petroleum distillates may be the source for symptoms experienced. DPR's Worker Health & Safety Branch recommends further investigation into the effect of the petroleum-based ingredients to help determine if some of these illnesses can be attributed to odor from the solvents. A summary the reported illness as well as episodes affecting five (5) or more people can be found in CDPR (2017).

I.F.2. Analysis of Human Exposure

Under the California Environmental Contaminant Biomonitoring Program (CECBP; http://biomonitoring.ca.gov), community studies are conducted in particular geographic areas or subpopulations that may be experiencing a common health outcome. Small pilot projects are designed to collaborate with laboratories and researchers on the collection and testing of urine and blood specimens from California residents. Through the program, four such biomonitoring studies were conducted to assess exposures to CPF in the environment by testing urine for 3,5,6-trichloro-2-pyridinol (TCPy), a urinary metabolite and exposure surrogate of CPF and CPM-methyl. While the results can be used to estimate the levels and probabilities of exposure in the represented populations, it is beyond the scope of these studies to associate levels of TCPy in urine with any specific health outcome. The studies are summarized below.

The Biomonitoring Exposures Study (BEST) Pilot study was jointly conducted by CECBP and the Kaiser Permanente Northern California (KPNC) Division of Research and part of a more extensive Kaiser Permanente Research Program on Genes, Environment, and Health (Das and Van Den Eeden, 2011). Urine and blood specimens were collected from 112 subjects from California's Central Valley in 2011 and 2012 for bioanalysis of analytes that included brominated flame retardants, environmental phenols, heavy metals, and pesticides, including the urinary metabolite TCPy. TCPy levels in urine that exceeded the limit of detection (LOD; 0.500 µg/L) were detected in 81% of 109 total specimens. The geometric mean of urinary TCPy was 1.23 µg/L. The BEST study was expanded to include 341 male and female adults from the Central Valley with expanded emphasis on Hispanic subjects and those from Asian/Pacific Island descent (DiBartolomeis, 2013). Urine and blood specimens were collected in 2013, although the data were not reported at the time of this publication.

The Firefighter Occupational Exposures (FOX) Project was jointly conducted by CECBP, the University of California (UC) Irvine Center for Occupational Health, and the Orange County Fire Authority (OCFA) (Das, 2010). The study was designed to quantify approximately 40 environmental chemicals in the blood and urine of Orange County, CA firefighters. A subset of chemicals was also analyzed in dust samples collected from three Orange County fire stations. Urine and blood specimens were collected from 101 subjects in 2010 and 2011. The environmental chemicals of interest included brominated fire retardants, perfluorinated chemicals, polychlorinated biphenyls, organochlorine pesticides, heavy metals, pesticide metabolites (including TCPy), and a polycyclic aromatic hydrocarbon metabolite. TCPy levels in urine that exceeded the LOD (0.500 µg/L) were detected in 89% of 101 total specimens. The geometric mean of TCPy detected was 1.78 µg/L.

The Maternal and Infant Environmental Exposure Project (MIEEP)-Chemicals in Our Bodies Project was jointly conducted by the UC San Francisco (UCSF) Program on Reproductive Health and the Environment, CECBP, and the UC Berkeley School of Public Health (Woodruff, 2009). The aims of the project were to assess exposures to environmental chemicals in 65 mother infant pairs and 27 pregnant women. English and Spanish speaking subjects were recruited at San Francisco General Hospital in 2010 and 2011. Urine specimens were collected in the third trimester of pregnancy while maternal and cord blood specimens were collected at parturition for bioanalysis. Environmental chemicals of interest included multiple compounds and metals, as well as pesticides and their metabolites (including TCPy). TCPy levels in urine specimens

exceeded the LOD (0.200 µg/L) and had a geometric mean of 0.52 µg/L with a 95% confidence interval bounded by 0.41 and 0.65 µg/L (N = 89).

Although several human epidemiological studies have also measured urinary TCPy and other general OP pesticide metabolites (Berkowitz et al., 2003; Eskenazi et al., 2004; Whyatt et al., 2009; Bouchard et al., 2011), there is no one background standard concentration that is currently used for comparison at this time and there is no reference concentration of urinary TCPy that this linked with a defined adverse health outcome.

The National Health and Nutrition Examination Survey (NHANES) is conducted by the Centers for Disease Control and Prevention (CDC) (https://www.cdc.gov/nchs/nhanes/biospecimens/serum_plasma_urine.htm). Some NHANES subset studies have analyzed for TCPy, including the NHANES-III subset of 1000 adults who were tested from 1988 – 1994. TCPy was detected in over 80% of the samples, with a median level of 2.2 µg/g creatinine (Hill et al., 1995). A subset of 80 adults were selected from the National Human Exposure Assessment Survey (NHEXAS-MD) and serially sampled in Maryland. TCPy was detected in 96% of samples with a median concentration of 4.6 µg/g creatinine (MacIntosh et al., 1999). In the Minnesota Children's Pesticide Exposure Study (MNCEPS), a Phase III special study that was part of NHEXAS, 102 children 3-13 years old were monitored for commonly used pesticides in 1997 (Adgate et al., 2001). TCPy was present in 93% of the samples and the mean urinary level was 9.2 µg/L. TCPy levels were significantly higher in urban than in nonurban children (7.2 vs. 4.7 µg/L, $p = 0.036$), although the sampling occurred before the US EPA ban on indoor application of chlorpyrifos.

Table 2. Summary of TCPy Levels Measured in Humans

Study	No. of	% Samples	Urinary TCPy	Urinary TCPy	Reference
BEST	112	81%	1.23 µg/L (GM)		Das and Van Den Eeden (2011)
FOX	101	89%	1.78 µg/L (GM)		Das (2010)
MIEEP	92	NA	0.52 µg/L (GM)		Woodruff (2009)
NHANES-III	1000	80%		2.2 µg/g	Hill et al. (1995)
NHEXAS-MD	80	96%		4.6 µg/g	MacIntosh et al. (1999)
MNCEPS	102 (children)	93%	9.2 µg/L		Adgate et al. (2001)

* GM, Geometric mean noted if available
NA = data not available

I.G. Environmental Fate

A review of the CPF environmental fate is presented in Koshlukova and Reed (2014) and is briefly summarized here. The half-life for interaction with photochemically generated hydroxyl radicals in air to produce dechlorinated products is 6.3 hours. CPF is spontaneously degraded by photolysis and hydrolysis in soil and water and can persist from 2 weeks to 1 year, depending on soil type, climate, and presence of soil microbes. Hydrolysis products including TCPy and

phosphorthioic acid may form under alkaline conditions. Hydrolysis is increased with increased temperature and alkalinity of the water source (e.g., river or water well; $T_{½}$ = 4.8 to 38 days). The Log K_{oc} (3.73) indicates that CPF adsorbs strongly in soil and resists leaching to ground water. CPF will persist for weeks or months in indoor environments (Berkowitz et al., 2003; Rauh et al., 2006; US EPA, 2014a). In the environment, CPF is oxidized to the toxic metabolite CPF-oxon by photolysis, aerobic metabolism, and chlorination (e.g., drinking water). The CPF K_{ow} (4.8) indicates a potential for bioaccumulation in aquatic (TCPy and conjugates detected in fish tissues) and terrestrial food chains. Information on chlorpyrifos environmental fate from the DPR Environmental Monitoring branch can be found here: http://www.cdpr.ca.gov/docs/emon/airinit/2560_chlorpyrifos_final.pdf and http://www.cdpr.ca.gov/docs/emon/pubs/tac/tacpdfs/chlrpfs/append_a_chlorpyrifos_use_information.pdf

II. TOXICOLOGY PROFILE

Chlorpyrifos (CPF) is a chlorinated organophosphorus (OP) ester used as an insecticide, acaricide, and miticide. The toxicity of CPF is associated with binding and inhibition of the enzyme acetylcholinesterase (AChE) in insects and mammals. CPF requires metabolic activation to CPF-oxon to yield anticholinesterase activity. CPF causes developmental neurotoxicity at exposure levels that do not induce overt toxicity or inhibit cholinesterase (ChE) activity. CPF has major uses in California as an insecticide for nut trees, fruit, vegetable, and grain crops as well as non-food crop scenarios (e.g., golf course turf, industrial sites, greenhouse and nursery production, sod farms, and wood products).

An overview of the toxicity of CPF is presented below. The studies evaluated were submitted by the registrant and/or obtained from the open literature. More detail of the registrant-submitted studies and other studies contributing to the hazard assessment can be found in the HHA Summary of Toxicology Data (Appendix 1) and in the US EPA 2011 Preliminary Human Health Risk Assessment for Reregistration and in the US EPA 2014 Revised Human Health Risk Assessment (US EPA, 2011a; US EPA, 2014a).

II.A. Acetylcholinesterase Inhibition

AChE normally breaks down the neurotransmitter acetylcholine (ACh) within the central nervous system (CNS) synaptic cleft or at neuromuscular or neuro-glandular junctions in the peripheral nervous system (PNS) (Casida and Quistad, 2004; Testai et al., 2010). The active metabolite of CPF is CPF-oxon, which inhibits AChE by binding at the active site. When AChE inhibition occurs, ACh accumulates and results in unremitting nerve impulses that lead to continuous muscle responses in the peripheral nervous system (PNS) or neural stimulation in the central nervous system (CNS).

Cholinesterase exists in plasma in the form of BuChE. However, in red blood cells cholinesterase only occurs as AChE and in the brain primarily as AChE (Eaton et al., 2008; Testai et al., 2010). In the rat brain, AChE activity is higher than BuChE activity (90% versus 10% of total)(Mortensen et al., 1998; Li et al., 2000b). The BuChE:AChE ratio varies with species, with a ratio of 1000:1 in humans, 7:1 in dogs, 2:1 in female rats, and 1:3 in male rats (Scarsella et al., 1979; Brimijoin, 1992).

In general, HHA considers brain cholinesterase inhibition to be indicative of overt toxicity not only because the brain is a primary functional target site, but also because more subtle central neurological signs such as memory and learning losses may not be easily detected or quantified. In contrast, the toxicological significance of AChE inhibition in plasma and RBCs is less certain because the physiological function of cholinesterase in blood has not been clearly established. Plasma cholinesterase, or more specifically BuChE, may be involved in the binding or metabolism of certain drugs, suggesting that BuChE inhibition may compromise an organism's ability to defend against subsequent toxic insults (Lockridge and Masson, 2000). BuChE is also the predominant form of cholinesterase in the developing nervous system of birds and mammals (Brimijoin, 1992). Other evidence suggests that BuChE may also play a role in the co-regulation of ACh levels in the adult nervous system (Li et al., 2000a). Gene-targeted mice deficient in AChE ($AChE^{-/-}$) showed that BuChE and likely other enzymes may have assumed the function of AChE during early development(Li et al., 2000a; Xie et al., 2000). The $AChE^{-/-}$ mice showed no physical defects at birth. Their organs and blood cells showed no morphological abnormalities. Electron microscopic examination of the neuromuscular junctions showed normal morphology. Interestingly, BuChE levels in the tissues were similar to those in the wild-type and AChE heterozygous mice. In addition, in the absence of AChE, BuChE was apparently essential for vital functions. When $AChE^{-/-}$ mice were treated with bambuterol, a specific BuChE inhibitor, they died immediately after treatment, while wild-type mice treated with the same dose were not affected. Despite the low levels of BuChE in the brain, BuChE in the brain of $AChE^{-/-}$ mice may help maintain a minimal level of cholinergic function by hydrolyzing extrasynaptic acetylcholine.

Although blood cholinesterase inhibition is generally not considered detrimental, it may be a useful surrogate for brain and/or peripheral AChE inhibition (US EPA, 2000a). This is because blood cholinesterase inhibition occurs well before brain AChE inhibition. Therefore, protecting inhibition in blood may potentially protect the downstream effects in the brain and peripheral nervous system (Nolan et al., 1984). RBC AChE inhibition data are generally preferred over BuChE inhibition data because RBCs contain only AChE whereas plasma can contain both BuChE and AChE (Testai et al., 2010). This is important in determination of no-observed-effect-levels (NOELs) or PoDs because CPF may have considerably different affinity for the active site of BuChE versus AChE (US EPA, 2000a).

The Joint Meeting on Pesticide Residues of the World Health Organization (WHO) concluded that RBC AChE inhibition should only be used as a surrogate for peripheral cholinesterase inhibition at the time of peak effect with acute exposure since RBCs lack the ability to synthesize new AChE (Brimijoin, 1992; WHO/JMPR, 1999). Consequently, the recovery of RBC AChE activity is much slower than in neurological and neuromuscular tissue because it is dependent on the replacement of RBCs. HHA is currently reevaluating the use of cholinesterase inhibition data in its risk assessments. In anticipation of changes in the use of these endpoints, NOELs for blood and brain inhibition were identified in this document based on statistical significance.

II.B. Metabolism and Pharmacokinetics

Numerous articles have described the metabolism of CPF in animals and humans (Timchalk et al., 2002a; Timchalk et al., 2002b; Timchalk et al., 2005; Timchalk et al., 2006; Eaton et al.,

2008; Timchalk and Poet, 2008; Testai et al., 2010). P450s oxidize CPF to form an unstable phosphooxythiiran intermediate that undergoes oxidative desulfuration to form CPF-oxon. Additionally, dearylation (oxidative ester cleavage) of the intermediate results in the formation of TCPy and diethylthiophosphate (DETP) (Figure 4). The active metabolite CPF-oxon can inhibit AChE or form TCPy, the latter of which is considered the detoxification pathway. The balance of CPF activation to detoxification is dependent on species, gender, age, P450 enzyme profiles, and P450 enzyme polymorphisms (Ma and Chambers, 1994).
CPF-oxon is formed in humans when CPF is metabolized by three main forms of P450:

Activation of CPF→ CPF-oxon by CYP2B6 (desulfuration)
Activation of CPF→ CPF-oxon by CYP3A4/5
Detoxification of CPF → TCPy by CYP2C19 (dearylation) and CYP3A4/5

CPF-oxon is unstable and can be further metabolized by calcium-activated A-esterases (PON1) and B-esterases (BuChE and carboxyesterases) in blood, brain, liver, and other tissues (Figure 4) (Testai et al., 2010). These enzymes can detoxify CPF-oxon before it inhibits AChE in the central or peripheral nervous systems. The A and B-esterases as well as P450s can detoxify CPF-oxon to form the urinary metabolite 3,5,6-trichloro-2-pyridinol (TCPy) which has served as a biomarker for CPF metabolism (Testai et al., 2010). TCPy is a product of both the activation and detoxification pathways and therefore cannot be directly associated with toxicity.

Detoxification of CPF-oxon → TCPy by PON1 and ChE

TCPy in urine can also indicate exposures to CPF-oxon, CPF-methyl and triclopyr (Barr and Angerer, 2006; Whyatt et al., 2009). Environmental, dietary and home exposure to TCPy can occur as a degradate of CPF, CPF-oxon or CPF-methyl (Barr and Angerer, 2006; Eaton et al., 2008; Whyatt et al., 2009). Significant intra-individual variability in repeat urine samples from the same individual has been observed (Whyatt et al., 2009).

PON1 activity is generally less in newborns than in adults. PON1 activity increases approximately 3.5 fold until age 7, when activity levels are closer to those found in adults (Cole et al., 2003; Holland et al., 2006; Huen et al., 2010). PON1 polymorphisms [glycine (Gln; *Q* allele) to arginine (Arg; *R* allele) substitution] have esterase activities that are substrate-dependent(Ginsberg et al., 2009). These alleles and phenotypes develop at different ages, and these developmental differences affect the age-dependent pharmacokinetic disposition and age-dependent pharmacodynamic activities of CPF (Huen et al., 2010).

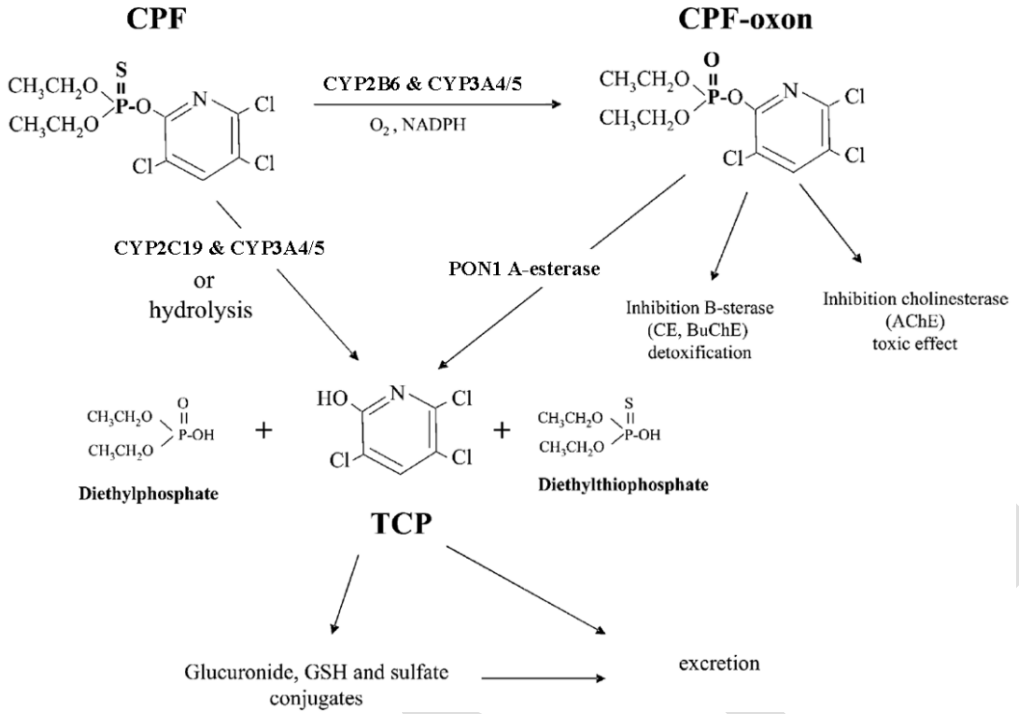


Figure 4. The Major Metabolic Pathways for CPF
(Adapted from Testai *et al.*, 2010)

II.B.1. Metabolism and Pharmacokinetics in Rat

Nolan et al. (1987): ^{14}C-labeled CPF was administered via gavage to Fischer 344 rats (5/sex/dose) in corn oil (2 ml/kg) in a single labeled dose of 0.5 or 25 mg/kg or via 15 consecutive daily doses of unlabeled CPF at 0.5 mg/kg/d followed by a single 0.5 mg/kg dose of ^{14}C-labeled CPF. The ^{14}C label was on the TCPy moiety. Investigators evaluated ^{14}C levels in urine, feces, and tissues and identified the three significant urinary metabolites. Urine plus cage wash accounted for 86 – 93% of administered dose regardless of sex or dosing regimen (~100% absorption). Six to 11% of the total administered ^{14}C was detected in feces. Urinary excretion was rapid, with over 50% of the administered dose collected in urine usually within the first 12 hours. $T_{1/2}$ was 8 – 9 hours for single or multiple 0.5 mg/kg treatment groups and somewhat longer for the 25 mg/kg group. Urinary metabolites were comprised chiefly of TCPy. Together with the glucuronide conjugate, TCPy accounted for over 90% of urinary metabolites. About 5% of urinary residues consisted of the sulfate conjugate of TCPy. Parent CPF was not found in urine. Most fecal ^{14}C was obtained within the first 24 hours. Exhaled CO_2 from the 25 mg/kg group was trapped for radioanalysis and accounted for < 0.01% of administered dose. Fecal metabolites were not assessed. Tissue residues were assessed at 72 hrs for males and 144 hrs for females. Total tissue residues were small to negligible, accounting for only 0.2% of administered dose in 25 mg/kg group and < 0.01% in all other groups. These residues were generally only quantifiable in peri-renal fat in both sexes.

Marty and Andrus (2010): Rat pups (post-natal day [PND] 11) and young adult female Sprague-Dawley rats (70-80 days old) were dosed with CPF or CPF-oxon as an acute (single) or

repeat dose (11 days). **CPF Treatment:** Acute gavage CPF dose regimen in pups (8/sex/dose/group) was 0, 0.05, 0.1, 0.5, 2 and 5 mg/kg (in corn oil vehicle [c.o.] or rat milk) and adults it was 0 (corn oil vehicle or in diet; 8/dose/group), 0.05, 0.1, 0.5 or 10 mg/kg. Repeat gavage CPF dosing in pups (8/sex/dose) and adults (8/dose) was 0 (c.o.), 0.05, 0.1, 0.5, 1, or 3.5 mg/kg/d. **CPF-oxon Treatment**: Acute gavage CPF-oxon dose regimen in pups was 0 (c.o.), 0.005, 0.01, 0.05, 0, or 0.5 mg/kg and in adults it was 0 (c.o.), 0.05, 0.1, 0.5, or 10 mg/kg. Repeat gavage dosing in pups and adults was 0 (c.o.), 0.01, 0.5, 1, or 3.5 mg/kg/d. **Methods:** Preliminary studies were performed in order to establish the time-to-peak inhibition profile for plasma, red blood cell, and brain cholinesterase inhibition. In the dose-response studies, animals were euthanized at the time-to-peak cholinesterase inhibition. The concentrations of CPF, CPF-oxon, and TCPy in the blood of selected animals were determined. A functional observational battery was performed on the study animals in the multiple-dosing regimen after 9 days of dosing. **Results:** Untreated pups showed no significant differences among plasma, RBC, or brain cholinesterase activity and there were no differences in the enzymes activities between males and females. In pups, plasma cholinesterase was 4.5 times less active than RBC AChE, while brain AChE activity was 3.7 times higher than RBC AChE activity. For adults, RBC AChE was 2.6 more active than in plasma, but brain AChE activity was 9.6 times higher than RBC AChE. Both plasma cholinesterase and brain AChE were higher in adults than in pups, however RBC AChE activity was lower in adults than pups. The measured time-to-peak enzyme effects were as follows:

Animals	Dose	Time to peak enzyme effect
Rat pups	CPF in corn oil vehicle	6 hrs
	CPF-oxon in corn oil vehicle	4 hrs
	CPF in rat milk vehicle	8 hrs
Adult rats	CPF in corn oil vehicle	8 hrs
	CPF-oxon in corn oil vehicle	4 hrs
	CPF in diet (after 12-hr exposure period)	8 hrs

Based upon the results of the dose response studies, no effect levels were established for plasma, RBC, or brain AChE inhibition under the different dosing scenarios. In the single dose regimen, NOELs for plasma and RBC AChE inhibition were 0.5 mg/kg for both sexes of pups after treatment with CPF (in corn oil or rat milk vehicle) and in adults (in corn oil or in diet). The NOEL values for brain AChE inhibition were 2 mg/kg for the male pups treated with CPF (in corn oil or rat milk vehicle), as well as for the female pups and adults (corn oil vehicle only). For the pre-weanling females dosed with CPF in the rat milk vehicle, the brain AChE inhibition NOEL was 0.5 mg/kg. The NOELs from a single dose of CPF-oxon to pups were 0.05 mg/kg for plasma cholinesterase inhibition, 0.1 mg/kg for RBC AChE inhibition, and 0.5 mg/kg for brain AChE inhibition. For the adults, the NOEL for plasma, RBC, and brain AChE inhibition were 0.1, 0.1, and 0.5 mg/kg, respectively. In the multiple dose regimen in which the pups and adults were treated with CPF in corn oil by gavage, the NOEL values for cholinesterase inhibition in pups were 0.1 mg/kg in plasma and RBCs and 0.5 mg.kg in brain. For adults, the NOEL values were 0.1 mg/kg/d for plasma, 0.5 mg/kg/d for RBCs, and 0.5 mg/kg/d for brain. The NOELs for ChE inhibition in both pups and adults after multiple treatments with CPF-oxon in corn oil were 0.01 mg/kg/d in plasma and RBCs and 0.5 mg/kg/d in brain. The NOEL values were reduced from 0.5 mg/kg to 0.1 mg/kg/d for plasma and RBC ChE inhibition in the pre-weanlings after

multiple treatments with CPF in corn oil. The brain AChE inhibition for these animals was lowered from 2 mg/kg to 0.5 mg/kg/d. In the young adult females, the NOELs for plasma and brain ChE inhibition were lowered from 0.5 mg/kg to 0.1 mg/kg/d and from 2 mg/kg to 0.5 mg/kg/d, respectively. The concentrations of CPF and TCPy in the blood at the NOEL and/or LOEL treatment levels for the various treatment scenarios were examined. Treatment with CPF in corn or in rat mild to pre-weanling rats in either a single dose or multiple dose regimen resulted in TCPy/CPF concentration ratios ranging from 70 to 209 ng/g of blood. In certain instances, the CPF concentration in young female rats was below the LOD and the ratio could not be calculated. Otherwise, the ratios were 935 and 449 (0.5 and 2.0 mg/kg, by gavage, respectively), 7243 (2.0 mg/kg in the diet) in the single dose regimen, and 2450 (0.5 mg/kg/d) and 651 (1.0 mg/kg/d) after multiple doses by gavage. These data indicate a possible difference in the metabolic disposition of CPF between the pre-weanling pups and the young adult animals. No treatment-related effects were identified in the FOB. Study deficiencies include the limited sample sizes with which to analyze CPF (2 pups, 4 adults), CPF-oxon and TCPy in blood, which led to increased variability. Therefore it was difficult to find a correlation between blood levels of these compounds and AChE inhibition. Analyses were performed at peak effect levels. Because only CPF-oxon is the active inhibitor, correlation with blood levels of CPF and TCPy with inhibition is difficult to interpret.

Mattsson et al. (1998); Mattsson et al. (2000b): Pregnant Sprague-Dawley rats were gavaged at 0 (corn oil), 0.3, 1.0 or 5.0 mg/kg/d from gestation day (GD) 6 to postnatal day (PND) 10. On GD 20 (4 h post gavage), fetal CPF in blood (46 ng/g blood) was half that of dams (109 ng/g blood) at 5.0 mg/kg/d. CPF-oxon was detected only once in fetuses (1 ng/g blood). No blood CPF was detected in dams (limit of quantitation 0.7 ng/g); however, there was significant plasma and RBC AChE inhibition at 0.3 mg/kg/d. This is likely due to production of CPF-oxon metabolized from CPF in blood. In contrast, fetuses of dams at 1 mg/kg/d had a detected blood CPF (1.1 ng/g); without ChE inhibition in any tissue. Inhibition of AChE was greater in dams at all doses but occurred only at 5.0 mg/kg/d in fetuses. At 5.0 mg/kg/d the inhibition was RBC > plasma > heart > brain (least inhibited). At 5.0 mg/kg/d milk CPF was 200-fold greater than in blood and pups were exposed in milk at approximately 0.12 mg/kg/d. Nursing pup exposure was lower than that of dams and AChE inhibition at 5.0 mg/kg/d was back to control levels by PND 5. The authors of this article concluded that "Based on the lesser ChE inhibition in fetuses, and on estimates of CPF consumption in milk, neither fetuses nor neonates demonstrated greater sensitivity to ChE inhibition than their dams."

Hotchkiss et al. (2010) ***Phase I:*** Sprague-Dawley rats (6/sex/dose) were exposed to CPF via nose-only inhalation to 0, 13.3 or 66.7 mg/m^3 for six hours. Blood was drawn from an in-dwelling jugular catheter at 2, 4 and 6 hours of exposure and at 0.5, 1, 2, 4, 6, 12, and 24 hours post-exposure. Red blood cell and plasma ChE activities were assayed for each time point. ***Phase II:*** Female rats (54/dose) were exposed via nose-only inhalation to CPF at 0, 3.7, 12.9, 22.1 or 53.5 mg/m^3 for up to 6 hours. Rats (6/dose/time point) were euthanized at 2, 4, and 6 hours of exposure and at 2, 6, 12, 24, 48 and 72 hours post-exposure. ChE activities in RBCs, plasma, lungs and brain were assayed and the blood concentrations of CPF, CPF-oxon and TCPy were measured. Urine was collected (6/dose) at 0-12, 12-24, 24-48 and 48-72 hours and TCPy concentrations were determined. ***Results***: In Phase I, significant RBC and plasma ChE inhibition was evident at 13.3 mg/m^3. RBC AChE had a peak inhibition of 65% (males) and 80% (females) at 2 hours post-exposure. Plasma ChE had a peak inhibition of 66% (males) and 87%

(females) occurred at 6 hours of exposure to 1 hour post-exposure. Based on these results, females were deemed to be more sensitive to the effects of CPF on ChE activity and thus were selected for testing in Phase II. ***Phase II:*** Plasma ChE inhibition was at a maximum of 48% at 6 hours of exposure in the 3.7 mg/m^3 group. In the lungs, a maximal level of AChE inhibition was 47% at 3.7 mg/m^3 at 6 hours of exposure. Brain AChE was significantly inhibited at 12.9, 22.1 and 53.5 mg/m^3; with maximal inhibitions of 19, 21 and 22% at 6, 6 and 2 hours post-exposure, respectively. For RBC AChE activity, the results were inconsistent at 3.7 mg/m^3 possibly due to the variability of the control values. Maximal AChE inhibition was not evident until 24 to 48 hours post-exposure. CPF in blood was highest at 4-6 hours of exposure for at all doses (peak value 65 ng/g at 53.5 mg/m^3). CPF-oxon was recovered in the blood (peak: 0.22 ng/g) during exposure at 53.5 mg/m^3. Peak levels of 2400 ng/g of TCPy for the highest exposure occurred at 12 hours post-exposure. The plasma half-life ($t_{1/2}$) of CPF was 0.463-3.34 hours over the exposure concentration range. The ratio of the areas under the curve for TCPy/CPF ranged from 545 to 1057. The inhaled dose of the test material was calculated to be 1.04, 3.62, 6.21 and 15.0 mg/kg. Excretion of TCPy in the urine $t_{1/2}$ was 10.6-11.6 hours. Using these excretion data the percentage of inhaled CPF which was absorbed was approximately 36-79%. An inhalation NOEL was not achieved due to increased plasma ChE and RBC AChE at 3.7 mg/m^3 (LOEL ~1.0 mg/kg/d inhaled dose).

Hotchkiss et al. (2013): Crl:CD(SD) female rats (40/dose) were exposed via inhalation (nose-only) at 0 (filtered air) or 17.7 ppb (0.254 µg/l) of a saturated vapor of CPF for 6 hours. Females (8/dose/time point) were euthanized at 0, 2, 4, 6 and 12 hours post-exposure. Blood, brain and lung tissue were procured from each animal. ChE activity (plasma, RBC, brain and lungs), as well as CPF, CPF-oxon and TCPy (in blood), were assessed. Females had no signs of toxicity during the exposure or for 12-hour post-exposure. Peak CPF in blood occurred immediately after completion of exposure; diminishing to a non-detectable level by 6 hours post-exposure. TCPy peak occurred up to 2 hours post-exposure and gradually diminished over the next 12-hours post-exposure. CPF-oxon was not detectable in any of the samples; however it may have been totally degraded before assessment. None of the tissues which were assayed from the exposed group demonstrated a significant decrease in AChE activity compared to controls. Activity in the blood and plasma of the exposed animals was 93 and 86%, respectively, of the control values at 4 hours post-exposure, the maximal reduction. The ChE activity in the lungs of the exposed animals was 89% of the control group at that time point. There was no apparent effect upon AChE activity in the brain.

II.B.2. Metabolism and Pharmacokinetics in Humans

II.B.2.a. Human Oral Studies

Kisicki et al. (1999): ***Part 1:*** Six male and six female human volunteers/treatment group were fasted overnight prior to being dosed orally once with 0 (placebo: lactose monohydrate), 0.5 or 1.0 mg/kg of CPF powder (purity: 99.8%) in capsules (phase 1) or 0 or 2.0 mg/kg (phase 2) in a double blind, randomized study. The health status of each subject was monitored for up to 7 days. Vital signs (blood pressure, pulse rate, respiration rate, and body temperature) were recorded prior to dosing and at 1, 2, 4, 8, 12, 24, 48 and 168 hours after dosing. Blood samples for RBC AChE analysis were drawn 10 hours prior to dosing, at the time of dosing and at 2, 4, 8, 12, 24, 36, 48, 72, 96, 120, 144 and 168 hours post-dose for RBC AChE activity and CPF and

metabolite analyses. A blood sample was drawn prior to dosing for PON1 activity determination. Urine samples were collected at 12 hour intervals starting 48 hours prior to dosing and at 0 to 6 and 6 to 12 hours post-dose and 12 hour intervals thereafter up to 168 hours after dosing. Although clinical symptoms such as anorexia, diarrhea, nausea, vomiting, dizziness, dyspnea, and headache were reported, none of these signs occurred in a dose-related manner. There was no apparent treatment-related effect upon any of the vital signs. Mean RBC AChE activities were not significantly affected in a dose-related manner. One subject in the 2.0 mg/kg treatment group demonstrated a maximal 30% inhibition between AChE activity reported at 0 and 12 hours post-dose. Otherwise, no other subject in the high dose group had a reduction in RBC AChE activity greater than 12% based on the higher of the two baseline values. The blood and urine levels of CPF and its metabolites and the paraoxonase activity analysis for individual subjects were not included in this initial report and thus could not be evaluated. No adverse effects were indicated. **NOEL:** 1.0 mg/kg (based upon the 30% inhibition of RBC AChE demonstrated by one of the subjects in the 2.0 mg/kg treatment group). ***Part 2:*** As a continuation of the above study, 30 days after the oral treatment, the human volunteers (6/sex/dose) received a single oral dose of 0.0, 0.5, 1.0 or 2.0 mg/kg (capsule form) in a double-blind clinical trial; blood and urine specimens were collected and analyzed for CPF and its metabolites (CPF-oxon and TCPy) using gas chromatography-mass spectrometry (GC-MS). CPF paraoxonase (PON1) prior to treatment was determined spectrophotometrically. The blood and urine specimens were generally below the limit of quantitation (LOQ) for CPF. An average area under the curve for TCPy in blood (by increasing dose) was 14.0, 25.2 and 51.2 µg/g, respectively. TCPy excreted in the urine was 4.1, 8.7 and 15.9 mg, by dose, respectively, during the first 168 hr following ingestion; Blood and urinary TCPy levels increased rapidly, remained constant over first 48 hr post-treatment, and then declined with an average half-life of 29 to 36 hours. Administration by capsule probably reduced absorption (average of 34.7%, 30.8% and 29.5% absorbed in 0.5, 1.0 or 2.0 mg/kg dose group, respectively). The serum CPF PON1 activity was within the range of activity reported in previous studies and there were no extreme values. RBC AChE inhibition was seen in only one individual (female at 2.0 mg/kg) that showed unusually high absorption of CPF (87.9% versus 29.5%).

II.B.2.b. Human Oral Treatment and Dermal Absorption Studies

Nolan et al. (1982); Nolan et al. (1984): Researchers selected healthy male volunteers (n = 5) to characterize CPF kinetics and production of the major metabolite TCPy, and to follow changes in plasma and RBC AChE over time. Exposures were a 0.5 mg/kg single oral dose, followed 4 weeks later by a single 5 mg/kg dermal dose. None of these doses elicited clinical signs. Following 0.5 mg/kg oral dosing, plasma ChE was inhibited to about 15% of baseline, with the greatest inhibition at 0.5 to 2 hrs after dosing. By 8 hours, plasma ChE activity levels were 3-4-fold higher than the lowest activity. By 27-30 hours, plasma ChE activity returned to baseline activity. Dermal dosing with 5 mg/kg CPF had no definitive effect on plasma ChE at any time post-dose. RBC AChE activity was not measurably affected by these oral or dermal exposure levels. Blood CPF levels following 0.5 mg/kg oral dosing was either non-detectable, or was in the range of 5-30 ng/ml blood. The highest blood CPF levels did not appear at consistent times post-dosing, and clearly would not represent a reliable measure of exposure. Blood concentrations of CPF following 5 mg/kg dermal exposure were either non-detectable or did not exceed 10 ng/ml. Blood levels of TCPy following 0.5 mg/kg oral dosing showed quite variable kinetics between subjects, but tended to peak at 2-8 hours at about 1 µg/ml blood, with levels at

24 hours being no less than 50% of peak concentrations. This confirms that this metabolite would be a reliable indicator of exposure. Dermal exposure of 5 mg/kg yielded TCPy blood levels which occasionally exceeded 0.1µg/ml. There was about a 4-fold range of peak TCPy blood between dermal exposure subjects. Investigators estimated the half-life of TCPy to be about 27 hours by either route. Urinary peak excretion rates of TCPy were at about 9 hours for oral route, and about 42 hours for the dermal route. Time to decrease to about 50% of maximum urinary TCPy levels were roughly 30 hours for oral exposure and 84 hours for dermal route. This study showed that CPF is only moderately absorbed through the skin (1.28% absorption), that plasma ChE is a good marker of systemic load for several hours after exposure, whereas urinary TCPy assays would be useful for qualitative exposure assessment for 2-3 days for oral route and slightly longer for dermal exposure.

Griffin et al. (1999): A human volunteer study (n = 5; 4 men, 1 woman) was performed with CPF to determine the kinetics of urinary excretion of dialkylphosphate (DAP) metabolites and plasma and RBC AChE inhibition after oral (1 mg) treatment, followed one month later with dermal (28.59 mg; 8 hrs) treatment. After 8 hours skin was washed and the CPF residue was collected for analysis. After both oral and dermal treatments blood was collected over 24 hours. Plasma and RBC AChE concentrations were determined for each sample. Urine was collected for 100 hours and the CPF metabolites (DAPs) were assayed in each urine sample. Elimination half-life for DAPs in urine after oral dosing was 15.5 hours and 30 hours for dermal dosing. Average recoveries were 93% and 1% for oral and dermal dosing, respectively. Dermal dose recovery from the skin surface was 53% and 456 ng/cm^2/h based on urinary DAPs. ChE (plasma or RBC) was not significantly inhibited after oral or dermal exposure. CPF exposure was indicated only through urinary DAPs in this study.

II.B.2.c. Human Dermal Absorption Studies

Meuling et al. (2005): Dermal absorption of CPF in humans was assessed by urinary elimination of TCPy. Male volunteers were administered CPF dermally (100 cm^2) at 5 mg or 15 mg (n = 3/dose) for 4 hours. Subsequently, the unabsorbed CPF residue was washed off. At designated intervals, CPF and TCPy were assessed in the dosing and wash solutions and in urine samples up to 120 hours post-dosing. Most of the treatment dose was found in "wash-off" from the skin (42%–67%). At 5 mg and 15 mg CPF, the urinary TCPy was 131.8 µg and 115.6 µg, respectively at 120 hrs post-dosing. Approximately 4.3% of the applied dose was absorbed as indicated by the lack of significant increase in urinary TCPy (115.6 µg) from the low to high dose. Therefore, the higher dose did not result in increased absorption when compared to the lower dose (i.e., percutaneous penetration rate was constant.) CPF clearance was not complete by 120 hours, therefore CPF or TCPy was likely retained in the skin and/or various body compartments. The elimination $T_{½}$ was 41 h indicating that repeated occupational exposure may result in accumulation of CPF and/or its metabolites.

II.B.3. PBPK-PD Model

Risk assessment of CPF is benefited from the use of the physiologically-based pharmacokinetic-pharmacodynamic (PBPK-PD) model developed initially by Timchalk et al. (2002a); Timchalk et al. (2002b). The model generated PoD values based on 10% inhibition of RBC AChE after an acute (single day, 24 hr) or steady-state (21-d) exposure of CPF. When a steady-state has

occurred then the same inhibition is expected to continue for longer durations as shown in chronic animal studies. The model has undergone numerous revisions (Poet et al., 2003; Timchalk et al., 2007; Timchalk and Poet, 2008; Lowe et al., 2009; Smith et al., 2011; Poet et al., 2014; Smith et al., 2014; Poet, 2015; Poet et al., 2017a) to include such parameters as human life-stage (age related change of physiology and metabolism), pregnancy-related changes, as well as multi-route/variation (inhalation, oral, dermal). The data were judged to be acceptable for modeling because of completeness as well as having the best concordance for RBC AChE and BuChE inhibition and TCPy biomarkers for oral, dermal and inhalation routes of exposure(Timchalk and Poet, 2008; Poet et al., 2014). Note that some parameters are obtained by use of animal data.

III.B.4. PBPK-PD Model Predicts Life-Stage-Related Inter-individuality and Susceptibility to CPF

There are four main publications and one registrant submitted article that describe the development of the PBPK-PD model currently used in this risk assessment. All versions of the model have been validated, reviewed by outside experts, published in peer reviewed journals and externally reviewed by PBPK model experts. The models and their critical findings are described below:

Smith et al. (2011). Smith and colleagues investigated the age-dependent (life-stage) metabolism of CPF in human tissues. This model included CPF and CPF-oxon metabolism and TCPy metabolite disposition as well as carboxyesterase and plasma ChE inhibition. Metabolism was quantified by use of 20 samples of pediatric human microsomes (13-day to 6-month (n = 7), 6-month to 2-years (n = 6), and 2 to 12-years (n = 7)). Microsomes were cryopreserved and prepared by XenoTech, LLC (Lenexa, KS) according to standardized protocols[2]. Liver microsomal samples were procured from subject aged3 days to 75 years in order to optimize population distributions (e.g., to include potential sensitive individuals) but not compromise central tendency. Plasma samples (20 total) included pediatric 3-day to 6-month (n=5), 6-month to 2-year (n = 6), and 2- to 12-year (n = 4) age groups, along with five adult samples (age 16-43 years). **Microsomal Activity**: Metabolic activity in microsomes for the four main P450s associated with CPF metabolism (CYP1A2, 3A4/5, 2B6, and 2C19) was characterized (Sams et al., 2000; Tang et al., 2001; Buratti et al., 2003; Mutch and Williams, 2004; Sams et al., 2004; Foxenberg et al., 2011). Three P450 enzymes (CYP2B6, 2C19, and 3A4) had different age-related expression. **CYP2B6** occurred in 64% of fetal samples and had a 2-fold rise from birth to 1 month (variability = 25-fold). The high variability was likely due to individual metabolic

[2] XenoTech LLC, https://www.xenotech.com/company; Rewerts, C., Maciej Czerwinski, M. and Loewen, G. personal communication). Human livers were flash cryopreserved as is done for the purpose of organ transplant prior to microsome preparation (https://www.xenotech.com/products/subcellular-fractions/human/liver/microsomes). The stability of microsomes obtained from human livers has been documented over 10 years, with little effect in metabolic activity over multiple freeze-thaws during that time span. Utilization of microsomes derived from human tissues is described and recommended in the Federal Food and Drug Administration Guidance for Industry Drug Interaction Studies — Study Design, Data Analysis (FDA, 2012).

regulation and genetic polymorphisms (Croom et al., 2009). **CYP2C19** in newborns was 15% of adult values but increased in a linear fashion up to 5 months; at age 10 the values were similar to adults (21-fold variation) (Koukouritaki et al., 2004). In addition, CYP2C19 showed high, non-age-related variability (62-fold). **CYP3A4** was previously characterized as having low gene expression in infants, but by age 6-12 months it had increased to within 50% of adult levels (Blake et al., 2005). The activity levels increased beyond adult levels in late infancy and then decreased to adult levels over time (Blake et al., 2005). The late infancy surge could be explained by increasing CPF desulfuration and dearylation (CYP3A4 is involved in both reactions) product formation for both reactions (CPF-oxon and TCPy, respectively) without changing the product ratios. **Activity in Plasma:** Plasma samples were phenotyped for PON1 status and frequencies of PON1 [glycine (Gln; Q allele) to arginine (Arg; R allele)] genetic phenotypes were 0.5, 0.4, and 0.1 for QQ, QR, and RR phenotypes, respectively. Results showed that plasma PON1 metabolism of CPF-oxon had an age-related increase. This is in agreement with other studies reporting lower PON1 in newborns compared with adults (Cole et al., 2003; Holland et al., 2006). The difference was 26-32% lower for PON1 activity in newborns, depending on the phenotype, when compared to children at age 7, where levels were within 4% of adult PON1 activity (Huen et al., 2010). In the current study, CPF-oxon was metabolized at adult levels by age 10, based on plasma volume.

Smith et al. (2014). This study provided a description of human life-stage changes in a PBPK-PD model utilizing the measured parameters from Smith et al. (2011). Physiology and pharmacodynamic parameters relating to production of CPF-oxon and changes in activities of AChE, BuChE, and carboxylesterase in brain, diaphragm, liver, lungs, plasma, and RBCs were model inputs. Adipose and lipid compartments were added (Figures 5 and 6) to simulate the age-related variability in changes to body weight, organ volumes, and metabolism, after oral exposure to CPF. Parametric distribution was simulated for each metabolic parameter (means and coefficients of variation [CV] determined) by quantitatively integrating each age-dependent CPF and CPF-oxon metabolic parameter to represent a typical person. The descriptors for these age-dependent changes were obtained from controlled human CPF exposure studies for comparison to the model predictions (Nolan et al., 1987; Kisicki et al., 1999; Timchalk et al., 2002a; US EPA, 2014a). A sensitivity analysis was performed to pin-point the most critical parameters for estimating 10% RBC AChE inhibition after a simulated oral dose of 3 µg/kg CPF in 6 month old and 30 year old humans (Smith et al., 2014). Sensitivity endpoints also included TCPy in blood and urine, CPF in blood, and plasma ChE inhibition. Initially all parameters were fixed and the model was run to determine a baseline of variability. Then, systematically, each parameter was individually varied by ±1% until all parameters had been tested to determine which of the 120 parameters was the most sensitive to variation. Sensitivity coefficients (distribution of change in peak RBC AChEI ÷ change in parameter) were calculated for each parameter. Small parameter changes were ~1%. Greater changes meant a > 1% change in predicted RBC AChE inhibition. Values near zero meant that AChEI was not affected by that parameter. Modeled data were subsequently validated by findings in human dosing studies (Nolan et al., 1982; Nolan et al., 1984; Kisicki et al., 1999).

At doses $\geq$ 0.6 mg/kg, CPF was predicted to be lower and CPF-oxon higher in children compared to adults due to CPF metabolism-based body weight and liver/body weight differences. At $\geq$0.6 mg/kg the increases in CPF-oxon in children predicted by the model may be

due to the CPF-oxon levels overwhelming the metabolic capacity in plasma (Smith et al., 2011). However at <0.6 mg/kg, CPF-oxon is lower in children than adults due to increased metabolism in children at that exposure. Pharmacokinetic differences in metabolism and distribution are influenced by age-related body fat content because CPF is lipophilic and adults have more fat than 6 month old infants (~2-fold). Higher body fat can translate to lower CPF metabolism, altered distribution results, and increased half-life of CPF in adult blood to twice that of infants.

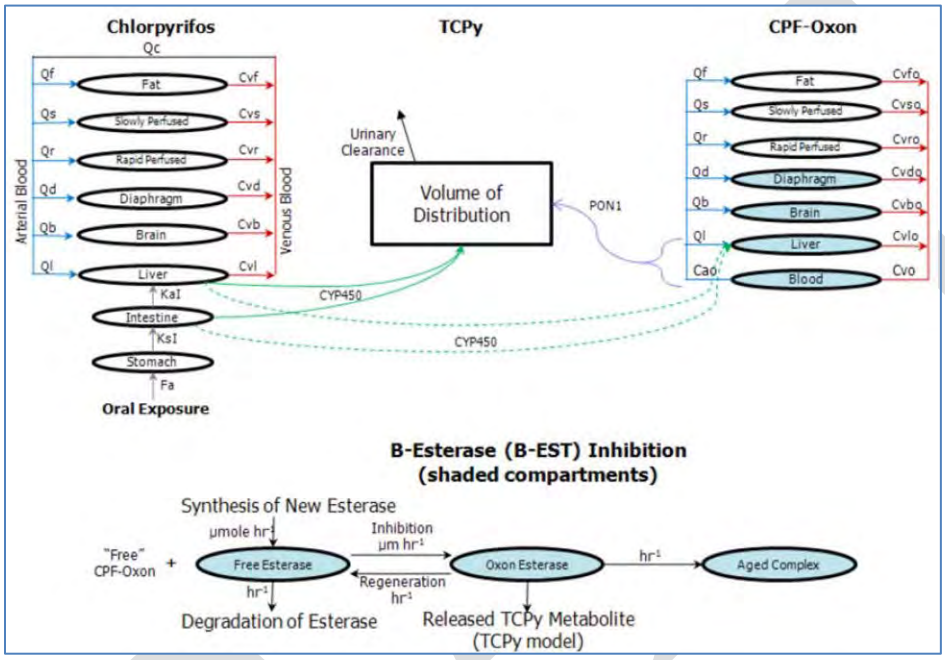


Figure 5. PBPK-PD Model Structure (typical adult)

The shaded compartments denote tissues which contain B-esterases (BuChE, CES: bottom panel). Tissue volumes and enzyme activities (Vmax) change with age based on liver and/or blood compartmental growth (Smith et al., 2014).

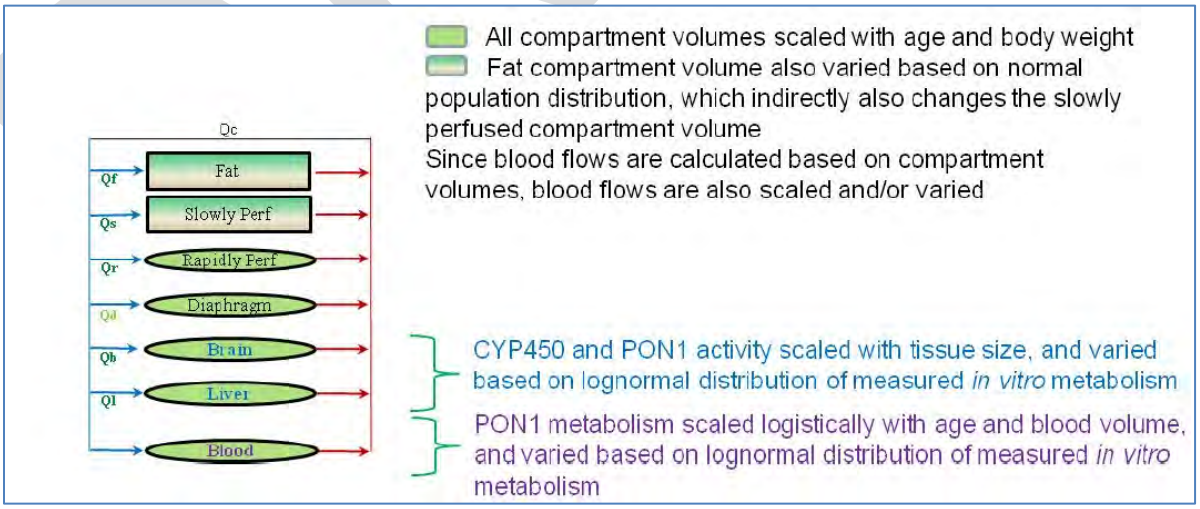


Figure 6. Schematic of Age and Body Weight Dependences in PBPK-PD model

Compartment volumes and blood flows vary with age and body weight. *In vivo* metabolic rates are scaled based on tissue size (measured *in vitro* values scaled to describe brain, blood, and liver metabolism); in blood, PON1 metabolism of oxon is dependent on blood volume and age (Smith et al., 2014).

Poet et al. (2014), Poet (2015). Poet and colleagues developed a multi-route (oral, dermal, and inhalation) PBPK-PD model for CPF and CPF-oxon metabolism. The oral life-stage model (Smith et al., 2014) served as a basis for optimizing metabolic rate constants and tissue growth in both humans and rats to apply to the multi-route model. Human metabolic data was collected from volunteers (7 males and non-pregnant females aged 21-55) who were exposed to Empire*20 insecticide (0.5% CPF in water) used to treat apartment carpet (Vaccaro et al., 1993). Two carpet treatments were done with four subjects in apartment #1 and three different subjects in apartment #2. After exposure, each volunteer (dressed in T-shirt and shorts) crawled, rolled, or laid on the carpet for 4 hours to simulate how a child might behave on the carpet in an apartment. Air exposure of CPF was also measured on the floor where most activity occurred (cassette filters backed by a Chromosorb tube 15 in were placed near each volunteer). Air samples from Apartment #1 had a time weighted average (TWA) of 11.4 mg/m^3. The TWA from Apartment #2 was 5.53 mg/m^3. Data from the cassettes were added to the model to estimate human exposure. An acute rat CPF (aerosolized) inhalation study provided parameters for the PBPK-PD modeled route (Hotchkiss et al., 2013). The authors note that the *in vivo* results for critical metabolic parameters (plasma CPF and CPF-oxon; TCPy concentration in urine; plasma, RBC and brain AChE inhibition) compared well with those predicted for humans in the PBPK-PD route. The authors go one to state that due to the low vapor-pressure of CPF, inhalation exposure is expected to be low and that based on modeled data, 23% of inhaled CPF (aerosol) in humans would be deposited in the alveolar region of the lung. The model assumes that CPF aerosol deposited in the nasal passages and upper and lower airways eventually reaches he liver. Therefore, liver metabolic activity (100% absorption) was used for the inhalation route (Corbo et al., 1989; Dahl and Hadley, 1991; Sarkar, 1992; Gerde et al., 1998; Song et al., 2004). Exhalation was included in the model, but is predicted to be near zero. B-esterases were included, but not PON1 (no lung data available).

For dermal exposure to CPF, the hands of each volunteer were rinsed 3 times in 250 ml of 0.008 dioctyl sodium sulfosuccinate soap. Hand surface area for adults is approximately 4% of the body and the rest of the body surface area (minus the part covered by T-shirt and shorts) is 66%. It was assumed in the study that the main parts of the body were subjected to the same dose. The normalized dermal dose was calculated for each individual's exposure based on body surface area (as calculated from their body weight), specific dermal absorption, and measured air sampling data. Nolan et al. (1984) showed that after a 5 mg/kg CPF dermal treatment in human volunteers, there was a 5-fold lower plasma ChE inhibition when compared to a 0.5 mg/kg oral dose. This information along with the TCPy measurements indicated that dermal absorption on the lower arm was 1.3% CPF over a 12-24 hour period, compared with almost 100% absorption via the oral route. Griffin et al. (1999) estimated that dermal absorption was 1% based on metabolites detected in urine. Data from the volunteer carpet study were used to validate the PBPK-PD model for the dermal route of CPF (Poet, 2015). Note that some parameters are obtained by use of animal data but as shown in Table 3, below, there was concordance between human and rat data for 4 major biomarkers. Using animal data in designing a PBPK model is

standard procedure. Parameters can be scaled to humans by use of body weights, blood flow, and other pharmacokinetic measurements.

Table 3. Data Concordance and Completeness for PBPK-PD Model Validation

Route	Pharmacokinetic (PK) Biomarkers					Cholinesterase Biomarkers		
	Blood CPF	Blood Oxon	Blood TCPy	Urine TCPy	Plasma	RBC	Diaphragm/ lung	Brain
ORAL					**ORAL**			
Rat Data	X	X	X	X	X	X	X	X
Human Data	X	X	X	X	X	X	--	--
INHALATION					**INHALATION**			
Rat Data	X	X	X	X	X	X	X	X
Human Data	--	--	--	--	--	--	--	--
DERMAL					**DERMAL**			
Rat Data	--	--	--	X	X	--	--	X
Human Data	X	--	X	X	X	X	--	--

[a]- "X" indicates measured data in rat and human for PBPK-PK validation
"—" indicates no data
Yellow highlighted area indicates measured data that was the most complete and showed the best concordance (rat and human) for RBC AChE and BuChE/plasma ChE inhibition and TCPy biomarkers for oral, and dermal routes of exposure (data from Poet et al. (2014); Timchalk and Poet (2008).

Poet et al. (2017a). Poet and colleagues built on previous versions of the PBPK-PD model to provide simulations of CPF and CPF-oxon metabolism after oral exposure in infants and adults and in pregnant and non-pregnant females. Modifications to the life-stage PBPK-PD model (Smith et al., 2011; Smith et al., 2014) included growth during pregnancy (metabolism, uterine, placental and fetal compartments; changes in slowly perfused and fat compartments; and, changes in blood such as increasing blood volume; decreasing hematocrit; increased lipids, triglycerides, cholesterol). The inter-individual differences in a parameter due to body composition and metabolic activity define variability while uncertainty is from model assumptions, extrapolations, or experimental data interpretation. Of the 120-160 parameters tested, sixteen were identified as having the greatest impact on AChE inhibition, accounting for >95% of total inter-individual variation (Table 4). Monte Carlo analyses were performed using the means and the coefficients of variance of the 16 distributions from the raw data from Smith et al. (2011)to generate 1000 simulated infants (6 months) and adults. These simulated subgroups were exposed to 0.3 mg/kg/day for one or 5 days to assess RBC AChE inhibition. Single dose tests were performed with 3000 simulated infants or adults. Degree of variability defined the most sensitive parameters based on the raw data and the sensitivity analyses from Smith et al (2014).

Table 4. Sixteen Main Parameters Considered in the PBPK-PD Model Design

Hepatic CYP activation of CPF-CPF-oxon	Total blood volume	RBC AChE degradation rate	Transfer rate of CPF or oxon from stomach to intestine
Hepatic PON1 CPF-oxon detoxification TCPy	Hepatic blood flow	RBC AChE degradation rate	Liver volume
PON1 CPF-oxon detoxification to TCPy in plasma	RBC AChE inhibition rate	Intestinal CYP CPF-oxon bioactivation	Hepatic carboxyl basal activity rate
Hepatic PON1 CPF-oxon detoxification to TCPy	Hematocrit	Intestinal CYP detoxification to TCPy	Hepatic carboxyl reactivation rate

After testing the 16 most sensitive parameters, four were identified as having the greatest impact on RBC AChE inhibition (Table 5). Bioactivation and detoxification had the greatest impact on RBC AChE, including physiology and non-metabolism parameters.

The liver microsome reactions were:

1) CYP450 activation of CPF to CPF-oxon
2) CYP450 detoxification of CPF-oxon to TCPy
3) PON1 detoxification of CPF-oxon to TCPy

The plasma reaction was:

PON1 detoxification of CPF-oxon to TCPy

The raw data from Smith et al. (2011) characterizing the two CYP450 reactions and two liver PON1 reactions were from 30 individuals. In order to characterize the impacts of small sample sizes on the means and coefficients of variance on the bioactivation and detoxification parameters (listed above), a parametric bootstrap methodology was applied. The bootstrap technique can increase the variability beyond that of the measured population samples (Table 5). Raw data was used in the PBPK-PD model to generate means and coefficients of variance for the major subpopulations (infants, men and women, non-pregnant and pregnant women) by Monte Carlo distributions (built into the model). These data for 1000 individuals were bootstrapped (resampled) 20 times (1000 individuals, 20 bootstraps = 20000 individuals) to maximize the initial small sample size and increase the variability of the critical parameters. The width of the dose-response showed that the doses eliciting 10% RBC AChE inhibition ranged from 0.08-2.4 mg/kg/d for CPF and from 0.03-0.9 mg/kg/d for CPF oxon. The bootstrap method resulted in a range of 3.5 (CYP450 to oxon) to 10-fold (plasma PON1 in adults) wider (Table 5) than the raw data (Smith et al., 2011). The predicted values were about twice the range reported for maternal (8.5-fold) and infant (34-fold) PON1 in plasma (Huen et al. (2012). According to Ginsberg et al. (2009), the intra-genotypic variability in activity due to the PON1 192 polymorphism in activity was 15-fold for CPF which is similar to that of all ages(Smith et al., 2011). The PBPK-PD model exceeds the range of CPF allotype variability by about 2-fold beyond the projected (measured) range for PON1 based on Ginsberg et al. (2009). It exceeds the measured PON1 activity values by a maximum of 10-fold when compared to the measured values from Smith et al. (2011). Table 5 summarizes the data for the 4 metabolism-related parameters and the comparative variability of raw data, parametrically distributed data (Monte Carlo), and bootstrapped/Monte Carlo distributions.

Table 5. Ratios of the Maximum to Minimum Value in the Raw Data and Bootstrap Model Simulations for the Critical Enzyme Activities

Parameter	**CYP450 to TCPy**	**CYP450 to Oxon**	**Hepatic PON1[a]**	**Plasma PON1[a]**
Range in raw *in vitro* data[b]	12	28	10/11[c]	6/16[c]
Range in parametric distribution[d]	26	34	33	33
Range in 20 parametric bootstraps[e]	74	98	58	58
Ratio[f]	1:6.1	1:3.5	~ 1:5.2	1:3.6/9.6

a -Values for PON1 in liver & plasma assumed to be correlated and thus have the same variation (Poet et al., 2017a)

b- Data based on Smith et al. (2011).
c- Smith et al. (2011): Hepatic PON1 Ratios Vmax (nmol/min/mg microsomal protein) = 10 (age 0.04-2 yr) and 11 all ages (0.04 to 75); Plasma PON1: Ratio Vmax (nmol/min/ml plasma) = 6 (age 0.01-2 yr) and 16 all ages (0.01 to 46)
d- Data based on Smith et al. (2014).
e- Data based on Poet et al. (2017a).
f- Ratio of raw data range to range in 20 parametric bootstraps.

Impact of Variability: Ninety percent of all summed model variability (global sensitivity) has parameters with a sensitivity coefficient of 0.3. Of the 160 model parameters, 20 have sensitivity coefficients of $\geq$0.1, accounting for more than 95% of all the local sensitivity. The remaining parameters showed almost no impact on modeled predictions. The critical parameters related to inter-individual variation in RBC AChE were for clearance of CPF and CPF-oxon.

Impact of Parameter Uncertainties: A Monte Carlo program was used to calculate Data Derived Extrapolation Factors (DDEF) for acute oral exposures for the following sub-populations: general population of adult males and females, non-pregnant females, pregnant females (8^{th} month; 3^{rd} trimester was determined to be most sensitive median pregnant females based on 10% RBC AChE inhibition), and infants 6 months of age. DDEF calculated for the above populations were designed to replace default uncertainty factors with quantitative intraspecies physiological and biochemical determinations.

$$DDEF_{HD} = PoD_{H} \div PoD_{SH}$$

PoD_H is the oral dose (ED_{50}) resulting in 10% RBC AChE inhibition for the median individual from a simulated population and PoD_{SH} is the oral dose (ED_{10}) resulting in 10% RBC AChEI for the 1^{st} percentile). The Monte Carlo program simulations allowed the researchers to evaluate the inter-individual variation of RBC AChE inhibition. DDEFs were very similar for CPF for males and females (3.4), infants (3.6), non-pregnant female (3.4) and pregnant female (2.9). For CPF-oxon the DDEF for males and females (1.8) was similar to infants (2.1); the other groups were not measured.

The range of PoDs (ED_{10}) for all populations was 0.39-0.52 mg/kg/d. Pregnant females had an ED_{10} that was 20% lower (0.39 mg/kg/d; most sensitive population) than that of non-pregnant females and adult men. A time course for pregnancy or for young life stages could not be performed but the model was adjusted based on data from the open literature on pregnancy-related changes in maternal metabolism and physiology. Changes in P450 CYPs relating to CPF and CPF-oxon metabolism showed 33% increased bioactivation and 25% decrease in detoxification over the course of pregnancy. PON1 in plasma and liver was decreased by 7% by week 26 of pregnancy. The simulated median for 10% RBC AChE inhibition in pregnant women was at doses of 3-20% less than nonpregnant women; however variability was also less in pregnant women. Pregnant women were only slightly more sensitive to CPF exposure than non-pregnant women; however at the 10th percentile the values were very similar. This may be due to changes in physiology or biochemistry during gestation. Poet et al. (2017a) have shown that inter-individual variability could decrease in pregnant women by increased CPF to CPF-oxon and decreased detoxification to TCPy metabolite. Due to pregnancy, the increased plasma lipids

could decrease the partitioning of CPF from blood to tissues and decrease intraspecies variability in metabolic clearance.

III.B.5. US EPA use of the PBPK Model to Simulate CPF Exposures

In 2016, US EPA developed a PBPK model to simulate CPF concentrations in human blood(US EPA, 2016b). PBPK exposure data were estimated from US EPA standard operating procedures (SOP) for indoor crack and crevice/hard surface use of CPF for the same time frame as the initial Columbia CCCEH Cohort study (1998-2004) (see footnote 1). These data were used in forward dosimetry to model blood levels of CPF in the pregnant women and newborn cord blood. It was assumed that biological responses are equivalent based on equal tissue doses (not equal external exposures). Biomarker data (CPF measurements in cord blood) from the Columbia CCEH Cohort were used as an *in vivo* standard for comparisons with predicted PBPK values (US EPA, 2016b). A benchmark dose analysis (linear regression) applied measured decrements in the working memory index (WMI measured by the Wechsler Intelligence Scale for Children WISC-IV) from children who were exposed to CPF *in utero* versus CPF measured in cord blood in newborns (Rauh et al., 2011). At the 1% change in WMI, the BMDL was close to the limit of detection (LOD) of 0.5-1.0 pg CPF/gram cord blood which introduced a great deal of uncertainty. However at the 3-5% change in WMI the CPF residues in cord blood were near the 6.17 pg CPF/g blood levels that are more closely associated with neurodevelopmental effects (Rauh et al., 2006; Rauh et al., 2015). A BMDL representing a 2% decrease in WMI was associated with an internal dose of 2.16 pg/g CPF in cord blood. Columbia Cohort publications did not report frequency of CPF exposure or timing in terms of maternal or cord blood sampling. Therefore forward dosimetry was used with PBPK modeling to compare the values for CPF in cord blood to predicted values from presumptive exposure scenarios and a known sequence of exposure/sampling parameters. The PBPK model was not used for the determination of a PoD, only for prediction of blood concentrations from likely exposure scenarios. A time-course for CPF concentrations in blood was simulated based on likely exposure scenarios and presumptive time between exposure and blood sampling (~4 hours to 2 days).

II.C. Acute and Short-Term Toxicity

The profile of acute CPF toxicity has been extensively described and reported by others (US EPA, 2007; Eaton et al., 2008; Testai et al., 2010; US EPA, 2011b; US EPA, 2014a). Severe poisoning in humans causes neurotoxic effects such as slurred speech, tremors, ataxia, convulsions, depression of respiratory and circulatory centers, which may culminate in coma and possibly death (Ecobichon, 2001). The following profile of acute toxicity for CPF consists of Health Effects Test Guideline studies submitted to HHA by registrants (see Appendix 1) as well as open literature studies that were considered by the current authors to be relevant and well-performed. Acute exposure to toxic levels of CPF results in the typical signs and symptoms of cholinergic toxicity: salivation, lacrimation, urination and defecation. The oral, dermal and inhalation LD_{50}, dermal and eye irritation, dermal sensitization, and acute delayed neurotoxicity studies using technical CPF and that were required for registration were submitted by the registrant (Table 6). Oral and dermal effects in the rat were primarily rated as Category II. Inhalation effects were rated Category II/III. Rabbits were not sensitive to CPF when applied dermally, however they did exhibit slight to moderate eye irritation. CPF did not cause dermal irritation, dermal sensitization, or acute delayed neurotoxicity.

Table 6. Acute Toxicity Studies for Technical Grade Chlorpyrifos

Study Type	Species	Result	Category	Reference [a]
Oral LD_{50}	Rat	223 mg/kg (M/F)	II	1*
	Rat	221 mg/kg (M) 144 mg/kg (F)	II	2*
Dermal LD_{50}	Rat	202	II	3*
	Rabbit	>5000 mg/kg (M/F)	IV	4*
	Rabbit	>2000 mg/kg (M/F)	IV	5*
Inhalation LC_{50}	Rat	> 4.07 mg/l (M) 2.89 (2.01 - 4.16) mg/l (F)	III	6*
	Rat	> 14 ppm (0.22 mg/l) M/F	II	7*
Primary Eye Irritation	Rabbit	Slight irritation (resolved within 24 hrs)	IV	8*
	Rabbit	Mild irritation	III	9*
Primary Dermal Irritation	Rabbit	Mild irritation (resolved within 7 days)	IV	10*
Dermal Sensitization	Guinea pig	Not sensitizing	NA	11*
Acute Delayed Neurotoxicity	Hen	No delayed neurotoxicity or other effects at HDT	NOEL>100 mg/kg/d	12*

[a] References: 1.Stebbins (1996b); 2. Nissimov and Nyska (1984b); 3.US EPA (2007); 4.Stebbins (1996a); 5. Nissimov and Nyska (1984a); 6. Buch (1980); 7. Landry et al. (1986); 8. Stebbins (1996e); 9.Buch and Gardner (1980); 10.Stebbins (1996d);11.Stebbins (1996c); 12. Rowe et al. (1978)
*The study was acceptable to HHA based on FIFRA guidelines.

The studies summarized in Table 7 are comprised of acute oral, dermal, or inhalation exposure to rats, mice, and rabbits during gestation, as neonates (pre-weaning), or as adults, as well as exposures to humans in order to compare AChE-related effects. Treatments are comprised of a single dosing or up to 10 days dosing by gavage, subcutaneous injection, dermal, or inhalation exposure. Study descriptions are found in greater detail in several sources (US EPA, 2007; US EPA, 2011b; US EPA, 2014a); See also Appendix 1 of this document). Findings from some of the open literature studies are described below.

Table 7. ChE Inhibition with Acute or Short Term (~2 week) Exposure to CPF and the Respective NOELs and LOELs

Species	Exposure	Cholinesterase Inhibition	NOEL mg/kg/d	LOEL mg/kg/d	Ref [a]
Oral Gavage or Subcutaneous Treatment to Pup/Neonate/Adult					
Rat SD M/F	Gavage c.o. or milk[b] PND 11	At 6-8 hr: ↓Plasma ChE, ↓RBC AChE ↓Brain AChE	Plasma: 0.5 RBC: 0.5 Brain 2.0	Plasma: 2.0 RBC: 2.0 Brain: 5.0	1
Rat SD M/F	Gavage c.o. PND 11-21	At 10 days 6 hr: ↓Plasma ChE ↓RBC AChE ↓Brain AChE	Plasma: 0.1 RBC: 0.1 Brain: 0.5	Plasma: 0.5 RBC: 0.5 Brain: 1.0	1
Rat SD M/F	Gavage c.o. PND 10-16[c]	At: 4 hr PND 16: ↓Plasma ChE ↓Brain AChE	Plasma: -- Brain: --	Plasma: 1.0 Brain: 1.0	2
Rat SD M/F	Gavage c.o. PND 10-16 [c]	At 4, 12, 24, & 48 hr PND 16: ↓Plasma ChE ↓Brain AChE	**Brain: --**	Brain: 1.0 (lowest dose tested)	3
Rat SD M/F	Gavage c.o. PND 10-16 [c]	At 4-10 hr PND 16: ↓Plasma ChE ↓Brain AChE	Plasma: – Brain: 0.5	Plasma: 0.5 Brain: 1.0	4
Rat SD M/F	Gavage c.o. PND 10-16 [c]	At 12 hr PND 16: ↓Bain AChE	Brain: 0.75	Brain: 1.0	5

Species	Exposure	Cholinesterase Inhibition	NOEL mg/kg/d	LOEL mg/kg/d	Ref [a]
Rat SD M/F	Gavage c.o. PND 10-16 [c]	At 12 hr PND 16: ↓Brain AChE	Brain: 0.75	Brain: 1.0	6
Rat M	Gavage c.o. PND 17	At 4 hr: ↓Whole blood AChE ↓Brain AChE	$BMDL_{10}$ [d] Blood: 0.43 Brain: 1.54	BMD_{10} [c] Blood: 0.62 Brain: 1.89	7
Rat SD M/F	Gavage c.o. Single treatment: PND 5, 12, 17	PND 5, 12, 17 at 3, 6 & 24 hr, respectively: ↓Plasma ChE, ↓RBC AChE ↓Brain AChE	RBC: -- Plasma: -- Brain: --	Plasma: 1.0 RBC: 1.0 Brain : 1.0	8
Rat SD M/F	Gavage c.o. PND 1-6 Tested PND 4, 7, 12	All time points: ↓Brain AChE	Brain: --	Brain: 1.5	9
Rat SD M/F	Gavage c.o. PND 1-21, 1-5, 6-13, 14-21	At 6 hr-9d PND 6, 12, 22, 30: ↓Brain AChE	Brain: --	Brain: 1.5	10
Rat SD M/F	Gavage c.o. PND 1-4 or 1-8	At 4 hr: PND 1-4: ↓Brain AChE	Brain: --	Brain: 1.0	11
Rat SD M/F PND 7 (neonate) PND 21 Adult 90d	Gavage Peanut Oil **Acute:** PND 7, 21 or 90 **Repeated**: 14d starting PND 7 or 90	All ages: 1 or 14 d at 4 hr post dose: ↓Plasma ChE ↓RBC AChE ↓Brain	Neonate acute: Plasma: 1.5 RBC: 0.75 Brain: 1.5 Neonate repeated: Plasma: 0.75 RBC: 0.75 Brain: 0.75 Adult acute: Plasma: 1.5 RBC: 0.75 Brain: ≥15 Adult repeated: Plasma: 0.45 RBC: 0.15 Brain: 1.5	Neonate acute: Plasma: 4.5 RBC: 1.5 Brain: 4.5 Neonate repeated: Plasma: 1.5 RBC: 1.5 Brain: 1.5 Adult acute: Plasma: 4.5 RBC: 1.5 Brain: ≥15 Adult repeated: Plasma: 0.75 RBC: 0.45 Brain: 4.5	12
Rat ? M/F	s.c. DMSO (1 ml/kg) PND 1-4	At 24 hr:↓Brainstem AChE	Brain: --	Brain: 1.0	13
Rat SD M/F	s.c. DMSO (1 ml/kg) PND 1 (1 dose only)	At 2 hr:↓Brainstem, cerebellum & forebrain AChE	Brain: --	Brain: 1.0	14
Mouse NMRI Pup M	Gavage 1:10 egg lecithin + peanut oil PND 10	↓ Brain AChE (only tested at 5.0 mg/kg/d)	Brain: <5.0 (only dose level for AChE)	Brain: 5.0	15
Oral Gavage or Subcutaneous Treatment to Dams During Gestation (Including DNT)					
Rat SD F	Gavage c.o. GD 6-PND 10 Test GD 20, PND 1,5 & 11	Dam GD 20 (24 hrs): ↓Plasma ChE, ↓RBC AChE ↓Brain AChE Pup: ↓Plasma ChE, ↓RBC AChE ↓ Brain AChE	Dam: Plasma: -- RBC: 0.3 Brain: 0.3 Pup: Plasma: 1.0 RBC: 1.0 Brain: 1.0	Dam: Plasma: RBC: 0.3 Brain: 1.0 Pup: Plasma: 5.0 RBC: 5.0 Brain: 5.0	16
Rat F-344 F	Gavage c.o. GD 6-15	At GD 21: ↓ Plasma ChE ↓RBC AChE	Dam: Plasma: 0.1 RBC: 0.1	Dam: Plasma: 3.0 RBC: 3.0	*17
Rat CD F	Gavage c.o. GD 6-15	At GD 20:↓ Plasma ChE	Plasma: --	Plasma: 0.5	*18
Rat Crl:CD7(SD) BR VAF/Plus F	Gavage c.o. GD6-LD 11	LD 22: ↓Plasma ChE, ↓RBC AChE ↓ Brain AChE	Dam: Plasma: -- RBC: -- Brain: 0.3	Dam: Plasma: 0.3 RBC: 0.3 Brain: 1.0	*19

Species	Exposure	Cholinesterase Inhibition	NOEL mg/kg/d	LOEL mg/kg/d	Ref [a]
Rat SD F	Gavage c.o. GD6-20	GD 20: ↓Plasma ChE, ↓RBC AChE ↓ Brain AChE	Dam: Plasma: -- RBC: -- Brain: 0.3	Dam: Plasma: 0.3 RBC: 0.3 Brain: 1.0	20
Mouse CF-1 F	Gavage cottonsee oil GD 6-15	At GD 18: ↓ Plasma ChE ↓RBC AChE	P0: Plasma: 0.1 RBC: 0.1	P0: Plasma: 1.0 RBC: 1.0	*21
Rabbit HY/CR-NZW F	Gavage c.o. GD 7-19	At GD 17d:↓ Plasma ChE	Dam: Plasma --	Dam: Plasma 2.5	*22
Rat SD M/F	s.c. DMSO (1 ml/kg) GD 9-12 or GD 17-20	At GD 21: ↓Brainstem & forebrain AChE	Brain: -- Only 1 dose level	Brain: 5.0	23
Adult Treatment					
Rat SD M/F	Gavage c.o. 10 d	At 6-8 hr D 10:↓Plasma ChE ↓Brain AChE	Plasma: 0.1 RBC: 0.1 Brain: 0.5	Plasma: 0.5 RBC: 0.5 Brain: 1.0	1
Rat SD F	Gavage c.o. Single dosing	At 8 hr: ↓Plasma ChE, ↓RBC AChE ↓Brain AChE	Adult: Plasma 0.5 RBC: 0.5 Brain: 2.0	Adult: Plasma: 2.0 RBC: 2.0 Brain: 10	1
Mouse C57Bl/6J M	s.c. DMSO (1 ml/kg); 1d or 5d	At 3-24 hr 5 injections: ↓Brain AChE	Brain: --	Brain: 5.0	24
Human M	1 dose (methylene chloride on a 0.5-g lactose tablet)	At 1-30 d: No significant effect on Plasma ChE	Plasma: --	Plasma: >0.5 (Only 1 dose level)	25
Human M/F	Powder in gelatin capsule[e]	At 2, 4, 8, 12, 24, 36, 48, 72, 96, 120, 144, and 168 hours post dose. ↓RBC AChE (1 subject)	RBC: 1.0	RBC: 2.0	26
Dermal Treatment					
Rat F344 F	Dermal c.o. 6 hr/d 4d	↓Plasma ChE ↓RBC AChE	Plasma: 1.0 RBC: 1.0	Plasma: 10.0 RBC: 10.0	27
Human M	1 exposure; dissolved in methylene chloride	No significant effect on Plasma ChE	Plasma: --	**Plasma:** >5 (Only 1 dose level)[f]	28
Inhalation Treatment (mg/m^3)					
Rat Crl:CD (SD) M/F	Aerosol Nose Only; 2-6 hrs	↓Plasma ChE ↓RBC AChE ↓Brain AChE	Plasma: – RBC: 3.7 Brain: 22.1	Plasma: 3.7 RBC: 12.9 Brain: 53.5	29
Rat CD(SD): Crl F	Vapor Nose Only; single dose	No significant effects on Plasma ChE, RBC or Brain AChE	Plasma: – RBC: -- Brain: --	Plasma: >0.254 RBC: >0.254 Brain: >0.254	30
Rat F-344 M/F	Vapor Nose only or Whole Body 6 hr	↓Plasma ChE in whole body exposure (attributed to oral ingestion or dermal exposure)	Plasma: 50.1	Plasma: 100.2	31

[a] References: 1. Marty et al. (2012), Marty and Andrus (2010); 2. Carr *et al.* (2011); 3. Carr et al. (2013); 4. Carr *et al.* (2014); Carr *et al.* (2015a); 5. Carr *et al.* 2015; 6. Carr 2017; 7. Moser et al. (2006); 8. Timchalk et al. (2006); 9. Betancourt and Carr (2004); 10. Richardson and Chambers (2005); 11. Guo-Ross et al. (2007); 12. Zheng et al. (2000); 13. Song et al. (1997); 14. Dam et al. (2000); 15. Mattsson *et al.* (2000a); 16. Ouellette et al. (1983); 17. Rubin et al. (1987a); 18. Hoberman (1998); 19. Maurissen et al. (2000); 20. Deacon et al. (1979); 21. Rubin et al. (1987b); 22. Qiao et al. (2002); 23. Speed et al. (2012); 25. Nolan et al. (1984); 26. Kisicki et al. (1999); 27. Calhoun and Johnson (1988); 28. Nolan et al. (1982); Griffin et al. (1999); 29. Hotchkiss et al. (2010); 30. Hotchkiss et al. (2013); 31. Landry *et al.* (1986b).

[b] Milk and corn oil (c.o.) results were the same for males and females except brain AChE with milk: NOEL: 2.0 M and 0.5 F

[c] Time of greatest post-natal brain development (PND 10-16)

[d] BMD and BMDL calculated by (US EPA, 2011a)
[e] Human volunteers treated at 0.5, 1.0 and 2.0 mg/kg CPF
[f] Reported as internal dose by (Hotchkiss et al., 2010)
* The study was acceptable to HHA based on FIFRA guidelines.
No NOEL denoted by –

II.D. Subchronic Toxicity

A number of acceptable Health Effects Test guideline subchronic studies are available for CPF as shown in Table 7, above. Table 8 focuses on NOELs and LOELs for plasma, RBC, and brain ChE inhibition in rats, mice, and dogs after oral, dermal, or inhalation exposure. Table 9 reports subchronic overt (non-ChE) effects in some of the same studies described in Table 7 (detailed in Appendix 1).

Table 8. AChE Inhibition with Subchronic Exposure to Chlorpyrifos and Respective NOELs and LOELs

Species	Exposure	Cholinesterase Inhibition	NOEL mg/kg/d	LOEL mg/kg/d	Ref [a]
Oral					
Rat F-344 M/F	Diet 13 Weeks	↓ Plasma ChE	Plasma: 0.1	Plasma: 1.0	1*
Rat SD M/F	Diet 2-Generation Reproduction	↓ Plasma ChE ↓ RBC AChE	Plasma: 0.1 RBC: 0.1	Plasma: 1.0 RBC: 1.0	2*
Rat Long-Evans F	Gavage c.o. 4 weeks	↓ Plasma ChE ↓ RBC AChE ↓ Brain AChE	Plasma: -- RBC: -- Brain: --	Plasma: 1.0 RBC: 1.0 Brain: 1.0	3*
Rat SD F	Diet 28 d	↓ RBC AChE ↓ Brain AChE	RBC: -- Brain: 0.4	RBC: 0.4 Brain: 2.0	4*
Rat Wistar M	Gavage c.o. 90 days	↓ Plasma ChE ↓ Brain AChE	Plasma: -- Brain: 1.3	Plasma: 1.3 Brain: 3.26	5
Beagle Dog M/F	Diet 6 weeks	↓ RBC AChE	RBC: --	RBC: 0.5	6
Dermal					
Rat F-344 M	21d, 6hr/d, 5d/wk	No effects	--	>5	7
Mice Balb/c M Adult (150 d) Pup (18 d)	4 hr/d, 2 weeks: 1 dose level administered on the tail	Pup/Adult: ↓ Plasma ChE	Pup/Adult: Plasma: --	Plasma: Pup/Adult: 101 Only 1 dose	8
Inhalation (mg/m^3)					
Rat F-344	Vapor, whole body	↓Plasma ChE	Plasma: 50	Plasma: 86	9*
Rat F-344 M/F	Vapor, Nose-only; 6 hr/d, 5d/wk, 13 weeks	No RBC, plasma, or brain ChE inhibition	--	>0.295	10
Rat F-344 M/F	Vapor, Nose-only; 6 hr/d, 5 d/wk, 13 wk	↓Plasma ChE	Plasma: 0.14 RBC: -- Brain: --	Plasma: 0.28 RBC: >0.28 Brain: >0.28	11

[a] References: 1. Szabo et al. (1988); 2. Breslin et al. (1991); 3. Maurissen et al. (1996); 4. Boverhof et al. (2010); 5. Wang et al. (2014); 6. Marable et al. (2001); 7. Calhoun and Johnson (1988); 8. Krishnan et al. (2012); 9. Landry et al. (1986a); 10.Corley et al. (1986); 11. Newton (1988)
*The study was acceptable to HHA based on FIFRA guidelines.
AChE: acetyl cholinesterase; RBC: red blood cell
No NOEL denoted by –

Table 9. Overt Effects with Subchronic Exposure to Chlorpyrifos and Respective NOELs and LOELs

Species	Exposure	Effects	NOEL mg/kg/d	LOEL mg/kg/d	Ref [a]
Oral					
Rat SD M/F	Diet 2-Generation Reproduction	Parental:↑ vacuolation in the adrenal zona fasciculata, altered tinctorial properties in this tissue. Pup: ↓pup weights & pup survival	Parent/Pup: 1.0	Parent/Pup: 5.0	1*
Rat F-344 M/F	Diet 13 Week Neurotoxicity	↑ clinical signs, ↑FOB, motor activity effects	1.0	5.0	2*
Rat Long-Evans F	Gavage Corn Oil 4 weeks	↑miosis & clinical signs; motor slowing and/or ↓ motivation (↑"actual total delay", ↑ "void trials", ↓numbers of nose-pokes/trial).	1.0	3.0	3*
Rat SD F	Diet 28 d Immunotoxicity assay	↓absolute & relative spleen & thymus weights; ↑anti-SRBC assay effects [b]	0.4	2.0	4*
Dermal					
Rat F-344 M/F	21 day dermal	No overt effects	5	LOEL>5	5
Inhalation [c]					
Rat -344 M/F	Aerosol, Nose-only; 6 hr/d, 5 d/wk, 13 wk	No overt effects	--	>0.286 mg/m^3	6

[a]References: 1. Breslin et al. (1991); 2. Shankar et al. (1993); 3. Maurissen (1996); 4. Boverhof et al. (2010); 5. Calhoun and Johnson (1988); 6. Newton (1988)

[b] The Boverhof et al. (2010)females (10/dose) showed that the hematology parameters were not affected by CPF at any dose. The anti-SRBC IgM serum titers were less at 2 and 10 mg/kg/d (not dose-related manner; i.e., the titers for 2 and 10 mg/kg groups were 36 and 59% of the control group, respectively); considered equivocal based on the range of variability demonstrated in the control group values and the lack of a clear dose-response. Other parameters (spleen and thymus weights, white blood cell differential counts) did not indicate any suppression of immunopotency.

[c]- No subchronic inhalation studies with reported overt effects.

* The study was acceptable to HHA based on FIFRA guidelines

No NOEL denoted by –

II.E. Chronic Toxicity/Carcinogenicity

II.E.1. Animal Carcinogenicity

A number of acceptable Health Effects Test guideline chronic studies submitted by the registrant are available for CPF as shown below. Table 10 focuses on NOELs and LOELs plasma, RBC, and brain AChE in rats, mice, and dogs after oral exposure. Table 11 reports chronic overt (non-AChE) effects. There was no significant increase in tumors with any of these long-term studies. These studies are more fully described in the HHA Summary of Toxicology Data (Appendix 1). CPF is not considered to be a carcinogen.

Table 10. ChE Inhibition with Chronic Exposure to Chlorpyrifos and the Respective NOELs and LOELs

Species	Exposure	Cholinesterase Inhibition	NOEL mg/kg/d	LOEL mg/kg/d	Ref [b]
Oral [a]					
Rat F-344 M/F	Diet 2 yr	↓ Plasma ChE ↓ RBC AChE ↓ Brain AChE	Plasma: 0.1 RBC: 0.1 Brain: 1.0	Plasma 1.0 RBC: 1.0 Brain: 10	1*
Rat F-344M/F	Diet 2 yr	↓ Plasma ChE ↓ RBC AChE ↓ Brain AChE	Plasma: 0.2 RBC: 0.2 Brain: 5.0	Plasma: 5 RBC: 5 Brain: 100	2*
Dog Beagle M/F	Diet 2 yr	↓ Plasma ChE ↓ RBC AChE ↓ Brain AChE	Plasma: 0.01 RBC: 0.03 Brain: 1.0	Plasma: 0.03 RBC: 0.1 Brain 3.0	3*
Mouse CD-1	Diet 79 wks	↓ Plasma ChE ↓ RBC AChE ↓ Brain AChE	Plasma: -- RBC: 0.9 Brain: 9.1	Plasma: 0.9 RBC: 9.1 Brain: 43.9	4*

[a] No chronic dermal or inhalation studies
[b] References: 1. Young and Grandjean (1988); 2. Crown (1990); 3.McCollister et al. (1971); 4. Gur (1992)
* The study was acceptable to HHA based on FIFRA guidelines.
No NOEL denoted by –

Table 11. Overt Effects with Chronic Exposure to Chlorpyrifos and the Respective NOELs and LOELs

Species	Exposure	Effects	NOEL mg/kg/d	LOEL mg/kg/d	Ref [b]
Oral [a]					
Rat F-344 M/F	Diet 2 yr	↓body weight; perineal yellow; vacuolation of the adrenal zona fasciculate; ↑diffuse retinal degeneration	1.0	10	1*
Rat F-344 M/F	Diet 2 yr	↓body weight; diffuse retinal atrophy & cataracts	1.25	50	2*
Dog Beagle M/F	Diet 2 yr	No systemic or non-ChE effects	--	LOEL> 61.7	3*
Mouse CD-1 M/F	Diet 79 wks	↓body weight, food & water consumption; ↑clinical signs; ↑Hepatocytic fatty vacuolation: centrilobular, Ulcerative dermatitis; Keratitis, panophthalmitis or endophthalmitis; accumulation of alveolar macrophages in lungs & septal thickening; bulbourethral gland cystic dilatation	0.78	7.9	4*

[a] No chronic dermal or inhalation studies
[b] References: 1. Young and Grandjean (1988); 2. Crown (1990); 3. McCollister et al. (1971); 4. Gur (1992)
* The study was acceptable to HHA based on FIFRA guidelines.
No NOEL denoted by --

II.E.1. Human Carcinogenicity

The Agricultural Health Study was conducted between 1993-1997 to investigate occupational pesticide exposure among farmers and commercial pesticide applicators and risk of cancer and other chronic diseases (Lee et al., 2004). The design was to examine risk factors for specific diseases (e.g., lung cancer) and then to focus on risk to subgroups with specific exposures. Participants were from Iowa and North Carolina and were characterized as <40 to ≥60 years

(n=57,311). Study enrollees completed questionnaires and cohort members were matched to cancer registries in Iowa and North Carolina and the National Death Index annually for case identification from 1993 through 2001. Questionnaires were self-administered to obtain comprehensive exposure data for 22 pesticides and ever/never use data for 28 pesticides, along with personal protective equipment used, pesticide application methods, pesticide mixing status, equipment repair methods, smoking history, alcohol consumption, history of cancer in first-degree relatives, and basic demographic data. The study participants also had a take-home questionnaire with questions having to do with detailed occupational and medical history and diet. The take-home questionnaire was returned by 24,671 pesticide applicators (43%). Most of the cohort (>60%) were less than 50 years of age and more than 50% were never smokers.

Lee et al. (2004) focused on CPF since it is widely used nationally. Questionnaire answers indicated that among the subjects with complete exposure data, 22,181 (41%) had used CPF. In order to evaluate a potential association between CPF exposure and cancer incidence, a Poisson regression analysis was used (after adjustment for potential confounders; two-sided). A CPF association for both lung cancer incidence and CPF intensity-weighted exposure days was reported. Subjects in the highest quartile for life-time of exposure-days (>56), along with adjustments for other pesticide exposures and demographics had a relative risk for lung cancer of 2.18 times (95% confidence interval: 1.31 to 3.64) that of subjects who were not exposed. The increased lung cancer risk was primarily limited to smokers who received the longest exposure (>56 days). In addition, the CPF-exposed applicators used this pesticide for an average of 6.6 years and for 9.4 days/year, with the highest quartile at >56 days (224 mean; 116 median) lifetime exposure-days. The authors defined pesticide applicators who used CPF as "exposed" and those who did not use CPF as "nonexposed." However, since CPF is so widely used, there is the possibility that these subjects received CPF exposure by non-occupational routes, leading to potential misclassification of exposure. In addition, product formulation and application methods for CPF have changed since the 1997 completion of the study, so the author caution that the data should be interpreted with that fact in mind (Lee et al., 2004).

Lee et al. (2007), used results from the Agricultural Health Study cohort of pesticide applicators described in Lee et al. (2004) to investigate incidence of rectal cancer associated with pesticide exposure. There were 50 pesticides which were analyzed for associations with colorectal cancer and occupational exposures. Pesticide applicators with no prior history of colorectal cancer (n=56,813) were included. Cancer registries showed that 212 colon and 93 rectal cancers were diagnosed in this cohort from the time of enrollment (1993) to 2002. CPF had an exposure response for rectal cancer at a 2.7-fold (95% confidence interval: 1.2–6.4) higher risk at the highest exposures (highest quartile of exposure days: >56). The study authors indicated that a potential confounder is subject recall bias associated with CPF use. Since there were 50 pesticides with multiple comparisons in this study, some statistically significant associations may have been due to chance alone. The authors suggest that further research is warranted.

Waddell et al. (2001) conducted a study with pooled data from three population-based case-control studies conducted in Kansas, Nebraska, Iowa, and Minnesota. They investigated the potential for an association between organophosphates (OP) use and non- Hodgkin's lymphoma (NHL) among white male farmers. Iowa/Minnesota subjects (≥age 30; n=780) with diagnosed NHL between 1981 and 1983. Nebraska subjects with NHL were diagnosed between 1983 and 1986 (≥age 21 years; n = 227). Telephone interviews were performed to obtain data on demo

graphics, medical conditions, family history of cancer, tobacco and alcohol use, occupation, agricultural practices, hobbies, and an abbreviated dietary history. The interview also involved detailed questions about agricultural practices, personal use of specific pesticides, years of use, days per year of use, protective practices, livestock and crops grown, and other farm-related activities. Persons who reported actual use of pesticides were considered to be exposed. The control subjects (n = 3379) were selected from the Health Care Financing Administration records. They were matched to living cases (≥65 years) by state, race, gender, 5-year age group, and vital status at the time of interview. The control subjects for the cases who were deceased were from state mortality records that were matched for year of death. There were 993 cases and 2918 controls who were actually interviewed Data were evaluated by calculating odds ratios (ORs) and 95% confidence intervals (CIs) by logistic regression analysis using a SAS program. Results among farmers showed 158 cases and 279 controls who had used OPs, including 117 direct and 41 proxy respondents among cases and 224 direct and 55 proxy respondents among controls (proxy majority = spouses). CPF OP was not mentioned in this study, although several others were (diazinon, malathion, and terbufos).

II.F. Genotoxicity

CPF is not mutagenic in bacteria (Simmon et al., 1977; Bruce and Zempel, 1986a; Bruce and Zempel, 1986b) or mammalian cells (Mendrala, 1985), but did cause slight DNA damage in yeast (Simmon et al., 1977). Mitotic recombination-gene conversion in yeast exposed to a 5% concentration of CPF for 4 hours, with and without metabolic activation was studied. No individual data were presented and without this the significance of the effect cannot be evaluated however, the possible genotoxic effect must be noted.

CPF did not result in DNA damage in human embryo fibroblasts or rat primary hepatocytes *in vitro* (Simmon et al., 1977; Mendrala and Dryzga, 1986). CPF was not clastogenic in the mouse micronucleus test *in vivo* (McClintock and Gollapudi, 1989). CPF did not induce unscheduled DNA synthesis in isolated rat hepatocytes (Mendrala, 1985). Mehta et al. (2008) treated male Wistar rats with CPF for 1, 2 or 3 days at 50 or 100 mg/kg/d or for 90 days at 1.12 or 2.24 mg/kg/d. Results showed increased DNA damage in liver and brain at all doses tested in all dosing regimens, especially at acute levels. This is likely because the treatment levels were above the maximally tolerated dose and excessively high, particularly at the acute levels. Therefore, it was not surprising that some form of cytotoxicity was noted. This study had several deficiencies, including the lack of cytotoxicity data, there was no positive control, the animals were treated intramuscularly, and data analysis was based on data point rather than number of animals. Rahman et al. (2002) tested CPF for the ability to induce *in vivo* genotoxic effect in leucocytes of Swiss albino mice using the single cell gel electrophoresis assay or comet assay. The mice were gavaged with CPF (0.28 to 8.96 mg/kg; no vehicle description; dosing schedule not described so single acute doses were assumed). Body weight and whole blood leukocytes were examined at 24, 48, 72, and 96 h. There was a dose-related increase in mean comet tail length, indicating DNA damage was observed at 24h post-treatment ($p<0.05$) with CPF in comparison to control. At 72 hours, all DNA effects were repaired except at > 4.48 mg/kg. By 96 h post-treatment, the mean comet tail length reached control levels indicating repair of the damaged DNA. This study had numerous deficiencies, including a lack of description of statistical analysis and no positive control.

II.G. Reproductive Toxicity

CPF (98.5% pure) was fed in the diet to Sprague-Dawley rats from premating through F_2 weaning (2 generations, 1 litter/generation) (Breslin et al., 1991). Concentrations were adjusted as needed to achieve exposures of 0, 0.1, 1.0, and 5.0 mg/kg/d. Treatment began approximately 10 and 12 weeks prior to breeding for the F_0 and F_1 adults, respectively. The ChE inhibition NOEL was 0.1 mg/kg/d based on decreased plasma and RBC AChE at 1.0 and 5.0 mg/kg/d (see Table 12). The parental NOEL was 1.0 mg/kg/d based on increased degree of vacuolation in zona fasciculata especially in males, as well as altered tinctorial properties in females. The reproductive NOEL was 1.0 mg/kg/d based on slightly reduced pup weights and slightly reduced pup survival at 5.0 mg/kg/d. There were no clinical signs specifically indicating cholinesterase inhibition. The reproductive findings at 5 mg/kg/d do not warrant a "possible adverse effects" designation, since brain cholinesterase levels were very markedly depressed at that dose level and all observed reproductive effects appeared to be due to failure of dams to nurture pups.

II.H. Developmental Toxicity

Table 12 summarizes acceptable Health Effects Test guideline CPF studies submitted by the registrant as well as open literature studies. All studies are detailed Appendix 1 as well as in the US EPA risk assessment documents (US EPA, 2007; US EPA, 2011a; US EPA, 2014a). The developmental studies reported below focus on overt effects and ChE inhibition in rat, mouse, and rabbit dams and fetuses after oral or dermal exposure of CPF to dams during gestation and in some cases to pups during the pre-weaning period. CPF was not teratogenic however; developmental delays (delayed ossification, decreased birth weight and lower crown-rump length) and increased implantation loss were observed at higher doses in rats, mice, and rabbits.

Table 12. Developmental Effects of CPF and the Respective NOELs and LOELs

Species	Exposure	Effects[a]	NOEL mg/kg/d	LOEL mg/kg/d	Ref [b]
Oral Gavage Treatment to Dams During Gestation (including DNT)					
Rat F-344	Gavage GD 6-15 Cottonseed o	**Dam:** Cholinergic signs, clinical signs, ↓ body weight gain, enlarged adrenals **Fetus**: No developmental effects	Dam: 3.0 Fetus: 15	Dam: 15 Fetus: >15	1*
Rat CD	Gavage GD 6-15 Cottonseed o	**Dam:** Tremors, ↓ food consumption; ↓body weight **Fetus**: ↑post-implantation loss	Dam/Fetus: 2.5	Dam/Fetus: 15	2*
Mice CD-1	Gavage GD 6-15 Cottonseed o	**Dam**: Cholinergic signs, ↓ food and water consumption, ↓body weight gain **Fetus**: ↓live fetuses; ↓body weight; ↓crown-rump length; ↑delayed ossification in skull & sternabrae	Dam: 1.0 Fetus: 10	Dam: 10 Fetus: 25	3*
Rabbit HY/CR-NZW	Gavage GD 7-19 c.o.	**Dam:** ↓body weight gain **Fetus:** ↓body weight; ↓crown-rump length; ↑delayed ossification in 5th sternabrae & xiphisternum	Dam/Fetus: 81	Dam/Fetus: 140	4*
Dermal Treatment Pups and Adults					
Mice Balb/c M Adult (150 d) Pup (18 d)	4 hr/d, 2 weeks: 1 dose only	**Adult:** Dissolution of Nissl granules[c]; ↑GPAF[d] **Pup:** pyknosis in Purkinje neurons in cerebellum	Only 1 dose--	Pup/Adult: 101 Pup/Adult	5

[a] Effects on plasma, RBC and brain cholinesterase inhibition for these studies shown in Table 7 above.
[b] References: 1. Ouellette et al. (1983); 2. Rubin et al. (1987a); 3. Deacon et al. (1979); 4. Rubin et al. (1987b); 5. Krishnan et al. (2012)
[c] Nissl granules: free ribosomes in neuronal rough endoplasmic reticulum that are a site of protein synthesis.
[d] GPAF Glial fibrillary acidic protein, necessary for regulating astrocyte motility(Pekny et al., 1999) .
* The study was acceptable to HHA based on FIFRA guidelines.
No NOEL denoted –

Table 13. Effects of Chlorpyrifos on the Endocannabinoid System in Pre-Weaning Sprague-Dawley Rats

Dose	Endocannabinoid Effects[a]	NOEL mg/kg/d	LOEL mg/kg/d	Ref [b]
Oral Gavage Treatment to Pups/Neonates (Males and Females Gavaged with Corn Oil PND 10-16)				
1, 2.5, 5.0 mg/kg/d	↓Brain MAGL & FAAH activity ↓2-AG & AEA hydrolysis (4 hr termination)	MAGL: -- FAAH: -- AEA: -- 2-AG: --	MAGL: 1.0 FAAH: 1.0 AEA: 1.0 2-AG: 1.0	1
1.0, 2.5 or 5.0 mg/kg/d	↓Brain MAGL & FAAH at 4 hrs post-terminal dose ↓2-AG & AEA hydrolysis at 12 hrs post terminal dose	MAGL: -- FAAH: -- AEA: -- 2-AG: --	MAGL: 1.0 FAAH: 1.0 AEA: 1.0 2-AG: 1.0	2
0.5, 0.75 or 1.0 mg/kg/d	↓FAAH activity at 4 & 12h; ↑AEA	FAAH: -- AEA: --	FAAH : 0.5 AEA: 0.5	3
0.5, 0.75 or 1.0 mg/kg/d	↓Brain MAGL & FAAH activity ↓2-AG & AEA hydrolysis;	MAGL: 0.75 FAAH: -- AEA: -- 2-AG: 0.5	MAGL: 1.0 FAAH: 0.5 AEA: 0.5 2-AG: 0.75	4*
0.5, 0.75 or 1.0 mg/kg/d	↓MAGL ↓FAAH activity ↓2-AG hydrolysis, at 12 hr post terminal dose.	MAGL: 0.75 FAAH: -- 2-AG: 0.75	MAGL: 1.0 FAAH: 0.5 2-AG: 1.0	5

[a] Effects on plasma, RBC and brain cholinesterase inhibition for these studies shown in Table 7 above.
[b] References: 1. Carr et al. (2011); 2. Carr et al. (2013); 3. Carr et al. (2014); 4. Carr et al. (2015a); 5. Carr et al. 2017
* The study was acceptable to HHA based on FIFRA guidelines.
No NOEL denoted –
Abbreviations: AEA - anandamide; 2-AG - 2-arachidonoylglycerol; FAAH - fatty acid amide hydrolase; MAGL - monoacylglycerol lipase;

US EPA has not established a critical NOEL based on brain AChEI. Their critical acute PoDs in the 2011 and 2014 Preliminary and Revised Human Health Risk Assessments are based on 10% RBC AChEI. The critical PoD in the 2006 RED was based on plasma ChEI with a NOEL = 0.5 mg/kg/d. Table 14 compares RBC and brain AChEI in non-pregnant and pregnant rats (after 11 and 15 doses of CPF). The NOEL ($BMDL_{10}$) for brain AChE is at about 3-fold higher than RBC in non-pregnant animals and approximately 18-fold higher in pregnant animals.

Table 14. Comparison of RBC AChE and Brain AChE Inhibition in Rat Studies

Endpoint	Response	Comments
Repeated Dose ChEI - male and female rats (Hoberman, 1998; Mattsson et al., 1998; Maurissen et al., 2000; Marty and Andrus, 2010)	Female rats, 11 days (CCA) BMD10/BMDL10: RBC AChEI: 0.45/0.35 Brain AChEI: 1.03/0.95 mg/kg/d	Pregnant female rats more sensitive than non-pregnant female rats for RBC and Brain AChEI
	Female pregnant rats GD6-20; 15 days (DNT) BMD10/BMDL10: RBC AChEI: 0.06/0.03 mg/kg/d Brain AChEI: 0.65/0.54 mg/kg/d	RBC AChEI: 7.5-12 fold more sensitive Brain AChEI: 1.6-1.8 fold more sensitive

CCA: comparative cholinesterase study (Table from US EPA 2011a; page 25)

II.I. Behavior and Developmental Neurotoxicity

Studies that reported neurobehavioral and neurodevelopmental effects after CPF treatment included a developmental neurotoxicity study (DNT) submitted by the registrant, as well as published studies. These studies are detailed in the HHA Summary of Toxicology Data (Appendix 1), in the US EPA risk assessment documents (US EPA, 2007; US EPA, 2011a; US EPA, 2014a) and in a recent review of the neurodevelopmental effects of organophosphates (Lim and Bolstad, 2017). Table 15 focuses on neurobehavioral effects in pups that were treated with CPF postnatally and/or after rat or mouse pregnant dams were treated with CPF by oral gavage, diet, subcutaneous injection or dermally. Some citations overlap with those in Tables 7 and 13 but the focus in Tables 15 and 16 is specifically on neurobehavioral effects.

The studies were divided into two tables based on routes of exposure. Table 15 includes data with animals treated with CPF orally or dermally. HHA also reviewed studies employing routes of administration that mimic expected routes of exposure in humans, if they provide information pertinent to the selection of critical PoDs. The studies presented in Table 16 reported effects in animals treated with CPF by subcutaneous injection (s.c.). In some cases, dimethylsulfoxide (DMSO) was used as a vehicle for injection. At 1 ml/kg (standard DMSO vehicle concentration) DMSO did not have effects on brain AChE inhibition or neurotoxicity in rats (Whitney et al., 1995; Carr and Nail, 2008).

The most common neurodevelopmental outcomes observed in these studies were effects on cognition, motor control and social behavior. Qualitatively similar effects have been reported in the CPF epidemiology studies. Most animal studies in Table 15 and 16 were conducted with doses that also produced AChE inhibition at some time during the exposure. While the overall evidence indicates that CPF may cause neurodevelopmental effects, HHA identify few studies that included doses lower than 1 mg/kg/day, the threshold for ChE inhibition. These studies are summarized below.

Silva et al. (2017). Silva and colleagues investigated the effects on complex behaviors (particularly anxiety and depression) in Wistar rats exposed to CPF in utero. Pregnant dams (11-14/dose) received 7 consecutive daily doses of CPF (0.01, 0.1, 1 and 10 mg/kg/day) by oral gavage on gestation days 14–20. Controls received the vehicle only---Tween20 in 9% saline (0.1

mL/mL). The last third of the gestation period was chosen because it is a critical period for fetal brain development and neurogenesis. Behavioral parameters in male offspring were evaluated twice, during the infant-juvenile period (postnatal day [PND] 21) and in adulthood (PND70). Reproductive parameters---maternal body weight and weight gain, clinical signs of toxicity, gestation length, number of implants, post-implantation losses, average weight of offspring, offspring/mother ratios, number of live births and stillbirths, and male/female ratios at birth--- were also examined. Male pups were separated into 4 groups (8-10 pups/group) comprised of those tested on PND 21 or PND70. The elevated plus-maze test was used to assess anxiety levels. The open field test was used to evaluate locomotor activity. The modified forced swimming test was used to assess depressive behavior. Neither RBC nor brain AChE levels were determined in dams or pups. Gestational exposures to 10 mg/kg/day CPF resulted in reduced body weight gains in mothers during the treatment period. Maternal toxicity was not observed at lower doses. There were no clinical signs or effects on pregnancy that could be attributed to treatment. PND21 pups exposed in utero to 0.1 mg/kg/day showed anxiety-like behaviors, evident both in the statistically reduced times they spent in the open arms of the elevated plus-maze and in the increased locomotor activities detected in the open-field tests ($p < 0.05$ for both). Statistically significant effects were also observed at 1 and 10 mg/kg/day, though dose-dependent increases were not observed. There was no effect of CPF on depressive-like behavior as evaluated in the modified forced swimming test. PND70 animals did displayed neither anxiogenic nor motor activity behaviors. As with the PND21 animals, no changes in depressive behavior were detected in the modified forced swimming test. The authors concluded that CPF treatment during pregnancy induced anxiogenic behavior in pups at the end of lactation (PND21). As a result, they set the LOEL for neurodevelopmental effects at 0.1 mg/kg/day. The apparent absence of a dose-related exacerbation of this response above 0.1 mg/kg/day was unexplained, but was plausibly due to saturation of one or more of the many neural pathways unquestionably involved in regulation of complex behaviors such as these. For risk assessment purposes, the most important implication of this study is that the threshold for CPF-induced neurobehavioral effects in young rats following gestational exposure may be as much as 10-fold lower than the reported threshold of 1 mg/kg/day established for RBC AChE inhibition in adult rats

Lee et al. (2015). Male NMRI mice were treated CPF to investigate whether neurotoxicity occurs during rapid brain growth and maturation. A brain AChE inhibition group received CPF by gavage at 0 (20% fat emulsion/kg b.w. [1:10 egg lecithin + peanut oil]) and 5.0 mg/kg on PND 10 (n=4/dose) in a single treatment with assays performed at 1, 3, 6, 12, 24 or 36 hours post-dose. The vehicle was designed to simulate the fat content of mouse milk (~14%) in order facilitate the physiologically accurate absorption and distribution. Another group of males were treated with a single gavage dose of CPF at 0 and 5 mg/kg for protein analysis on PND 10. These mice were terminated at 24 hours or 4 months after exposure and the hippocampus and cerebral cortex were frozen (n=5-8/dose). A third group of mice were treated with CPF by gavage on PND 10 at 0, 0.1, 1.0 and 5 mg/kg in a single dose followed by assessment at 2 or 4 months of age (n= 12/dose/time point). Results showed that brain AChE inhibition was minimal, even at 5.0 mg/kg (↓8–12% peak at 3 hrs post-dose). CaMKII and synaptophysin were decreased at 5.0 mg/kg 24 hours post-dose but was reversed at 4 months. These proteins are associated with a brain growth spurt in mice. Results of behavioral tests showed there were dose × time at 2 months of age for locomotion, rearing and total activity variables, respectively. Pairwise testing

between CPF-exposed and control groups showed a significant difference in these 3 variables at 5 mg/kg/d. Locomotion and rearing means were decreased at 1 and 5.0 mg/kg/d thus. The LOEL for behavioral effects in mice was 0.1 mg/kg based on.

Gomez-Gimenez et al. (2017). Pregnant Wistar rats (6/dose) were treated with CPF at 0, 0.1, 0.3 and 1.0 mg/kg/d GD 7-PND 21 using corn oil + sweet jelly as a dietary vehicle. The purpose of the study was to see if CPF effects are gender-related, observe effects on spatial learning after developmental exposure and if hippocampal neuroinflammation is associated with effects on spatial learning after CPF exposure during development. Pups were weaned PND 21 and were tested for spatial learning (Morris water maze, 8-arm radial maze) at 2-3 months of age. At 5-7 days after the behavioral tests, rats (7-12 males/dose/group; 5-10 females/dose/group) were terminated and the hippocampus was for proteins indicative of neuroinflammation (Iba-1, IL-4 and IL-10, IL-1β and TNF-α, GABA- α 1, GABA α 5 and GABA γ2, GluR1, GluR2, NR1, NR2A and NR2B). Results showed equivocal effects on escape latency in the Morris water maze (time to reach platform) at all doses in males and no effects on females on day 3 of testing. Males did not show a dose-response, however because 0.1 mg/kg/d showed the highest escape latency, while 0.3 and 1.0 mg/kg/d values were equivalent. Time spent in right quandrant on day 3 of testing was decreased in males at 1.0 mg/kg/d CPF and unaffected in females. Spatial reference errors (first visits to unbaited arms) on testing day 4 were increased in males at >0.3 mg/kg/d and were equal to effects at 1.0 mg/kg/d. Females showed decreases at 1.0 mg/kg/d. Working errors (visits to arms already visited in the same trial) over the 5 days of testing were increased in males at 0.3 mg/kg/d, but again, were the same at 1.0 mg/kg/d; females were not statistically significantly affected. Learning index (#correct choice ÷ #errors for first entry into each arm) at day 4 were decreased in males at >0.3 mg/kg and were again the same value at the high dose. Females were statistically significantly increased at 1.0 mg/kg/d. It is difficult to interpret the meaning of this result. Males showed decreased IL10 at 1.0 mg/kg/d, while females had decreases at >0.3 mg/kg/d. Neuroinflammation was also equivocal since only one parameter (IL10) was positive out of 13 tested in both sexes. There was a definite difference in behavioral effects between males and females (males more affected). Since many of the results reported were equivocal for males, it would have been useful to see results from all testing days to see if effects were reversed. It would also have been useful to know how many pups/dose were tested in the behavioral studies. It is presumed based on the numbers used for neuroinflammatory protein tests. Most effects occurred at >0.3 mg/kg/d in males (discounting equivocal, non-dose-response effects), however there were effects to IL10 in females at 0.3 mg/kg/d. The LOEL for neuroinflammation is 0.1 mg/kg/d for both males and females.

Several studies from Carr's laboratory provided evidence for CPF-induced behavioral effects in young rats that may occur at doses lower than the threshold established for RBC AChE inhibition. The findings from these studies were presented in Section III.A.1., Acute and Short-Term Oral Toxicity and in Tables 13 and 15.

Table 15. Neurobehavioral Effects after Pre- and Postnatal Exposure to Chlorpyrifos

Dosing Period	ChE Inhibition	ChE Testing	Domain Affected [a]	Age of Behavior Testing	NOEL LOEL mg/kg/d				Ref [b]
					Plasma ChE	RBC AChE	Brain AChE	Behavior	
Oral Gavage to Sprague-Dawley Rat Pups/Neonates or to Fetuses *In Utero*									
Gavage c.o. PND 1-21 Dose regimen[c]	Brain AChE	PND 20, 30, 40, 50	↓ cognition (↓working & ↓reference memory:M; M more affected than F	PND 29-60	NA	NA	1.0 4.0	4 6.0	1
Gavage c.o. PND 1-21 Dose regimen[d]	Plasma ChE Brain AChE BuChE	PND 25, 30	↓ motor activity (line crosses) PND 25 & 30 No M/F difference	PND 25, 30	-- 1.0	NA	-- 1.0	1.0 3.0	2
Gavage c.o. PND 10-16 0.5, 0.75 & 1.0 mg/kg/d	Not tested	NA	↑ open field effects & ↑motor activity, (elevated plus maze, chasing crawling over/ under, play fighting, playing) No M/F difference	PND 25	NA	NA	NA	-- 0.5	3
Gavage c.o. PND 10-16 0.5, 0.75 & 1.0 mg/kg/d	Not tested	NA	↑anxiety & ↓sociability (↑time of emergence into illuminated area) No M/F difference	PND 25	NA	NA	NA	-- 0.5	4
Gavage c.o. PND 10-16 0.5, 0.75 & 1.0 mg/kg/d	Brain AChE	PND 16	↓anxiety; ↑sociability (↓time to emergence from a dark container to a novel aversive environment); No M/F difference	PND 25	NA	NA	0.75 1.0	-- 0.5	5
Gavage c.o. GD 6-LD 11 0.3, 1.0, 5.0 mg/kg/d	Dam Brain AChE	LD 22	↓ motor activity ↓ neuromotor function (↓latency to peak response for auditory startle habituation) ↓parietal cortex size; ↑hippocampal gyrus alterations; No M/F difference	PND 12-71	NA	NA	1.0 5.0	-- 1.0	6*
Oral Gavage to Wistar Rat Dams									
Gavage 10% Tween 20 in saline GD 14-20 0.01, 0.1, 1.0, 10 mg/kg/d	Not tested	NA	↑cognition (↓% time in open-arm of elevated plus maze); ↑motor activity (anxiogenic behavior) Only M tested	PND 21 and 70 by PND 70	NA	NA	NA	0.01 0.1	7
c.o. + sweet jelly in diet GD 7- PND 21 0.1, 0.3, 1.0 mg/kg/d	Not tested	NA	cognition (spatial reference errors ↑M, ↓F, working errors ↑M, learning index ↓M↑F); M more affected than F	2-3 months of age	NA	NA	NA	0.1 0.3	8
Oral Gavage to Mouse Dams									
CD-1 Gavage peanut oil GD 14-17 Only 1 dose: 6.0 mg/kg/d	Not tested	NA	F: ↑anxiety, emotion & social behavior (↑thigmotaxis; ↓ latency to enter in the dark compartment, ↑time in tunnel between sides in	PND 90	NA	NA	NA	1 dose 6.0	9

			light-dark box), 5HT system involvement[f]						
NMRI Gavage 1:10 egg lecithin + peanut oil[e] PND 10 0.1, 1.0, 5.0 mg/kg/d	Brain AChE	PND 10	↓ spontaneous movement in a novel home environment (↓motor activity; ↑rearing) Only M tested	PND 60 & 120	NA	NA	Only 1 dose tested 5.0	0.1 1.0	10
Dermal Treatment to Sprague-Dawley Dams During Gestation									
1 mg/kg/d in 70% ETOH) GD 4-20	Brain AChE	PND 90	↓basic neuromotor function (↓grip time M/F, ↓incline plane degrees; F) F more affected than M	PND 90	NA	NA	Only 1 dose 1.0	1 dose 1.0	11
Long-Evans Female Rat Adult Oral									
Gavage c.o. 4 week Cognitive Study 1, 3, 10 mg/kg/d	Plasma ChE RBC AChE Brain AChE	Day 21	motor slowing and/or ↓ motivation & memory (↑actual total delay, ↑ void trials, ↓number of nose-pokes/trial)[g]	Day 21 & Day 28	-- 1.0	-- 1.0	-- 1.0	3.0 10	12

[a] Parameters include neuropathology, brain weights, morphometrics, motor activity, body temperature, auditory startle response, delayed spatial alternation, ***assessments of choice, learning and working memory*** (T-maze for spontaneous alternation, radial arm water maze, 8-arm radial maze; passive/active avoidance of a specific event, rewarded behavior), ***locomotor activity*** (open field movements, maze challenges), ***neuromotor function*** (sensorimotor function; auditory startle: latency and magnitude; prepulse inhibition [reflex response]; fore- and hindlimb grip strength; degrees on an inclined plane), ***social behavior*** (sexual behavior, rearing, play-fighting, licking), ***socioagonistic behavior*** (fighting and attacking), ***balance coordination*** (negative geotaxis on an inclined plane), ***anxiety and risk taking*** (elevated plus maze, the open field test, and the light/dark choice test) and ***depressive behaviors*** (forced swim test).

[b] References: 1. Johnson *et al.* (2009); 2. Carr *et al.* (2001); 3.Carr *et al.* (2015a); 4. Mohammed *et al.* (2015); 5. Carr *et al.* (2015b); 6. Hoberman (1998); 7. Silva *et al.* (2017); 8. Gomez-Gimenez *et al.* (2017); 9. Venerosi *et al.* (2010); 10. Lee *et al.* (2015); 11. Abou-Donia *et al.* (2006); 12. Maurissen (1996); Table adapted in part from US EPA (2014a)

[c] Dosing regimen: 0 (c.o. vehicle), **low dose**: 1.0 mg/kg/d PND 1-20, **medium dose**: 1.0 mg/kg/d PND 1-5, 2.0 mg/kg/d PND 6-13, 4.0 mg/kg/d PND 14-20; **high dose**: 1.5 mg/kg/d PND 1-5, 3.0 mg/kg/d PND 6-13, 6.0 mg/kg/d PND 14-20.

[d] Dosing regimen: 0 (c.o. vehicle), **low dose**: 3.0 mg/kg every other day PND 1-21, **medium dose**: 3.0 mg/kg every other day PND 1-5 followed by 6.0 mg/kg/d every other day from PND 7-21; **high dose**: 3.0 mg/kg every other day PND 1-5, 6.0 mg/kg every other day PND 7-13, then 12 mg/kg every other day PND 15-21.

[e] Dosing regimen CPF at 0 (peanut oil), 3 or 6 mg/kg by gavage to dams GDs 15 to 18 by intraoral gavage; Postnatal treatment, CPF at 0, 1 or 3 mg/kg sc to prenatally treated pups from PNDs 11 to 14. Each litter assigned to one prenatal treatment (vehicle, 3 or 6 mg/kg), one male and one female were randomly assigned to vehicle (Veh), one male and one female to CPF 1 mg/kg (CPF1), and one male and one female to CPF 3 mg/kg (CPF3). Total = 9 treatment groups: preVeh-postVeh, preCPF3-postVeh, preCPF6-postVeh, preVeh-postCPF1, preCPF3-postCPF1, preCPF6-postCPF1, preVeh-postCPF3, preCPF3-postCPF3 and preCPF6-postCPF3.

[f] 5HT: serotonin or 5-hydroxytryptamine a monoamine neurotransmitter contributing to feelings of well-being, memory and cognition

[g] "actual total delay" (time of first lever press to press of the correct choice lever); "void trials" delays longer than set criteria; "nosepokes/trial" memory retention.

Table 16. Neurobehavioral Effects after Subcutaneous Pre- and Postnatal Injections of Chlorpyrifos

Dosing Period	ChE Inhibition	ChE Testing	Domain Affected [a]	Age of Behavior Testing	NOEL LOEL mg/kg/d				Ref [a]
					Plasma ChE	RBC AChE	Brain AChE	Behavior	
Subcutaneous Treatment to Male and Female Rat Pups									
Rat Long-Evans s.c. Peanut oil PND 11, 15 0.3, 7 mg/kg/d	Brain AChE	PND 11, 16, 28	↓ cognition (↑latencies to find platform in Morris water maze, ↓ time in training quadrant) No M/F difference	PND 7, 11, 15	NA	NA	O.3 7.0	-- 0.3	1
s.c. DMSO (1 ml'kg) PND 1-4; 1, 11-14 5 mg/kg	Brain AChE	PND 1, 11	↓ motor activity (M); neuromotor function (↓rearing PND 1-4 & ↑PND 11-14 (M); ↑righting reflex (F); ↓negative geotaxis (F)) No M/F difference	PND 3-4 (reflex righting),; Negative geotaxis[b], PND 5-8; PND 21, 30 (motor skills)	NA	NA	-- 1.0	-- 1.0	2
Rat SD Pup M/F s.c. DMSO (1 ml'kg) PND 1-4 1 mg/kg/d	Not tested	**NA**	↑motor activity (↑ center crossings in elevated plus maze, M.); ↓cognition (↑ radial arm maze working & reference memory errors, M; ↓working memory errors in radial arm maze, F) ↓anxiety (↑ open arm time in elevated plus maze);↓ chocolate milk preference (anhedonia)), M more affected than F	PND 52-53 & 64+	NA	NA	NA	1 dose tested 1.0	3
s.c. DMSO (conc not stated) 1 mg/kg/d PND 1-4 or 5 mg/kg/d PND 11-14	Not tested	NA	↓Spatial learning, memory (F) F more affected than F	T-maze spontaneous alternation & Figure-7 & locomotor activity: weeks 4–6; radial-arm; maze training weeks 14-17	NA	NA	NA	1 dose tested 1.0	4
Mouse Dam and Offspring									
CD-1 s.c. Peanut Oil PND 11-14 3 mg/kg/d Treated F mated PND 60	Not tested	NA	Pups: ↓Sociability F after giving birth: ↑anxiety & emotion (↓time to enter light side), ↑social behavior & maternal interaction (↑ latency to build nest, ↓latency to lick pups, ↓defensive; ↑digging) Pups:↑anxiety (↓motion in new cage) . No M/F difference	Pups: PND 40-45 After mating: PND 60; maternal behavior tested LD 1-7	NA	NA	NA	1 dose tested 3.0	5
Subcutaneous Treatment to Sprague-Dawley Rat Dams During Gestation and/or Pups									
s.c. DMSO (1 ml/kg) GD 9-12 1.0, 5.0 mg/kg/d	Not tested	NA	↑motor activity (↑ habituation, ↓ latencies in t-maze, ↑ center crosses in elevated plus maze); ↓cognition (↑radial arm maze working & reference memory errors) No M/F difference	PND 28-91	NA	NA	NA	1.0 5.0	6
s.c. injection DMSO (1 ml/kg) GD 17–20 1.0, 5.0 mg/kg/d	Not tested	**NA**	↑**motor activity** (↓t-maze latencies, ↓Fig 8 habituation, ↓radial arm latency); ↓cognition (↑radial arm maze working & Reference memory errors F) F more affected than M	PND 28-42, 56-91	NA	NA	NA	-- 1.0	7
Subcutaneous Treatment to Sprague-Dawley Rat Dams During Gestation and/or to their Pups									
CD-1 Pup F s.c. Peanut Oil GD 15-18 &	Not tested	NA	F Pups of dams treated 6.0 mg/kg/d GD 15-18: ↑social investigation, ↑vocalization; ↑motor activity & ↑exploring; F only	PND 120	NA	NA	NA	3.0 6.0	8

PND 11-14 3, 6 mg/kg/d									
CD-1 gavage peanut oil GD 15-18 (3 & 6 mg/kg/d) + s.c. peanut oil PND 1-14 (1 & 3 mg/kg/d)[c]	Pups only: Plasma Brain	24 hr post dose	**Dam**: ↓ Social behavior (↓licking, ↓sniffing; ↑crouching) **Pup (pre & post-natal treatment)**:↑ motor activity (↑crossing open field), ↓anxiety & emotion (↓head dips in +maze); ↑social behavior (↑attack response & offensive posture (M)) PN treatment: ↑%time in open arm (F); F affected more than M	PND 70, 75-80, 90, 120	-- 1.0	NA	6.0 >6.0	Dam: 3.0 6.0 Pup: 1.0 3.0	9
HS/lb s.c. DMSO (conc. not stated) GD 9-18 1, 3, 5, 10, 20 mg/kg/d	Not tested	NA	↓cognition (↓Morris water maze learning) No M/F difference	Pups PND 75	NA	NA	NA	-- 1.0	10
HS/lb s.c. DMSO (1 ml/kg) GD 9-18 3.0 mg/kg/d	Not tested	NA	↓cognition (↓Morris water maze learning) M/F data pooled	PND 80	NA	NA	NA	Only 1 dose tested 3.0	11
Swiss Webster Pup F s.c. DMSO (conc. not stated) GD 17-20	Not tested	NA	↓cognition (↓learning of food recognition & position) ; F only	PND 60-81	NA	NA	NA	-- 1.0	12
Swiss-CD-1 s.c. DMSO (conc. not stated) PND 1-4 PND 11-14 1, 3 mg/kg/d	Pup Plasma Brain	PND 4	↑motor activity (↑ activity at door opening in 2-chamber box (M)); ↓social behavior (↓self-grooming M/F); ↑agonistic behavior (M); M more affected than F	PND 25, 35-38, 38, 45, 60	-- 3.0	NA	>6.0	-- 1.0	13
ICR s.c. DMSO (conc?); GD 13-17 at 1, 5 mg/kg/d	Not tested	NA	↓ memory (T-maze delayed spatial alteration); M more affected than F	PND 45-60	NA	NA	NA	1.0 5.0	14

a References: 1. Jett et al. (2001); 2.Dam *et al.* (2000); 3. Aldridge et al. (2005a); (Aldridge et al., 2005b); 4. Levin *et al.* (2001); 5. Venerosi et al. (2008); 6. Icenogle et al. (2004); 7. Levin et al. (2002); 8. Venerosi et al. (2006); 9. Ricceri et al. (2006); 10. Billauer-Haimovitch et al. (2009); 11. Turgeman et al. (2011); 12. Haviland et al. (2010); 13. Ricceri et al. (2003); 14. Chen et al. 2012; Table adapted in part from US EPA (2014a).

b Negative geotaxis: ability to turn 180° on an inclined plane.

c Dosing regimen CPF at 0 (peanut oil), 3 or 6 mg/kg by gavage to dams GDs 15 to 18 by intraoral gavage; Postnatal treatment, CPF at 0, 1 or 3 mg/kg sc to prenatally treated pups from PNDs 11 to 14. Each litter assigned to one prenatal treatment (vehicle, 3 or 6 mg/kg), one male and one female were randomly assigned to vehicle (Veh), one male and one female to CPF 1 mg/kg (CPF1), and one male and one female to CPF 3 mg/kg (CPF3). Total = 9 treatment groups: preVeh-postVeh, preCPF3-postVeh, preCPF6-postVeh, preVeh-postCPF1, preCPF3-postCPF1, preCPF6-postCPF1, preVeh-postCPF3, preCPF3-postCPF3 and preCPF6-postCPF3.

No NOEL denoted "—"

* DMSO used as a vehicle at approximately 1 ml/kg. This dose is reported to be non-toxic in animal studies (Whitney *et al.*, 1995).

II.J. Immunotoxicity

CPF was administered in diet to female Sprague-Dawley rats (10/sex/group) at 0, 0.4, 2.0 and 10.0 mg/kg/d for 28 days (Boverhof et al., 2010). Another 10 females were dosed by intraperitoneal (i.p.) injection with 20 mg/kg/d of cyclophosphamide from day 24 through day 28 as the positive control group. No deaths occurred during the treatment period. There were no treatment-related effects on body weight or food consumption. The hematology parameters were not affected by the treatment. RBC AChE activity was reduced in a dose-related manner for all treatment groups. Brain AChE activity was significantly less than that of the controls at the 2 and

10 mg/kg treatment levels. The mean absolute and relative weights of the spleen and thymus were not affected by the treatment. The anti-SRBC IgM serum titers were reduced for the 2 and 10 mg/kg treatment groups. However, the effect was not manifested in a dose-related manner (i.e., the titers for 2 and 10 mg/kg groups were 36 and 59% of the control group, respectively). These results were judged to be equivocal based on the range of variability demonstrated in the control group values and the lack of a clear dose-response. Other parameters (spleen and thymus weights, white blood cell differential counts) did not indicate any suppression of immunopotency. The positive control was functional. The AChE NOEL was less than 0.4 mg/kg/d and the immunology NOEL was 0.4 mg/kg/d.

II.K. Epidemiological Studies Related to Neurodevelopmental Effects

There are several ongoing prospective cohort studies investigating the associations between environmental exposures during pregnancy or in early childhood and the effects on learning, development, and behavior. Many of these have included the evaluation of potential exposure to organophosphate pesticides, including chlorpyrifos.

II.K.1. Biomarkers of Human Chlorpyrifos Metabolism

Understanding the results of the epidemiological studies is helped by providing context for the variety of markers analyzed in these studies. For humans, metabolic activation of chlorpyrifos occurs predominantly in the liver while detoxification can take place in the liver or plasma (ATSDR, 1997; FAO/WHO, 1999). Metabolism is generally rapid and extensive, with the parent and/or the active metabolite found only in trace concentrations in blood or urine (ATSDR, 1997; FAO/WHO, 1999). The biological half-life for the major metabolite in humans following oral or dermal exposure was approximately 27 hours (Nolan et al., 1984) and chlorpyrifos metabolites are excreted primarily in the urine (ATSDR, 1997; FAO/WHO, 1999). The following table summarizes the main nonspecific metabolites of OP pesticides. See also Figure 4 earlier in this document.

Table 17. Specific and Nonspecific Urinary Metabolites of OP Pesticides in Humans

Pesticide	**Non-specific dialkyl phosphate (DAP) metabolites**			**Specific metabolites**
Chlorpyrifos	DEP	-	DETP	TCPy
Chlorpyrifos-Methyl	-	DMP	DMTP	TCPy
Diazinon	DEP	-	DETP	-
Oxydemeton methyl	-	DMP	DMTP	-
Methamidophos	-	DMP	DMTP	-

DAP - Dialkyl phosphate
DEP - Diethyl phosphate
DMP - Dimethyl phosphate
DETP - Diethyl thiophosphate
DMTP - Dimethyl thiophosphate
TCPy - 3,5,6-trichloro-2-pyridinol

Barr and Angerer (2006) succinctly categorized the biomarkers and environmental exposures for chlorpyrifos as follows:

- Biomarker of CPF Exposure: TCPy, DEP, DETP, CPF-oxon
- Biomarker of Effect: AChE inhibition
- Biomarker of Susceptibility: PON1 genotype/phenotype
- Primary route of environmental exposure: Diet
- Biologically active agent: CPF-oxon

Summaries of recent findings from major epidemiological cohorts as well as other independent studies are enumerated below.

II.K.2. Childhood Autism Risks from Genetics and the Environment: The CHARGE Study, The MIND Institute, University of California Davis Medical Center

The CHARGE study started in 2003 to investigate environmental causes and risk factors for autism and developmental delay. The CHARGE study has enrolled over 1600 participants and the pediatric participants either have either full autism spectrum disorder or developmental delay. Children in the study must be between 24-60 months of age when enrolled and have been born in California. The children are assessed for social, intellectual, and behavioral development. Questionnaires are designed to collect information about chemical use in the home, environmental exposures, medical history, diet, and alcohol and drug use both before and after birth.

Shelton et al. (2014) used data from the CHARGE study to determine whether mothers of children identified as having autism spectrum disorder or developmental delay lived near reported applications of certain agricultural pesticides (including carbamates, organophosphates, organochlorines, or pyrethroids) while pregnant with the affected children. Proximity to chlorpyrifos applications was independently assessed. Parents who completed the surveys were asked for all addresses where they lived going back to 3 months before conception. Participating children were given standardized tests to classify them as having autism spectrum disorder or developmental delay or if they were normally ("typical") developing for purposes of the study. The authors used information from the DPR 1997-2008 Pesticide Use Report (PUR) Database as a surrogate for actual exposures. Exposure levels (e.g., levels of parent compound or metabolites in blood, urine, or tissues) or durations were not measured in either the mothers during pregnancy or in the infants at birth or during the years of follow up.

Addresses of the cohort mothers were identified as being within 1.25 km, 1.5 km and 1.75 km of an agricultural pesticide application in the 3 months prior to conception through full-term delivery. The children evaluated in the cohort included 486 autism spectrum disorder cases, 168 developmental delay cases, and 316 cases that were normally developing. The study used Multinomial Logistic Regression to calculate odd ratio (OR) of autism spectrum, developmental delay, or typical development associated with residential location. The major findings were that children of mothers living near OP pesticide applications during the third trimester were at greater risk for autism spectrum disorder (60%). OP pesticide applications that occurred within 1.5 km of designated residences during the third trimester included documentation of use of 21 unique OP pesticides, including chlorpyrifos (20.7%), acephate (15.4%), and diazinon (14.5%). Researchers found a positive association between maternal proximity to chlorpyrifos applications

(1.5 km) in the second trimester and autism spectrum disorder (14% higher risk). In addition, the association between autism spectrum disorder and developmental delay and applications near residences during pregnancy decreased with increased distance from the application site. Altogether, the study concluded that when biological samples are unavailable, proximity to pesticides can serve as a proxy of potential exposure in the assessment of associations between environmental exposures and neurodevelopmental delay (Shelton and Hertz-Picciotto, 2015).

II.K.3. The Mount Sinai Children's Environmental Health Cohort, Children's Environmental Health Center, Icahn School of Medicine at Mount Sinai

From 1998 to 2002, the Mount Sinai Children's Environmental Health Study enrolled a multiethnic population of more than 400 pregnant women into a prospective study to investigate linkages between environmental exposures and impaired child cognitive development. All mothers gave birth at Mount Sinai Hospital in New York City between May 1998 and July 2001. They were screened and excluded for various potentially confounding birth parameters, including serious chronic diseases, a serious pregnancy complication that could affect fetal growth and development, and risky health behaviors including alcohol consumption in excess of two alcoholic beverages per day or illicit drug use. Children who were born with a congenital malformation or who were severely premature were also excluded.

The research team collected urine samples from the mothers during pregnancy and analyzed them for the evidence of metabolized pesticides. Questionnaires were administered to obtain information on characteristics such as environmental exposures, maternal smoking, and indoor pesticide use. The women participated in follow-up interviews when their children reached 12 months, 24 months, and 6 - 9 years of age. At 12 and 24 months, the children were assessed using the Bayley Scales of Infant Development for mental and psychomotor developmental indices. Between the ages of 6-9 years old, the children were given the Wechsler Intelligence Scale for Children 3rd or 4th version (WISC-III or WISC IV) with composite indices for Verbal Comprehension, Working Memory, Processing Speed, and Perceptual Reasoning, as well as Full Scale IQ.

The concentration of 3,5,6-trichloro-2-pyridinol (TCPy) and non-specific measures of OP pesticide exposure were measured in maternal urine collected during the 3rd trimester and in infant cord blood samples at birth. Berkowitz et al. (2003) measured TCPy concentrations in urine in 365 participating mothers. Forty-two percent of samples were above the limit of detection (LOD) of 12.0 µg/L and the median concentration adjusted for creatinine was 11.3 µg/g. The authors found no association between reported pesticide use or exposure in the questionnaire results and the quantitative urinary metabolite measurements (Berkowitz et al., 2003). The authors went on to assess the correlation between urinary pesticide metabolite concentrations, fetal growth measures, and metabolizing enzyme activity (paraoxonase-1, PON1). The authors found a significant positive trend between maternal paraoxonase activity and decreased head circumference among the offspring of mothers whose prenatal measures of TCPy were above the LOD (Berkowitz et al., 2004). When TCPy concentrations were removed from the equation, the trend remained for the association between decreased head circumference and PON1 activity, independent of any measure of pesticide exposure (Berkowitz et al., 2004). Associations between birthweight were also assessed. Wolff et al. (2007)found no significant association between diethylphosphate (DEP) concentrations and PON1 activity or the PON_{192}

genotype and decrements in birthweight. However, there was a 164 g deficit in birthweight between the extremes of interaction. That is, the slowest PON1 enzymatic activity and the highest total DEP concentrations were associated with the biggest decrements in birthweight, although none of the associations was significant (Wolff et al., 2007).

Researchers then considered the associations between concentrations of prenatal urinary metabolites and metabolites present at the time of birth and mental or psychomotor developmental indices, WICS-III or WISC-IV composite indices, Full Scale IQ, as well as with PON1 enzymatic activity levels and PON1 genotypes (Engel et al., 2011). Third-trimester maternal urine samples (n=360) were analyzed for OP metabolites and maternal blood samples were analyzed for PON1 activity and genotype. The Bayley Scales of Infant Development for mental development and psychomotor development were administered at approximately 12 months of age (n=200) and 24 months of age (n=276). There was no association between total diethylphosphate (DEP) metabolites and decreases in mental development indices at 12 months of age. There was no association between any OP urinary metabolite psychomotor development indices at 12 months of age. At 12 months, children of mothers with the $PON1_{192/QR/RR}$ genotype experienced a 2 point decline in the mental development index for each $\log_{10}$ unit increase in total DEP concentration in prenatal urine, although this effect also disappeared at 24 months. Increasing total DEP urinary metabolites were associated with slight decrements in Full Scale IQ, Perceptual Reasoning, and Working Memory assessed when the children were 6-9 years old, although the estimated effects were modest and imprecise. The overall results support the association of prenatal OP exposure and the presence of specific PON1 genotypes associated with slower catalytic activities with negative effects on cognitive development. However, the authors note that reconciling estimated effects when only using nonspecific urinary metabolites can be complicated when those metabolites derive from multiple parent compounds (Engel et al., 2011).

II.K.4. Mothers and Newborn Cohort, Columbia Center for Children's Environmental Health, Mailman School of Public Health, Columbia University

The Columbia Center for Children's Environmental Health (CCCEH, or Columbia) enrolled a sample of pregnant nonsmoking African-American and Dominican women between 18-35 years old residing in Washington Heights, Central Harlem, and the South Bronx, New York. The cohort started in 1997 to evaluate effects of prenatal exposure to ambient and indoor pollutants on birth outcomes, neurocognitive development, and procarcinogenic damage among a cohort of mother and newborns from minority communities in New York City (Whyatt et al., 2003). In 1998, the study began collecting information on prenatal pesticide use and exposure in response to growing concern of the extent of residential pesticide use (Whyatt et al., 2003). Ethnicity was self-identified and the women had registered at the OB/GYN clinics at NY Presbyterian Medical Center or Harlem Hospital by their 20^{th} week of pregnancy. The prospective cohort was designed to assess exposure to environmental contaminants and the effects on birth outcomes. The cohort lived in New York for more than one year before pregnancy and was screened for history of various potential confounders (drug abuse, diabetes, hypertension, or HIV infection). Potential exposure was measured as CPF in maternal blood collected within 1 day post-partum and fetal cord blood collected at delivery, as TCPy in maternal and fetal urine and meconium within 2 days of delivery, and via air concentrations collected by personal monitors during the third trimester of pregnancy (Perera et al., 2003; Whyatt et al., 2003). Participants responded to

questionnaires during the third trimester of pregnancy and then at follow-up assessments. The birth outcomes, delivery outcomes, and related medical information were also obtained for each participant. The cohort children were assessed for multiple measures of growth and development thought the years of follow-up, including an assessment of brain morphology between the approximate ages of 6 – 11. CPF was detected in 98% of maternal blood samples (mean = 7.1 pg/g) and 94% of cord blood samples (mean = 7.6 pg/g) (Perera et al., 2003)and the CPF concentrations in maternal (n = 263) and newborn (n=256) blood were highly correlated (r = 0.76) (Whyatt et al., 2004). The authors note that this shows CPF readily transfers from maternal to cord blood across the placenta. There was an association with CPF blood concentrations and decreased birthweight, which was significant in African-American mothers. CPF blood concentrations were associated with nonsignificant reductions in birth length in a subset of Dominican women. No associations were found between CPF blood concentrations at birth and head circumference (Perera et al., 2003). It is important to note that the association with CPF blood levels and reductions in birthweight and birth length were significant ($p = 0.008$ and 0.004, respectively) for infants born before January 1, 2001 (n=237) when compared to infants born after January 1, 2001 (n=77) (Whyatt et al., 2004). This likely reflects an overlap in subject recruitment with the US EPA restrictions on indoor chlorpyrifos use.

Air sampling was conducted for 2 consecutive days in the third trimester for mothers enrolled in the study from September 1998 through May 2001 (Whyatt et al., 2003). Indoor air concentrations ranged from 0.7 – 193 ng/m^3 CPF (Perera et al., 2003). Air concentrations collected < 1 month before delivery were highly correlated with maternal and cord blood CPF concentrations (Whyatt et al., 2003). However, there were no significant associations between OP pesticide air monitoring results and any birth outcomes (Whyatt et al., 2004).

Rauh and colleagues conducted a follow-up examination of the cohort children at 12, 24, and 36 months of age with the purpose of investigating the impact of prenatal CPF exposure on neurodevelopment and behavior (Rauh et al., 2006). Results showed that children categorized as highly exposed (maternal post-partum or cord blood levels > 6.17 pg CPF/g plasma) scored on average 6.5 points lower on the Bayley Psychomotor Development Index and 3.3 points lower on the Bayley Mental Development Index compared with those with lower CPF blood levels. Higher CPF blood levels were also significantly associated with attention problems, attention-deficit/hyperactivity disorder problems, and pervasive developmental disorder problems at 3 years of age (Rauh et al., 2006). The same cohort of children were again examined at 7 years old to estimate the long term effects prenatal CPF exposure on neurodevelopment using the Wechsler Intelligence Scale for Children – 4th Edition (WISC-IV) with composite indices for Verbal Comprehension, Working Memory, Processing Speed, and Perceptual Reasoning, as well as Full Scale IQ (Rauh et al., 2011). There were significant inverse correlations between CPF and Working Memory ($r = -0.21$; $p<0.0001$) and Full Scale IQ ($r = -0.13$; $p<0.02$), as well as a weak correlation between CPF and Perceptual Reasoning. There was a dose-effect relationship of CPF and log-transformed Working Memory and Full Scale IQ, with decreases of 2.8% and 1.4%, respectively, for each standard deviation (± 4.61 pg CPF/g cord blood plasma) increase in CPF exposure (Rauh et al., 2011). Working Memory (a component of IQ) is the ability to memorize new information, retain the memory short-term, and concentrate and manipulate information, all of which are considered predictors of the ability to learn and academic success (Whyatt et al., 2015). As assessed in by Rauh and colleagues (2011), Working Memory was not

confounded by lead (Pb) exposure and was not likely to be affected by socioeconomic or cultural conditions. Rauh et al. (2012) performed magnetic resonance imaging studies on 40 cohort children (5.9 – 11.2 years old) to see if CPF exposure in utero affected brain morphology. Brain cortical surface features were compared between children with high concentrations of CPF in cord blood plasma (n = 20; ≥ 4.39 pg/g) and those with lower concentrations (n = 20; < 4.39 pg/g). Numerous morphological differences were reported in the children in high CPF group, including enlarged superior temporal lobe, posterior middle temporal lobe, and inferior postcentral gyri bilaterally, as well as enlarged superior frontal gyrus, gyrus rectus, cuneus, and precuneus along the mesial wall of the right hemisphere. These children also showed frontal and parietal cortical thinning and an inverse dose–response relationship between CPF in cord blood and cortical thickness. Although expected, no sex differences in brain morphology were found between the high and low CPF groups (Rauh et al., 2012), but rather a reversal of sex differences in the high CPF group similar to those reported in animal models where early exposure reverses normal sex differences in learning, memory, and emotional behaviors (Hoberman, 1998; Levin et al., 2001; Aldridge et al., 2004; Aldridge et al., 2005a).

All cohort children not lost to follow-up (n=271) were assessed again at age 11 (range = 9.0 – 13.9)(Rauh et al., 2015). A total of 21 cohort children were diagnosed with a neurological, psychiatric, or learning disorder, the most common of which was ADHD. The children underwent a full battery of neurodevelopmental measures, including a test of motor function. CPF exposure was significantly associated with tremor in the dominant arm (p = 0.015), tremor in either arm (p = 0.028), and tremor in both arms (p = 0.027), and marginally associated with tremor in the non-dominant arm (p = 0.055) (Rauh et al., 2015). The authors state that morphologic changes appear to be related to lower IQs in these children and that the results support the notion that in utero exposure to CPF is associated with general cognitive deficits (Rauh et al., 2012) and potential central or peripheral nervous system effects later in life (Rauh et al., 2015).

II.K.5. Center for the Health Assessment of Mothers and Children of Salinas (CHAMACOS) Cohort, Center for Children's Environmental Health Research, University of California, Berkeley

The CHAMACOS project within the UC Berkeley Center for Children's Environmental Health Research is a longitudinal birth cohort study of the effects of pesticides and other environmental exposures on the health of pregnant women and their children living in the Salinas Valley of California (Eskenazi et al., 2004). Eligible women were 18 or older and were less than 20 weeks pregnant at the time of enrollment (Oct 1999 – Oct 2000) through the Natividad Medical Center or one of five Clinicas de Salud de Valle de Salinas. The subjects were either farm laborers or were living with someone employed as a farm laborer in Salinas Valley, CA (Eskenazi et al., 2004).

Researchers evaluated nonspecific metabolites of OP pesticide exposure as well as specific metabolites for several pesticides, including CPF in urine at 13 weeks (mean) and 26 weeks (mean) of gestation. Levels of ChE in whole blood or BuChE in plasma in maternal and umbilical cord blood were measured in blood collected from mothers at 26 weeks of gestation and in the hospital before delivery (umbilical cord blood samples) (Eskenazi et al., 2004). A large proportion of women in the study had specific CPF metabolite values that were below the

limit of detection. For those samples in which TCPy was detected, the median value was 3.3 µg TCPy/L urine (range = 0.2 – 56.1 µg/L) (Eskenazi et al., 2004). No association was found between urinary concentrations of TCPy and any fetal growth outcome, although results indicated decreased gestational duration was associated with nonspecific urinary biomarkers of dimethyl OPs, such as malathion (Eskenazi et al., 2004). Results from questionnaires showed that very few home-use pesticides in the CHAMACOS study contained chlorpyrifos, and that the more likely sources of exposure included diet, indoor residues, or nearby agricultural use (Eskenazi et al., 2004).

Eskenazi and colleagues went on to explore multiple growth and development indices in the children of the CHAMACOS cohort, including the Bayley Scales of Infant Development for mental and psychomotor developmental indices at 6, 12, and 24 months of age. No association was found between decrements in any developmental indices and urinary concentrations of TCPy, a more specific marker of chlorpyrifos exposure. However, the nonspecific OP metabolite DEP in maternal urine was significantly associated with decrements in the child's mental development indices at 24 months, leading the authors to postulate that the observed association may be attributed to compounds other than just malathion or chlorpyrifos (Eskenazi et al., 2007). The investigation was expanded by considering the metabolic enzyme PON1 and its activity and genotypes/phenotypes in the cohort population, hypothesizing that there may be a subgroup of children that by virtue of their genetic makeup may be more susceptible to the adverse effects of OP exposure during pregnancy (Eskenazi et al., 2010). There were no statistically significant interactions between any nonspecific maternal urinary metabolites of OPs (DAPs) and enzyme measurements in relation to any of the neurobehavioral endpoints. There was a slightly stronger relationship of psychomotor development scores and maternal DAPs, particularly for the diethyl phosphate metabolites, among children with the lowest aryl esterase enzyme activity when compared to children with the highest PON1 activity (both measured in cord blood collected at the time of birth) (Eskenazi et al., 2010). There was a suggestion that children with $PON1_{-108T}$ allele showed a stronger association with general OP pesticide exposure in utero (as measured by prenatal DAPs) and the mental development indices, but the interaction was not significant (Eskenazi et al., 2010). Harley et al. (2011)went on to investigate infant PON1 genotype and activity. Infants with lower PON1 activity or those with a susceptible genotype ($PON1_{-108T}$) had a stronger association with shorter gestation duration and smaller head circumference at birth (Harley et al., 2011). Maternal metabolizing enzyme genotype and activity did not have the same association. The authors go on to postulate that PON1 may contribute to fetal growth impacts and decrements perhaps through an oxidative stress mechanism (Harley et al., 2011).

The children were followed up again at 3.5 and 5 years when both maternal and psychometrician assessments of behavior and neurodevelopment were conducted (Marks et al., 2010). The battery of tests conducted at each visit included visual attention, reaction time, accuracy, impulse control, motor activity, and distractibility. Prenatal DAPs were positively associated with attention problems and ADHD diagnoses. Composite measures of ADHD and attention were adversely related to both child urinary diethyl concentrations (reflecting recent OP exposure) and prenatal diethyl phosphate concentrations (Marks et al., 2010). Data for the more specific chlorpyrifos metabolite TCPy were not reported. Bouchard and colleagues (2011) went on to report that children 7 years old in the highest quintile of prenatal DAP concentrations have an average deficit of 7.0 IQ points compared to the lowest quintile of prenatal urinary DAP. Prenatal DAP concentrations were also associated with poorer scores for Working Memory,

Processing Speed, Verbal Comprehension, and Perceptual Reasoning (Bouchard et al., 2011). Child urinary DAP concentrations were not consistently association with any WISC finding, leading the authors to postulate that prenatal but not childhood DAP metabolites are associated with poorer intellectual development (Bouchard et al., 2011).

In 2016, Stein and colleagues published findings investigating early childhood adversities and the impact they may have on the association between prenatal OP pesticide exposures and the decrements in Full Scale IQ noted in the CHAMACOS cohort children. The authors collected information on potential sources of adversity in the homes of CHAMACOS cohort participants, including annual income, food insecurity, family structure, maternal depression, stressful life events, family conflict (including physical punishment), home learning environment, and social and emotional interactions between parent and child (Stein et al., 2016). Seventy percent (70%) reported income below the federal poverty line and 15% of mothers were at risk of clinical depression. Several types of adversity were significantly associated with decreased scores in Verbal Comprehension, Perceptual Reasoning, Working Memory, and Full Scale IQ. Adversity in relationships between parent and child were associated with decreases in Verbal Comprehension, Working Memory and Full Scale IQ (Stein et al., 2016). There were some sex differences in the outcomes, but overall there were stronger associations between prenatal OP exposures (as measured by nonspecific urinary metabolites) and IQ scores among children who are experiencing certain adversities (Stein et al., 2016).

II.K.6. Additional Studies and Pooled Analyses

Multiple studies continue to investigate associations between prenatal and early life exposures to OP pesticides and neurodevelopment in geographic locations as varied as Northern Ecuador, Cincinnati, Ohio, Norway, Brittany, France, Southeastern Spain, Mexico City, and Shenyang, China. A small sample of representative studies is summarized below.

In a prospective cohort of pesticide exposure in maternal and fetal biological matrices, 150 pregnant women scheduled for C-sections in New Brunswick, NJ from July 2003-2004 were recruited by convenience sampling (Barr et al., 2010). During the pre-operative procedures, 10 ml of maternal blood was collected. Within 15 minutes of delivery, 30-60 ml of cord blood was collected from the newborns. Both blood samples were analyzed for chlorpyrifos. CPF was detected in 98.5% of maternal samples and 62.8% of newborn sample, with many at or near the LOD. Maternal serum contained a mean level of 0.009 ng/g (SD = 0.87) and the cord blood contained an average of 0.55 ng/g (SD = 0.73). There were no associations with blood CPF levels are birthweight or birth length (Barr et al., 2010).

In a study of 119 children with ADHD ranging from 8 to 15 years old (a subset of NHANES subjects), researchers considered the association between urinary DAPs and ADHD subsets as defined in the Diagnostic and Statistical Manual of Mental Disorders, 4th Edition (DSM-IV). Children with higher urinary concentrations of DAPs, and especially dimethylthiophosphate (DMTP), were at higher risk of being diagnosed with hyperactive-impulse ADHD subtype (Bouchard et al., 2010). Metabolites from O,O-diethyl substituted OPs were not significantly associated with any increased risk of ADHD, whether defined strictly by the DSM-IV criteria or when including children taking ADHD medications. There were no significant sex- or age-related differences in the findings (Bouchard et al., 2010).

The Canadian Health Measures Survey (2007-9) considered biomarkers of exposure in 779 children 6-11 years old and their relation to growth and development (Oulhote and Bouchard, 2013). The children, who were representative of the general Canadian population, underwent blood and urine analysis, a household survey, and a Strengths & Difficulties Questionnaire (SDQ) to measure emotional symptoms, conduct problems, hyperactivity/inattention, peer problems, and pro-social behavior. Results indicated that total DAP levels decreased significantly with age (Oulhote and Bouchard, 2013). No significant association was found with any SDQ measurement of difficulty or any association with hyperactivity as found in Bouchard et al. (2010), even though total DAP levels in the Canadian children were higher than their American counterparts.

The Generation R cohort is a population based birth cohort in Rotterdam, The Netherlands. Over 8800 women enrolled during pregnancy and had delivery dates between April 2002 and January 2006. Eighty randomly selected women were recruited from the main cohort to provide 3 urine specimens throughout pregnancy and an additional 40 provided two urine samples during pregnancy (Spaan et al., 2015). All samples were tested for the non-specific DAP metabolites of OP pesticides. For all 6 DAP metabolites, the within-person variability exceeded the between-person variability, indicating poor-to-moderate reliability of one measurement as an indication of OP pesticide exposure throughout pregnancy. High total DEP metabolites were observed in women with a high daily vegetable, legume, and fruit intake (0.999, 1.001, and 1.002 nmol/g creatinine (lognormal-transformed, respectively).

Pooled analysis of 4 birth cohorts looked for association between metabolites in maternal urine and mental and psychomotor developmental indices (MDI and PDI, respectively), In Engel et al. (2016), the author notes that the geometric means for total DAP and total DMP concentrations were substantially higher in the CHAMACOS cohort than in the Columbia CCCEH, HOME (Health Outcomes and Measures of the Environment), and Mt. Sinai studies. There was significant heterogeneity in the associations between total DMP and total DAP and MDI, driven largely by a strong negative association from the CHAMACOS cohort. As such, the author states that this result argues against interpreting the pooled associations and that differences in the cohorts limited the interpretability of the overall pooled estimates (Engel et al., 2016). Different chlorpyrifos sources in the different cohorts also limit the ability to cross-compare results. For instance, subjects enrolled in the HOME study after the US EPA restriction on indoor use, so it is likely those subject may have received a higher proportion of their exposure through dietary means (and a higher quality diet high in fruits and vegetables) as compared with the two NY cohorts, whose subject enrollment spanned the period when indoor CPF restrictions were initiated (Engel et al., 2016).

Harley et al. (2016) considered fetal growth, exposure, and PON1 genotype and activity in the pooled data from the CHAMACOS, HOME, Mt. Sinai, and Columbia CCCEH cohorts. Total DEP concentrations measured in maternal urine during pregnancy in nmol/g creatinine were highest for the CHAMACOS cohort and lowest for the Columbia CCCEH cohort, with a pooled mean and standard deviation of 13.11 nmol/g creatinine (5.49).

Columbia CCCEH < HOME < Mt. Sinai < CHAMACOS

The authors found no significant associations between metabolites and birthweight, length, or head circumference in the pooled data of over 1000 pregnant women. However, there was a negative association between total DEP concentration and birthweight of the infants whose mothers exhibited the $PON1_{-108CC}$ genotype.

II.K.7. General Observations from Human Epidemiological Studies

As mentioned at the beginning of this section, CPF can be metabolized into dialkyl phosphate (DAP) metabolites. These metabolites are considered general metabolites of OP-containing compounds in the environment. Because each urinary metabolite has multiple sources, the presence of any DAP metabolite in urine (e.g., DMP, DEP, DMTP, DETP, etc.) may result from exposure to the parent compound (such as an OP pesticide) or an environmental degradate. DEP and DETP are common metabolites for many O,O-diethyl substituted pesticides such as diazinon, and therefore they cannot be considered specific markers of chlorpyrifos exposure. TCPy and DAP metabolites each represent one-half of the chlorpyrifos molecule and are produced in approximate equal-molar ratios (Barr and Angerer, 2006). Therefore, TCPy and DAP measurements should not be summed to determine CPF exposure, because in so doing, the exposure would be overestimated by a factor of 2 (Barr and Angerer, 2006).

Rather than the nonspecific urinary OP metabolites mentioned above, quantified chlorpyrifos levels in blood or blood product provides the best estimation of exposure to the parent pesticide. Chlorpyrifos exists in extremely low concentrations in blood compared to metabolites in urine (ppt versus ppb levels) (Barr and Angerer, 2006) and can be difficult to quantify above the analytical limit of detection. In addition, it requires obtaining a biological sample that is more difficult to collect than urine. Nevertheless, several epidemiological studies quantified chlorpyrifos in blood to characterize maternal and fetal exposure, most notably the Columbia CCCEH cohort (Perera et al., 2003; Whyatt et al., 2003; Perera et al., 2004; Whyatt et al., 2004). Over the course of cohort participant recruitment (c. 1998 – 2004), there were significant decreases in the level of parent compound measured in blood, indicating that changes in regulation have thus far resulted in significantly lower body burden of chlorpyrifos. In Whyatt et al. (2009), there was a significant decrease from 2001 – 2004 in urinary TCPy concentrations measured in participants. The percent of mothers with TCPy above the LOD steadily declined from 2001 (91%), to 2002 (84%), to 2003 (31%), to 2004 (29%). Both maternal and newborn blood samples had CPF levels below the LOD in all samples collected after 2002 (Whyatt et al., 2009).

II.L. The Toxicity ForeCaster (ToxCast™) Program

The Toxicity Forecaster (ToxCast^{TM}) program was launched by US EPA in 2007 as part of the Toxicity Testing in the 21st Century (Tox21) program in collaboration with the National Toxicology Program, the National Institutes of Health's National Center for Advancing Translational Sciences, and the Food and Drug Administration (http://www.epa.gov/chemical-research/toxicity-forecasting; accessed 12-2015). ToxCast was designed to prioritize chemicals based on the results of high-throughput screening assays indicating potential disruption of key biological pathwaysChemicals were selected for screening by US EPA (ToxCast and Tox21 collaborators), as well as international programs such as the Organization for Economic Co-operation and Development (OECD) and other stakeholder groups. The multi-phase ToxCast

program includes over 700 unique assays and 300 signaling pathways and to date has evaluated over 2000 chemicals with established or unknown toxicity, including cosmetics, drugs, pesticides, and environmental contaminants (Tice et al., 2013). ToxCast data may be used to elucidate biochemical mechanisms as well as common pathways for human disease outcomes. Ultimately, a goal of this US EPA program is to use the ToxCast hazard and exposure data predicted by computer modeling to facilitate chemical risk assessments and prioritization.

II.L.1. US EPA ToxCast Assays *In Vitro*

Results were obtained from the 11 ToxCast assay platforms that reported active results for CPF and CPF-oxon ("actives"): ACEA Biosciences, Inc. (ACEA), Apredica (APR), Attagene (ATG), Bioseek (BSK), CEETOX (Cyprotex), CellzDirect (CLD), Simmons Lab (NCCT), Novascreen (NVS) and Odyssey Thera (OT), the NIH Chemical Genomics Center (NCGC or Tox21) and zebrafish (National Health and Environmental Effects Research Lab - Padilla Lab [NEERL] or TANGUAY). The active results for CPF-oxon were included in the data presentation as none of the assay platforms have metabolic activation and it is known that CPF-oxon is the primary toxic metabolite of CPF. Table 17 provides detailed information on these assay platforms.

All assay results reported here were obtained from the Interactive Chemical Safety for Sustainability (iCSS) Dashboard (http://actor.epa.gov/dashboard/), the Endocrine Disruptor Screening Program Dashboard (http://actor.epa.gov/edsp21) and the FIFRA SAP Meeting on Integrated Endocrine Activity and Exposure-based Prioritization and Screening (http://www.regulations.gov/; Docket #: EPA-HQ-OPP-2014-0614). All assays reported on the dashboard were performed at multiple concentrations with the exception of Novascreen assays that were performed at one concentration only (25 µM all assays except 10 µM CYPs), and were reported on the iCSS Dashboard in the ToxCast Summary Files (http://www.epa.gov/ncct/toxcast/data.html).

Table 18. ToxCast Vendors and Assay Descriptions

Vendor	Organism Tissue	Cell Line Type	Biological Response	Target Family	Detection Technology
ACEA	Human Breast	T47D	Cell Proliferation	Cell Cycle	Label free
Apredica (APR)	Human Liver	HepG2	Mitochondrial depolarization	Cell morphology	Fluorescence
Attagene (ATG)	Human Liver	HepG2	Regulation of transcription factor activity	Background measurement	Fluorescence
Bioseek (BSK)	Human Tissues	Numerous primary cell types [a]	Regulation of gene expression	Depends on cell type system [b]	Fluorescence
CEETOX	Human Adrenal	H295R	Regulation of catalytic activity	Steroid Hormone	Spectrophotometry
CellzDirect (CLD/CRO)	Human Liver	Primary Cells	mRNA induction	Depends on assay design [c]	Chemiluminescence
Novascreen (NVS)	Human Proteins	Cell Free	Regulation of catalytic activity	Receptors, CYPs	Fluorescence
Simmons Lab (NCCT)	1. Rat Thyroid 2. Human Kidney	1.Cell Free 2. HEK293T	1. Regulation of catalytic activity 2. Cytotoxicity	1. Oxidoreductase 2. Cell cycle	1. Fluorescence 2. Luminescence

Vendor	Organism Tissue	Cell Line Type	Biological Response	Target Family	Detection Technology
NCGC (Tox21)	Human Kidney, Ovary, Breast	HEK293T	Regulation of transcription factor activity	Nuclear Receptor, cell morphology, DNA binding	Fluorescence, Reporter gene
Odyssey Thera (OT)	Human Kidney	HEK293T HeLa	Protein stabilization	Nuclear Receptor	Fluorescence
NHEERL or TANGUAY zebrafish	*Danio rerio* Whole animal [d]	NA	Malformations, neurobehavioral	Developmental Pathways	Visual/ Morphological

[a] Primary cultures from Primary human venule endothelial cells, Primary human vascular smooth muscle cells, Primary human dermal fibroblasts, Peripheral blood mononuclear + endothelial cells

[b] BSK tests for cytokine, cell adhesion, cell cycle, gpcr, growth factor, protease inhibitor, proteases depending on cell types assay.

[c] CLD tests for background measurement, CYP enzymes, transporters, transferase and lysase.

[d] Zebrafish assays are performed with chorion intact (Padilla et al., 2012) or with chorion removed (Tanguay et al., 2013; Truong et al., 2014). Zebrafish results are available with the other ToxCast results at: http://actor.epa.gov/dashboard/

II.L.2. ToxCast Assay Results for CPF and CPF-oxon

The results of ToxCast assays (reported as Concentration at 50% Activity: AC_{50}) that may be involved in CPF and CPF-oxon toxicity are shown in Table 17. Assay reactions are all without metabolic activation. However, a full complement of ToxCast assays was performed for both CPF and the major metabolite CPF-oxon (http://actor.epa.gov/dashboard/ accessed September 2017). All assay results and corresponding components or assay targets are compiled in histograms from the ToxCast Dashboard for CPF and CPF-oxon in Figure 7.

II.L.2.a ToxCast Assay Endpoints for Known CPF and CPF-Oxon Metabolism

CPF and CPF-oxon interaction with the following receptors or proteins is consistent with their metabolic pathway shown in Figure 3 above and described Table 18. Some of the assays are positive only with CPF-oxon because there is no metabolic activation to take CPF to the oxon form. Other assays may have high AC_{50} values because at high doses CPF becomes toxic and so the activity reported may or may not be due to a specific chemical/endpoint interaction.

- Human **AChE** and rat **BuChE** were active with CPF and CPF-oxon. The oxon form had greater sensitivity (lower AC_{50}) than CPF in NVS cell-free assays. CPF is associated with genes for AChE and BuChE (http://ctdbase.org/detail.go?type=chem&acc=D004390).

- **Cytochrome P450** (CYP) assays indicate that only CPF-oxon is active with the CYPS and the genes associated with CPF (**CYP1A1, CYP1A2, CYP3A4 and CYP2B6**) as would be predicted based on the metabolic pathway (Foxenberg et al., 2011). Aryl hydrocarbon hydroxylase receptor (**AhR),** also involved in xenobiotic oxidation, is active with both CPF and CPF-oxon (Fujita and Mannering, 1971). The oxon is more sensitive than CPF.

- **Farnesoid x receptor (FXR)** is an agonist and weak antagonist with CPF-oxon but is also active with CPF at higher concentrations. FXR is found in high levels in the liver and

intestines and interacts with peroxisome proliferators and retinoid x receptors (RXR) which also contribute to the metabolism of CPF (Jiao et al., 2015).

- **PXR (PXRE)** binds to the response element of the CYP3A4 promoter after forming a heterodimer with the 9-cis retinoic acid receptor (RXR), then regulating transcription of CYP3A4. Both CPF and CPF-oxon are active in the PXR assays. CPF is more sensitive then CPF-oxon (Kliewer et al., 2002).

- **Retinoid X receptor** (**RXR**) is activated by 9-cis retinoic acid and 9-cis-13,14-dihydro-retinoic acid and there are 3 main RXRs (RXRa, RXRb, RXRg). RXR hetero-dimerizes with constitutive androstenedione receptor (CAR), FXR, liver x receptor (LXR), peroxisome proliferator activated receptor (PPAR), pregnane x receptor (PXR), thyroid hormone receptor (TR), retinoic acid receptor (RAR), and vitamin D receptor (VDR). All of these genes interact with CPF, CPF-oxon, or both. RXR binding to agonist ligands results in promotion of downstream target gene mRNA production (Germain et al., 2006).

- **LXR** The **liver X receptor** (**LXRa or b**) is a transcription factors that is closely related to nuclear receptors such as the PPARs, FXR, and RXR. LXR regulates cholesterol, fatty acid, and glucose homeostasis and is classified as thyroid hormone receptor-like (NR1H3: LXRα; NR1H2: LXRβ). LXR hetero-dimerizes with 9-cis retinoic acid receptor (RXR) and, after activation, binds to LXR response element (LXRE). This receptor is activated by CPF (Song et al., 1994; Willy et al., 1995).

- **PPAR** is active with both CPF and CPF-oxon, but shows more sensitivity with CPF-oxon (detoxification) (Michalik et al., 2006).

- **CAR** interacts with PXR and functions as a sensor of endobiotic and xenobiotic substances. It activates metabolism of these compounds, functioning in conjunction with PXR to detoxify. CAR-regulated genes are members of the CYP2B, CYP2C, and CYP3A subfamilies, sulfotransferases, and glutathione-S-transferases. CPF-oxon is active with CAR nuclear receptor (Ueda et al., 2002; Wada et al., 2009).

II.L.2.b. Other ToxCast Assay Endpoints:

i. Central Nervous System (CNS):

CNS receptor assays show that CPF-oxon directly interacts with critical hormone regulating proteins in the brain. Notably these interactions have a high AC_{50} and are therefore not indicators of more sensitive pathways than the known AChE inhibition pathways (Table 18).

- The ɤ-aminobutyric acid receptor ($GABA_aR$) in the CNS (Hevers and Lüddens, 1998) is active with CPF in a cell-free assay.

- CPF-oxon also interacts with transmembrane G protein–coupled receptors (GPCRs) designed to detect compounds on the cellular exterior and activate internal responses (Wettschureck and Offermanns, 2005). Rat somatostatin inhibitory receptors are mediated by GPCR expressed in the anterior pituitary (NVS_GPCR_rSST). This interaction shows

the potential of CPF-oxon to affect growth hormone and other endocrine neurotransmitters in the brain. Although not a potent interaction, results from rat receptor assays nevertheless add to the potential for CPF-oxon to affect growth and development.

- Two rat opioid receptor assays are positive with CPF-oxon. Opioid receptors are also GPCR-coupled inhibitory proteins and are similar to the somatostatin receptors and function to affect pain (Janecka et al., 2004; Waldhoer et al., 2004; Reif et al., 2013). They are found primarily in the brain spinal cord and digestive tract.

- CPF-oxon interacts with the γ-hydroxybutyrate receptor in a brain tissue assay. This GPCR-coupled receptor normally binds γ-hydroxybutyric acid (GHB) a neurotransmitter as well as a psychoactive drug. Agonists and/or GHB receptor binding results in a stimulant effect mediated by an increased Na^+/K^+ current and increased release of dopamine and glutamate (Castelli, 2008; Castelli et al. 2003).

- CPF-oxon has activity with the glucocorticoid receptor (GR). This neuroendocrine receptor is part of the stress response regulated in the brain, including adaptation to stress, depression and other psychological states.

- CPF and CPR-oxon are both active in the vitamin D receptor element (VDRE) assay. Vitamin D is critical to brain and neurodevelopment both in utero and during childhood (Harms et al., 2011; Kočovská et al., 2012). Vitamin D deficiency has been associated with autism in children (Kočovská et al., 2012).

- Disruption of the RXR pathway, mentioned above, has been associated with neurodevelopmental effects, including pathways leading to schizophrenia (Goodman, 1998; Sun et al., 2010). This was one of the most sensitive assays with CPF.

Assays related to endocrine disruption show that CPF may interact with critical hormone systems (thyroid, androgen, estrogen), including inhibition of steroidogenesis even in the absence of metabolic activation. CPF interaction in receptors related to the steroidogenic, estrogenic, thyroid or androgenic pathways can directly affect human growth and development (Table 18). CPF is considered to be a weak estrogenic agonist on the EDSP dashboard (agonist Area Under the Curve, AUC = 0.0125; https://actor.epa.gov/edsp21/). CPF-oxon is a weak estrogen receptor antagonist with weak receptor binding. However the AC_{50}s for most of the endocrine-related effects are high (in the absence of metabolic activation) meaning that these are not likely to be primary targets and the positive results are likely non-specific interactions due to cytotoxicity.

Table 19. ToxCast Assays for Chlorpyrifos and Chlorpyrifos-oxon

Assay Name [a]	CPF AC_{50}	CPF Oxon AC_{50}
Acetylcholinesterase & Butyryl Cholinesterase Activity		
NVS_ENZ_rAChE	--	0.96
NVS_ENZ_hAChE	--	0.32
NVS_ENZ_hES (human plasma/BuChE ChE)	28.6	0.003
Cytochrome P450, Aryl hydrocarbon Hydroxylase & Aromatase Activities		
NVS_ADME_rCYP3A1	--	6.08
NVS_ADME_rCYP1A2	--	5.26
NVS_ADME_hCYP2C19	--	4.09
NVS_ADME_hCYP2C18	--	6.71

Assay Name [a]	CPF AC_{50}	CPF Oxon AC_{50}
NVS_ADME_hCYP2B6	--	9.04
NVS_ADME_hCYP1A2	--	3.8
NVS_ADME_hCYP1A1	--	8.49
CLD_CYP2B6_48hr	--	11.2
CLD_CYP1A2_48hr	--	4.1
CLD_CYP2B6_24hr	--	11.2
CLD_CYP1A2_24hr	--	0.404
CLD_CYP3A4_6hr	--	3.42
CLD_CYP2B6_6hr	--	11.9
CLD_CYP1A2_6hr	--	9.54
CLD_CYP1A1_6hr	--	5.84
TOX21_AhR_LUC_Agonist	41	--
ATG_Ahr_CIS_up	2.3	--
TOX21_Aromatase_Inhibition	--	14.4
Farnesoid x Receptor (NR1H4)		
TOX21_FXR_BLA_agonist_ratio	--	39.4
TOX21_FXR_BLA_antagonist_ratio	--	17
OT_FXR_FXRSRC1_1440	--	0.352
OT_FXR_FXRSRC1_0480	36.3	26.6
Retinoid x Receptor		
OT_NURR1_NURR1RXRa_0480	39.4	--
OT_NURR1_NURR1RXRa_1440	--	87.2
ATG_RXRb_TRANS_up	24.1	--
Pregnane x Receptor		
ATG_PXR_TRANS_up	4.3	--
ATG_PXRE_CIS_up	6.3	42.7
Liver x Receptor		
ATG_DR4_LXR_CIS_dn	35.2	--
Peroxisome Proliferator Activated Receptor		
TOX21_PPARg_BLA_antagonist_ratio	--	4.94
ATG_PPARg_TRANS_up	57.2	34
ATG_PPRE_CIS_up element	--	32.6
Constitutive Androstenedione Receptor		
NVS_NR_hCAR_Antagonist	--	21.9
Receptors in Human & Rat Brain		
NVS_GPCR_rSST rat forebrain; somatostatin receptor	--	13.4
NVS_GPCR_rOpiate_NonSelectiveNa	--	20.9
NVS_GPCR_rOpiate_NonSelective, forebrain opiate R	--	12
NVS_GPCR_rGHB forebrain, metabotropic glutamate R	--	21.8
NVS_LGIC_rGABAR_NonSelective	12.3	--
TOX21_GR_BLA_Antagonist_ratio	--	39.4
Vitamin D Metabolism		
ATG_VDRE_CIS_up	4.6	31.8
Thyroid Hormone		
TOX21_TR_LUC_GH3_Antagonist LXR PXR	79.7	35.8
Androgen Receptor		
OT_AR_ARSRC1_0960	85.1	--
TOX21_AR_BLA_Antagonist_ratio	--	40.7
Estrogen Receptor & Estrogen Metabolism		
TOX21_ERa_BLA_Agonist_ratio	--	1.55
TOX21_ERa_BLA_Antagonist_ratio	--	115
TOX21_ERa_LUC_BG1_Antagonist	--	43.7
OT_ER_ERaERa_0480	67	--
OT_ER_ERaERb_0480	64	--
OT_ER_ERbERb_0480	56.6	--
ATG_ERa_TRANS_up	20.2	33.8
ATG_ERE_CIS_up	34.3	--
Steroidogenesis		
CEETOX_H295R_11DCORT_dn	84.1	--
CEETOX_H295R_CORTISOL_dn	82.8	--
CEETOX_H295R_TESTO_dn	55.7	--

Assay Name [a]	CPF AC_{50}	CPF Oxon AC_{50}
CEETOX_H295R_ANDR_dn	54.8	--
CEETOX_H295R_PROG_up	39.8	--

[a] All assay abbreviations found at http://actor.epa.gov/dashboard/

Below is an illustration of CPF and CPF-oxon assays and their intended target families. There are more active assays in various target families for CPF-oxon versus CPF. This is expected since CPF-oxon is the active metabolite, while CPF requires metabolic activation which is not provided in the assays.

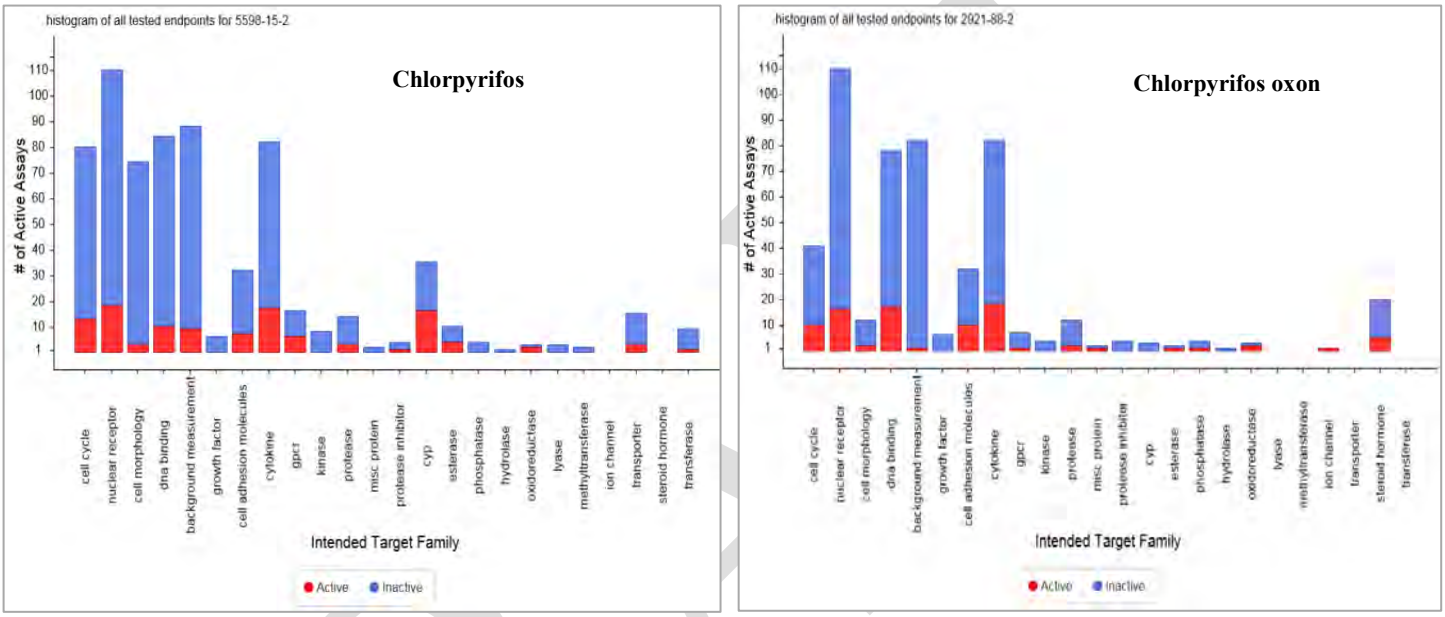


Figure 7. CPF ToxCast Assay Component Histograms

Active (red) and inactive (blue) ToxCast assays are shown for CPF and CPF-oxon, along with the respective intended target families

II.L.3. Toxicological Priority Index (ToxPi)

The Toxicological Priority Index (ToxPi) is a dimensionless index score calculated for each chemical as a weighted combination of all data sources that represents a formalized, rational integration of information from different domains. Visually is ToxPi represented as component slices each representing one piece (or related pieces) of information (Reif *et al.*, 2013; UNC, 2014). The ToxPi data in Figure 8 show relative ToxCast component activities between CPF and CPF-oxon. The input data were generated using AC_{50} values for all assays reported as active (ToxCast Dashboard: http://actor.epa.gov/dashboard/) and "100,000" for inactive assays. Inactives were included only in comparisons where at least one of the two compounds was active. The same scaling type ($-\log10^{(x)+6}$) was used for all ToxPi figures shown. The assay results were grouped into components specified on the ToxCast Dashboard as indicated in Figure 8 by color-coded slices. The unitless Toxicity Scores (Reif et al., 2010; Reif et al., 2013), calculated in the ToxPi program, were virtually identical (15.52 and 15.028 for CPF and CPF-oxon, respectively), despite the differences in the relative toxicities between components.

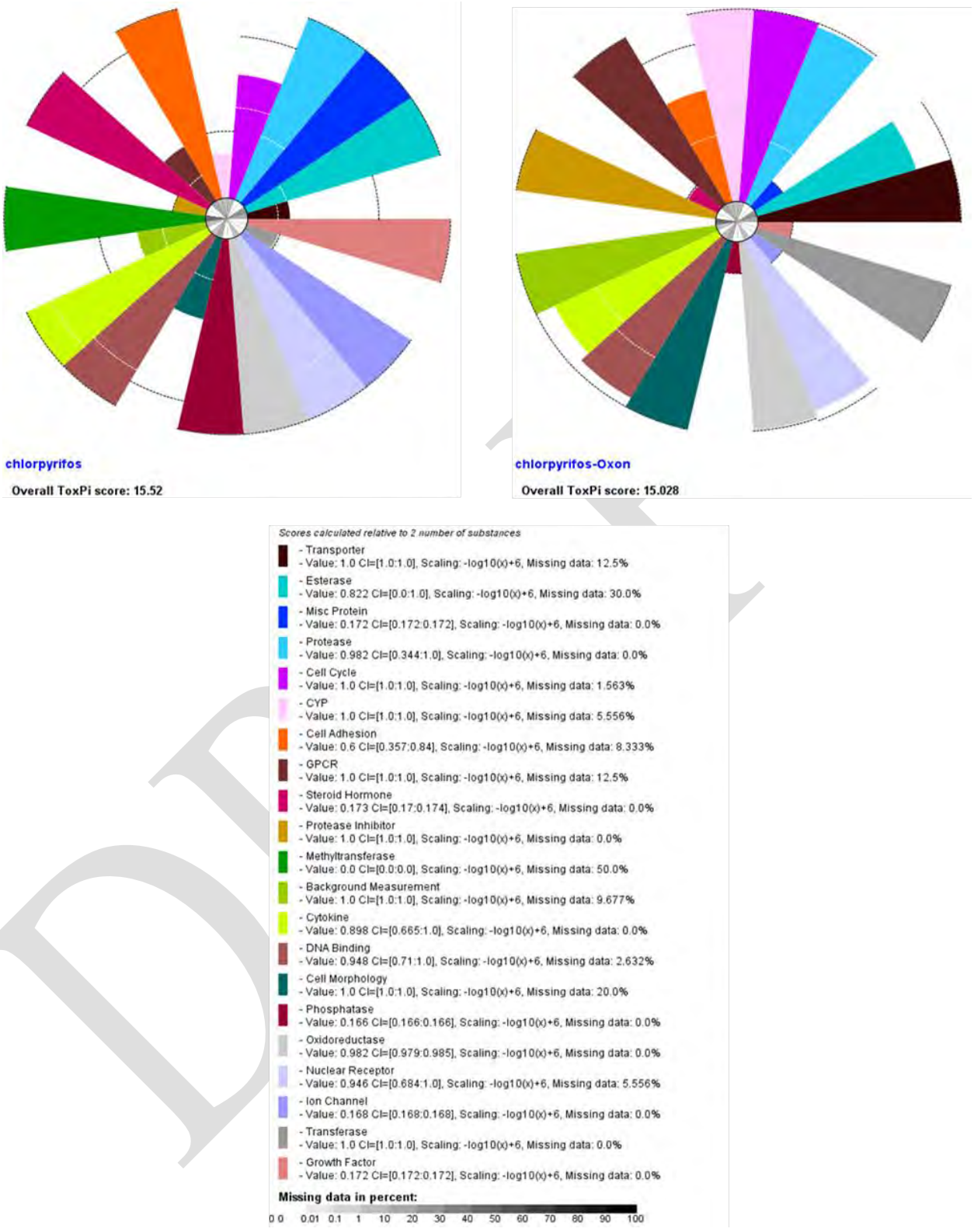


Figure 8. Toxicology Priority (ToxPi)

The ToxPi scale measured the presumptive components showing ToxCast assay activity for CPF (left) and CPF-oxon (right) (Data accessed: January 2017).

II.L.4. US EPA ToxCast Assays in Zebrafish

Zebrafish (zebrafish: *Danio rerio*) provide a model for studying effects of CPF *in vivo*. They share many developmental, anatomical, and physiological characteristics with mammals since molecular signaling is conserved across species (Padilla *et al.*, 2011; Sipes *et al.*, 2011; Padilla *et al.*, 2012; Tanguay, 2013; Tanguay *et al.*, 2013). They also require AChE for normal neurodevelopment (Behra *et al.*, 2002). For that reason, zebrafish are useful for studies of neurobehavioral developmental effects of AChE inhibitors like CPF.

DMSO was used as a vehicle in zebrafish studies. It is known to be neurotoxic at high concentrations (Kaisa et al. 2013; Maes et al. 2012) generating concern for augmented neurotoxicity when used as a vehicle in studies with CPF. In zebrafish DMSO must exceed 1.5-2%, depending on embryonic stage. At 2-4 cells and 4 hpf, 2.5% DMSO is non-toxic; at 1, 2 and 5 dpf, 2% DMSO is nontoxic and at 3 and 7 dpf 1.5% DMSO in solution is not toxic (Maes et al. 2006). Concentrations used in zebrafish studies are generally 0.01 – 0.64% (Hallare *et al.*, 2006; Maes *et al.*, 2012). The benefit of DMSO as a vehicle is to increase chemical uptake into the embryo order to aid in the elucidation of the mechanism of action.

Zebrafish embryos can reveal acute toxic effects of CPF since growth, development and behavior occur at such a rapid rate. Therefore, if a chemical is developmentally toxic in zebrafish, it would affect molecular pathways or processes that might be detected by phenotypic and/or neurobehavioral responses. These changes can then serve as indicators of affected pathways for target identification (Padilla *et al.*, 2011; Padilla *et al.*, 2012; Tanguay *et al.*, 2013; Truong *et al.*, 2014; Reif *et al.*, 2015). The two primary models consist of testing embryos with intact chorions (Padilla et al., 2012)or using embryos with the chorion removed (Tanguay *et al.*, 2013) (Results of each method on the ToxCast Dashboard: http://actor.epa.gov/dashboard/).

II.L.4.a. Zebrafish Method with Chorion Intact

Embryos (2 embryos/concentration/chemical) were exposed to each compound in a single treatment at 0.001 to 80 μM or a DMSO control (0.4% v/v). They were incubated in sealed plates within their aqueous media for ~4 days at 26±0.1 °C until hatching. They were then placed in an incubator and maintained on a 14:10 hour light:dark cycle. Each day through 120 hours (5 days) the animals had a complete change of medium with a fresh dose of compound. At 144 hours post-fertilization (hpf:6 days) each embryo/larva was evaluated for viability and developmental effects by use of a dissection microscope. The decision tree for collection of endpoints and descriptions of the categories and physical features within each category that were analyzed are presented in Padilla et al. (2011) and Padilla et al. (2012). Malformations received a "response" score for lethality and hatching status (Malformation Index [MI]: 20=non-hatching; 40=lethality; if alive and hatched, then MI = summation of aggregated scores across all categories of malformations for each condition) and the summation of all scores for all malformation categories was defined as the "Toxicity Score" (or "Terata Score"). In cases where larvae were alive and hatched then the Malformation Index and Toxicity score were equal. Graphically the Toxicity Score (y-axis) and chemical concentration (x-axis) were used in a custom "R implementation" (R Development Core Team, Vienna, 2011) of the Evolutionary Algorithm Dose Response Modeling (EADRM) (Beam and Motsinger-Reif, 2011) to determine a "hit" based on "efficacy," or response at the top asymptote of the sigmoidal fit (EMAX

Toxicity Score) (response): minimum cutoff is a score of 6.5 or one standard deviation above the mean of the vehicle control) and goodness-of-fit (R^2: minimum cutoff = 0.4). Chemical "potency" (AC_{50} and AC_{10} concentration at 10% maximal activity) and slope (W) were also determined (Figure 9).

Padilla et al. (2012) tested CPF-ethyl, which is the form of CPF evaluated in this risk assessment. The AC_{50} for CPF (8.5 µM; 2.97 µg/ml) was 21-fold greater than the AC_{50} for CPF-oxon (0.40 µM; 0.14 µg/ml). A Terata Score, or sum of all malformations and variations was reported for each chemical tested. CPF-oxon received the highest score (40) in the single 80µM test (CPF was not tested). Both compounds were tested up to concentrations producing a Terata Score of 40 in the concentration-response study (Figure 8). The slope was very steep for CPF between AC_{10} (3.0 µM) and the AC_{50} (8.5 µM). The AC_{10} in ToxCast assays is considered to be a NOEL equivalent (Judson et al. 2014).

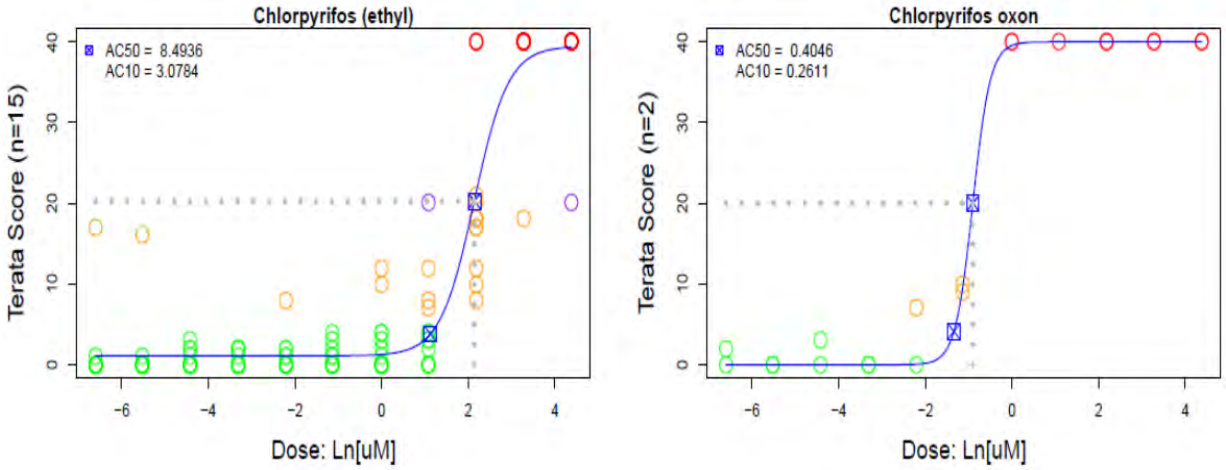


Figure 9. Terata Scores for CPF

Green = control levels; red = dead (Terata Score=40); purple= not hatched but alive (Terata Score ~ 20); yellow = animals alive and hatched (Terata score 8-20) (Padilla et al., 2012)

II.L.4.b. Zebrafish Method with Chorion Removed

Another method of treatment involved removal of the chorion from the zebrafish embryos prior to treating them with test compound in order to eliminate possible interference relating to absorption (i.e. exposure consistency), increase bioavailability, facilitate endpoint assessments and reduce confounders. Zebrafish (32/concentration) were treated with the test chemical at 0.064–640 µM (0.022 to 22 µg/ml: 10-fold serial dilutions) in DMSO (0.64% v/v). A positive control (5 µl trimethyltin chloride) was also used. Zebrafish were exposed daily with fresh media for 5 days (Truong et al., 2014). Plates were sealed to prevent evaporation and foil covered to reduce light exposure and kept in a 28°C incubator. Embryos were statically exposed (i.e., only one dose of test compound) until 120 hpf but at 24 hpf, they were assessed for photomotor response using a custom photomotor response analysis tool (PRAT) and for 4 developmental toxicity endpoints (MO24: mortality at 24 hpf, DP: developmental progression, SM: spontaneous movement, and NC: notochord distortion) (Truong et al., 2011). At 120 hpf, locomotor activity was measured using Viewpoint Zebralab (Saili et al., 2012; Truong et al., 2012) and assessed for 18 endpoints (Truong et al., 2011).

The graphs shown below indicated individual malformations by chemical (Figure12). Unlike what was observed with the Padilla method (i.e., chorion intact model) there were no effects for CPF. However, CPF-oxon showed mortality at 24 hours at all doses (MO24); developmental progress (inhibited) at 24 hours (DP24); mortality (mort); yolk sac (YSL), axis and trunk abnormalities were observed at ≥ 6.4 µM (2.24 µg/ml; pericardial edema (PE) and caudal fin (CF) abnormalities occurred at 64 µM (22.4 µg/ml). The increased mortality may have been due to the lack of a chorion barrier and a higher DMSO concentration (leading to higher permeability) than was used in the Padilla method.

The difference in toxic effects between the results of the chorionated versus dechorionated methods may be due to the different dosing methods as well as methods of scoring embryos or other unknown differences.

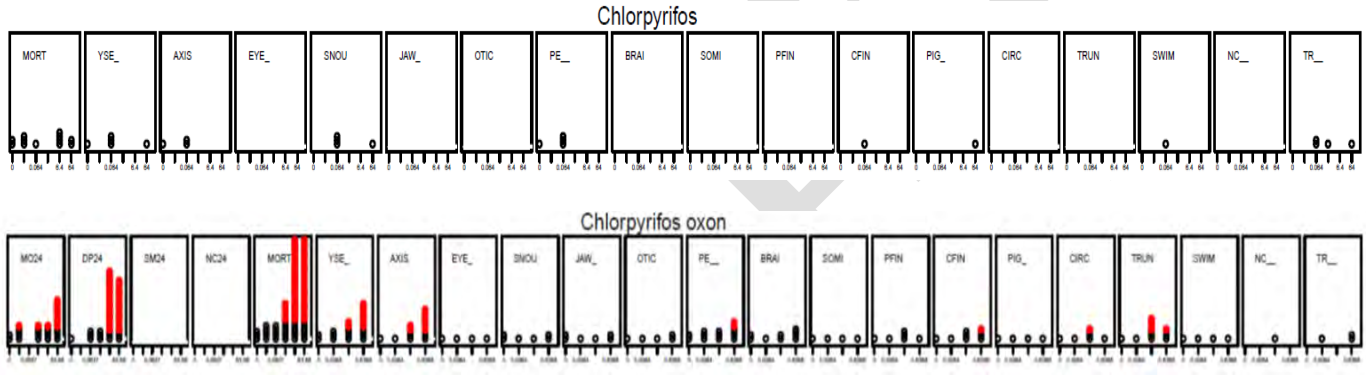


Figure 10. Morphological effects from CPF or CPF-oxon treatment in zebrafish

There were no effects for CPF.CPF-oxon caused mortality at 24 hours at all doses (MO24); developmental progress (inhibited) at 24 hours (DP24); mortality (mort); yolk sac (YSL), axis and trunk abnormalities were observed at ≥ 6.4 µM; pericardial edema (PE) and caudal fin (CF) abnormalities occurred at 64 µM (Truong et al., 2014).

Zebrafish behavioral effects were examined after treatment of embryos with CPF or CPF-oxon at doses of 0.0064 - 64 µM (daily: 5 days post-fertilization) (Reif et al., 2015). Animals were treated in the dark to which they adapted as they developed. At 24 hours hpf, animals received a light stimulus (30 second process) that was used to assess behavior as follows: Initial Phase (B): 1) a short prelight pulse (soft light background: "B"); Excitatory Phase (E): 2) immediately followed by a short pulse of bright light; 3) pause 9 seconds before the next light pulse; 4) a second pulse of light, and; Refractory Phase (R): 5) 10 seconds of dark . The animals were videotaped during the process and their behavior was later analyzed. Results showed that CPF only showed significant effects during the excitatory phase but not during B or R (these were within the control range). CPF-oxon showed effects from B at 6.4 µM, E at 0.64 µM, and no effects during R (within control range). This means that CPF-oxon caused noticeable behavioral effects at a 10-fold lower dose 0.64 µM when exposed to the bright light pulse as opposed to the background light. This is also the dose at which other developmental effects were observed as shown in (Figure 10) (Truong et al., 2014). CPF showed behavioral effects only for the bright pulse of light and only at the highest dose (64 µM); however CPF showed no morphological developmental effects at any dose (Figure 10).

II.L.4.d. Zebrafish Results From Laboratories Not Related to ToxCast (Chorion Intact)

Levin et al. (2003) used CPF at 0.028 µM and 0.28 µM (0.01 and 0.10 µg/ml: 0.02% DMSO vehicle) on zebrafish embryos (chorion intact) for 5 days. Animals were tested for behavioral effects intermittently up to 26 weeks. Mortality was high at 0.28 µM (0.10 µg/ml: 5/12 died) at 38 weeks (0/13 DMSO; 1/16 at 0.028 µM [0.01 µg/ml]). At 0.028 µM (0.01µg/ml), zebrafish had effects on average choice accuracy, decreased spatial discrimination, increases in average latency response when the animals were first tested (20 weeks). This indicated that neurobehavioral/ learning/cognition effects occurring after treatment with CPF in an embryonic stage were not reversible. Levin et al. (2004) then treated zebrafish for effects of CPF on swimming behavior. Tested at day 6, animals showed decreased swimming activity and decreased habituation of swimming activity at 0.28 µM (0.10 µg/ml). These effects involve the central nervous system (CNS: ≥0.028 µM [0.01 µg/ml]) as well as peripheral nervous system (PNS: 0.28 µM [0.10 µg/ml]: muscular).

Zebrafish embryos (chorion intact) were treated with 0.28 µM (0.10 µg/ml) CPF for various periods (0–1, 0–2, 0–3, 0–4, 0–5 days post-fertilization [dpf]) to optimize exposure for learning and memory impairments (Sledge et al., 2011). Persistent effects from dpf 5 to adult included: decline in brain dopamine and norepinephrine levels, decreased habituation to startle, "trend toward increased overall startle response," (Sledge et al., 2011) page 742) decreased escape diving response, increased swimming activity and lower learning rate. When placed in a new environment (novel tank exploration test) the zebrafish also showed a decrease in escape diving response and increased swimming after 5 days of treatment when tested at 3 months.

Jin et al. (2015) evaluated neurobehavioral and teratogenic effects in zebrafish (chorion intact) after CPF treatment at 0 (DMSO), 0.028, 0.084, 0.28, 0.84 µM (0.010, 0.030, 0.10 and 0.3 µg/ml) for 48, 60 or 96 hours post fertilization. Results at 96 hpf showed neurobehavioral (↓swim distance) effects related to stimulation of light/dark photoperiod transition at 0.084 µM and teratogenic effects (spinal deformities, pericardial edema) at 0.84 µM zebrafish. Neurobehavioral effects occurring after treatment with CPF in an embryonic stage were not reversible. In addition, AChE inhibition was increased at 0.28 µM and AChE mRNA was decreased at 0.84 µM, oxidative stress-related enzyme levels (↓GSH, ↓GST, ↑catalase, MDA, SOD) were affected at ≥0.028 µM and the transcriptional levels of genes related to neurotoxicity were affected at ≥0.028 µM.

CPF was shown to affect anxiety-related behaviors in zebrafish (chorion intact) at ≥0.01µM (0.0028 µg/ml) when they were exposed for 7 dpf (Richendrfer et al., 2012a). The altered behaviors exhibited included decreased swim speed and thigmotaxis (edge preference). There was a decrease in fish on the edge of the dish both with and without visual stimuli (decreased anxiety) at ≥0.01 µM. At 1.0 µM fish showed tails that curled up and the fish twitched but could not swim. They also had shorter body at 1.0 µM. There were no effects on avoidance behavior.

At 0.001 µM (0.00028 µg/ml) CPF, there were no changes in swim speed, thigmotaxis, or avoidance behavior and at 1 µM (0.028 µg/ml) CPF there were both behavioral and teratology effects. Thigmotaxis is an anxiety-related behavior in zebrafish larvae (Richendrfer et al., 2012b) and this behavior alteration appears to be directly related to exposure to low doses of CPF especially 3-5 dpf.

Zebrafish embryos (chorion intact) were exposed to CPF at 0, 0.28, 0.71, 1.42, 2.14 and 2.85 µM for 48 hours (media change every 12 hrs; 10 embryos/dose in triplicate) to assess the potential for endocrine disruption (Yu *et al.*, 2015). CPF was shown to increase hatching time in a dose-related manner. Indicators of cell proliferation and cell apoptosis were affected based on mRNA expression of c-myc, cyclin D1, Bax and Bcl-2, which are closely related to cell proliferation and cell at 48 h. Apoptosis occurred at 2.31 and 2.85 µM, indicating that endocrine disruption could be occurring. Increases in vitellogenin (VTG), a protein is a biomarker for vertebrate exposure to environmental estrogens, was assessed in the zebrafish embryos. The mRNA expression of VTG was increased at ≥0.71 µM but the estrogen receptor alpha data were equivocal. It appears that as with the ToxCast results, endocrine disruption occurs at doses higher than those affecting behavior and AChE inhibition.

Zebrafish (Tübingen strain) embryos were treated with 0 (0.01% acetone v/v) or 0.71 µM (0.25 mg/L) CPF at 2 hours post fertilization (hpf) for 24 hours (Liu et al. 2015). This CPF dose was tested and shown not to increase mortality or malformations compared to adult animals. Embryo media was changed at 12 hours. The acetone vehicle was shown not to affect protein expression (Hallare *et al.*, 2006). At 24 hours the major organ systems, somites, pronephros, heart and central nervous system have developed. The zebrafish proteome was mapped to indicate the effects on stress-related proteins. Results showed that many proteins involved in zebrafish development were affected including 9 that are related to CPF detoxification (heat shock protein, aldehyde dehydrogenase 2, and glutathione S-transferase M), cytoskeleton structure, protein translation, signal transduction and lipoprotein metabolism. Three of the up-regulated proteins were associated with detoxification (aldehyde dehydrogenase 2 (ALDH2) precursor, glutathione S-transferase M) and stress response (shock protein (Hsp60)).indicating a protective response in the zebrafish embryos exposed to CPF. Six down-regulated proteins were associated with cytoskeleton structure (Type I cytokeratin, enveloping layer), protein translation, signal transduction and lipoprotein metabolism. Detoxification-related proteins were presumably induced in response to CPF exposure (protective) while down-regulation of Apo lipoprotein A (a major protein component of HDL particles in plasma) may lead to disruption of the oxidative stress response.

II.L.4.d. Zebrafish and Acetylcholinesterase Inhibition (Intact Chorion)

AChE activity is critical to zebrafish nervous system development as has been demonstrated by Behra et al. (2002). They developed a genetically altered zebrafish strain (*ache: chorion intact*) which totally eliminated AChE activity (ACh hydrolysis) in homozygotes. The embryos with the mutant phenotype (-/-*ache*) have defective innervation (PNS) and muscle fiber development resulting in premature death of sensory neurons (Behra et al., 2002). Initially embryos are motile but when primary sensory neurons die, the lack of innervation of muscle fibers results in paralysis. "The neuromuscular phenotype in *ache* mutants is suppressed by a homozygous loss-of-function allele of the α-subunit of the nicotinic acetylcholine receptor (nAChR), indicating that the impairment of neuromuscular development is mediated by activation of nAChR in the mutant" (Behra et al., 2002).

Yen et al. (2011) examined the possibility that the CPF MOA also involves inhibition of zebrafish AChE resulting in hyperstimulation at cholinergic synapses and subsequent loss of neuromuscular activity by neuronal death. They examined AChE inhibition in zebrafish embryos

(intact chorion) after exposure to 0.28 µM (~0.105 µg/ml) throughout a 5 day post-fertilization (dpf) treatment. AChE was inhibited at 2 dpf and steadily increased until it peaked at 80% inhibition at 5 dpf when compared to DMSO control. Subsequently zebrafish movements were tracked at 6 dpf (one day after 0-5 dpf exposure). At 0.28 µM CPF exposures reduced locomotor activity by 35% 0.28 µM CPF (~0.105 µg/ml). This exposure level was about the same as used by Jin et al. (2015) and Levin et al. (2004) where neuromuscular effects were also observed.

A study by Richendrfer and Creton (2015) examined AChE inhibition and neurobehavioral toxicity in zebrafish (chorion intact) treated at lower doses of CPF (0.001, 0.01, 0.1 µM or ~0.00028, 0.0028, 0.028 µg/ml) during various treatment windows (1-5 dpf or late development 3-5 dpf). As shown by Jin et al. (2015), 80% of AChE is inhibited at 0.28 µM (0.105 µg/ml). This study was meant to examine what effects occurred at even lower doses. Results showed that AChE was significantly decreased only at 0.1 µM (0.035 µg/ml) CPF, whereas at ≥0.01 µM (0.0028 µg/ml) CPF there was a significant increase in abnormal behavioral ("fish at rest" was increased; swim speed was decreased after 1-5 dpf treatment). Zebrafish treated during 3-5 dpf showed a significant decrease in fish with a preference for being on the side or on the edge of their swim lane (signifies decreased anxiety), a decrease in swim speed and an increase in "fish at rest" at ≥0.01 µM (0.0028 µg/ml) with a complete absence of AChE inhibition. These results show that at CPF concentrations 10-fold lower than those that inhibit AChE can affect the behavior of zebrafish during development. A summary of the zebrafish studies is below in Table 19 (Oliver *et al.*, 2016).

Table 20. Summary of Zebrafish Studies

Study design (exposure, conc., solvent)	DMSO	Chorion +/-	ENDPOINT	Ref[a]
Conc: solvent control, 0.028, 0.084, 0.28, 0.84 µM (0.01, 0.030, 0.10 and 0.3 µg/ml; N = 30-50 eggs per assay x 4 reps; Exposure: 48, 60 or 96 hrs post fertilization; CPF purity provided	Yes, conc. Not stated	No mention assume +	Hatchability: ↓ ≥ 0.084 µM at 60 hpf; no effect at 96 hr Heart rate: ↓ at ≥ 0.084 µM at 48 hrs Body length: ↓ at ≥0.01 µM 96 hrs At 96 hpf: Locomotion (distance & speed): ↓ at ≥0.084 µM; ↓AChE activity 0.28 µM (≥ 100 ppb); ↓mRNA & proteins levels at 0.84 µM; ↑ oxidative stress-related enzyme levels (↓GSH, ↓GST, ↑catalase, MDA, SOD), ↑transcriptional levels of genes related to neurotoxicity, & immunotox at ≥0.028 µM	1
Conc.: solvent control, 0.028, 0.28 µM (0.01, 0.10 µg/ml); Exposure: 5 days (120 hrs); + recovery phases with behavioral testing (20-38 weeks) Analytical confirmation: No	0.2 µl/ml; 0.02%*	No mention assume +	Survival: ↓ at 0.28 µM at 26 &32 weeks, but not 20 or 38 weeks. Choice accuracy & spatial discrimination: ↓ ≥0.028 µM at 10 and 100 ppb (dose responsive); Response to stimuli: slowed responses at 0.010 µM and quickened response time at 0.1 µM (1-6 & 7-12 sessions)	2
Conc: solvent controls; CPF 80 µM single dose; or 0.001, 0.004, 0.012, 0.03, 0.11, 0.32, 1, 2.96, 8.8, 26.6 & 80 µM (dose-response); N= 4 embryos/conc. (single dose); 2 embryos per conc (dose-response) Exposure: 5 days; CPF-ethyl; Analytical confirmation: No; AC_{50} = Toxicity score (they assigned descriptive data a numerical score: 40=lethality; 20=nonhatching, larva alive & hatched Toxicity Score =MI	0.4% (v/v)*	+	CPF ethyl & CPF-oxon; Single conc. CPF-ethyl only: Toxicity score: 40 (lethal) at 80 µM; AC_{50}: 0.4046 µM; CPF--oxon (8 replicate sets); AC_{50}: 8.4936 µM. CPF-ethyl CPF slope between AC_{10} (3.0 µM; 1.05 µg/ml) & AC_{50} (8.5 µM; 2.97 µg/ml). Embryo death with CPF occurred at about 20 µM and with CPF-oxon the animals were killed at about 1 µM (20:1 toxicity ratio).	3
Conc.: solvent control, 0.001, 0.01, 0.1, 1 µM 7 days post fertilization; Analytical confirmation: No	0.1%*	-	↓Edge preference with and without visual stimuli (decreased anxiety) at ≥0.01 µM; with visual stimuli ≥0.1 µM; 1.0 µM fish showed tails that curled up and showed twitching but could not swim; 1.0 µM shorter body length, lethargic.	4

Study design (exposure, conc., solvent)	DMSO	Chorion +/-	ENDPOINT	Ref[a]
Conc.: solvent control, 0.001, 0.01, 0.1 µM; Exposure: 1-5 dpf or late development 3-5 dpf Analytical confirmation: No	0.1% *	+	Swim speed: ↓0.1 & 0.01 µM; ↑effects during the 3-5 dpf window. AChE activity significantly ↓only at 0.1 µM (0.035 µg/ml); ↑ abnormal behavioral (↑"fish at rest"; swim speed ↓after 1-5 dpf treatment) at ≥0.01 µM; during 3-5 dpf ↓fish with a preference for being on the side or on the edge of their swim lane (signifies decreased anxiety) at ≥0.01 µM with a complete absence of AChE inhibition.	5
Conc.: 0.0064–64 µM CPF, CPF-oxon, CPF-methyl; no mention of solvent control; Exposure: 120 hpf N = 16 per plate x 2 plates	0.64% *	-	CPF: no dose dependent trends in any of the 18 markers (morphology & locomotor activity); CPF-oxon: ↑ mortality, yolk sac edema; body axis effects with dose dependent trends. CPF-methyl: no dose-dependent trends apparent; mortality, eye, snout, jaw, truncated body, touch response effects ↑ at 64 µM	6
Conc.: solvent control; 0.003 - 1 µM CPF & CPF-oxon Exposure: 24 to 48 or 72 hours	0.1%*	+	CPF: No significant effect on AChE activity at 48 or 72 hrs; Uptake after exposure to 1 µM was 11.06, 32.48, & 36.86 ng/embryo, respectively. CPF-oxon: dose-dependent ↓ in AChE activity at 48 & 72 hours; sign. ↓ 0.03 - 1 µM; Morphology: ↑ pericardia edema, body axis curvature & ↓pigmentation at 1 µM only. Swim behavior: ↓ at ≥ 0.1 µM (dose-dependent trend); Axonal growth in sensory neurons: ↓at 1 µM (were recoverable)	7
Conc.: solvent control, CPF 0.3 - 30 µM; Exposure: 5 days N=10 (survival), 30 (AChE & motility)	0.1%*	No mention assume +	↑ mortality at ≥ 3 µM; 80%↓AChE activity at 0.28 µM 5 dpf; 35% ↓Locomotor activity at 0.28 µM	8
Conc.: solvent control, CPF 0.71 µM; Exposure 24 hr., N=150/dose; protein mapping for stress & developmental effects	0.1% acetone	No mention assume +	Mapping of up-regulating detoxification (aldehyde dehydrogenase 2 (ALDH2) precursor, glutathione S-transferase M) & stress response (shock protein (Hsp60)) proteins; 6 down-regulated proteins for cytoskeleton structure (Type I cytokeratin, enveloping layer), protein translation, signal transduction & lipoprotein (Apo-A) metabolism	9
Conc: solvent control, CPF 0, 0.28, 0.71, 1.42, 2.14 and 2.85 µM for 48 hours (media change every 12 hrs)	0.1% Acetone	+	↑apoptosis at >2.14 µM, mRNA effects on cell proliferation indicators at all doses (mRNA expression of c-myc, cyclin D1, Bax and Bcl-2); ↑ VTG at ≥0.71 µM	10

References: 1. Jin et al. 2015; 2. Levin et al. 2003; 3. Padilla et al. (2012); 4. Richendrfer et al., 2012a; 5. Richendrfer & Creton, 2015; 6. Truong et al. 2014; 7. Yang et al. 2011; 8. Yen et al. 2011; 9. Liu et al. 2006; 10. Yu et al. 2015

Abbreviations: DMSO=Dimethyl sulfoxide; hfp: hours post-fertilization; dpf: days post-fertilization

Table adapted from Oliver *et al.* (2016).

III. HAZARD IDENTIFICATION

Pesticide risk assessment starts with hazard identification (hazard ID) in which toxic endpoints are identified from studies performed usually in accordance with US EPA's Health Effects Test Guidelines (US EPA, 2000b) or from the open literature. Once the toxic endpoints are identified, a No-Observed-Effect-Level (NOEL), a Benchmark Dose Lower Estimate (BMDL), or Point of Departure (PoD) is obtained. This is the highest dose at which no biologically or statistically significant adverse effect for the primary exposure route (oral/dermal/inhalation) is expected to occur relative to the control group. The hazard ID for CPF focused on 10% RBC AChE inhibition as well as neurodevelopmental and neurobehavioral toxicity in humans.

Note that in our selection of critical studies, we do not include mammalian studies where DMSO was used as a vehicle or where chlorpyrifos exposure was by a subcutaneous route. DMSO is not acceptable as an oral vehicle since it may exacerbate neurotoxic effects (Carr and Nail, 2008) and subcutaneous administration is not an applicable route of human exposure for CPF.

III.A. Acute (1 dose) and Short-Term (~2 weeks) Toxicity

The profile of acute CPF toxicity has been extensively described (Eaton *et al.*, 2008; Testai *et al.*, 2010; Koshlukova and Reed, 2014; US EPA, 2014a). The database for the acute toxicity for CPF consists of Health Effects Test Guideline studies submitted to DPR by registrants as well as open literature studies that were considered by HHA scientists to be relevant and well-performed. Acute exposure to toxic levels of CPF results in the typical signs and symptoms of cholinergic toxicity: salivation, lacrimation, urination and defecation (Eisler, 2007).

III.A.1. Acute and Short-Term Oral Toxicity

The overt effects from acute or short-term oral exposure to CPF in adult rats, mice, and rabbits include cholinergic reduced body weight and food intake, enlarged adrenals, and increased resorptions. Fetal and pup overt toxicity in these species include increased post-implantation loss, reduced live fetuses, reduced survival, reduced body weights, reduced crown-rump length, increased delayed ossification, reduced pup growth, delayed pinna unfolding, preputial separation (M), vaginal patency, delayed vaginal opening, reduced brain size, reduced motor activity, reduced auditory startle habituation and latency to response, and reduced neuromotor function. The NOELs for these overt effects were at doses higher than those for AChE inhibition.

Carr et al. (2013)and Carr et al. (2014)were the only studies reporting overt toxicity with the same NOEL as for AChE inhibition (Table 7 and Table 13). Overt effects involved inhibition of endocannabinoid enzymes in the central nervous system. The studies explored effects of CPF on two serine hydrolase enzymes which are involved in endocannabinoid degradation, including monoacylglycerol lipase (MAGL) and fatty acid amide hydrolase (FAAH). The associated neuromodulatory lipid endocannabinoids were 2-arachidonoylglycerol (2-AG), which was metabolized by MAGL, and anandamide (AEA) which was metabolized by FAAH. These cannabinoids are essential in neurodevelopment, but their levels in CNS are controlled by MAGL and FAAH to keep ligand concentrations at optimal levels (Anavi-Goffer and Mulder, 2009). Results showed that FAAH was inhibited to a greater extent and for a longer duration than brain AChE in rat pups. Supporting these findings are studies by Carr et al. (2015a); Carr et al. (2015b); Mohammed et al. (2015) which showed significant neurobehavioral effects in rat pups treated with the same regimen at 0.5 mg/kg/d. Therefore, FAAH inhibition may be a more sensitive endpoint than AChE inhibition for neurodevelopment. However, sufficient information is not yet available about this system to use it for establishing a critical NOEL. Instead, these effects will be evaluated in relation to database uncertainties for potential increased sensitivity in infants and children.

The acute oral NOELs (or PoDs) used by US EPA were obtained from their PBPK-PD model based on 10% RBC AChE inhibition data from human studies (Nolan et al., 1984; Kisicki et al., 1999; Smith et al., 2011; Smith et al., 2014). Although the animal model provided a lower NOEL than the PBPK-PD model, it is preferable to use human data from well-conducted studies when

available. The chlorpyrifos PBPK-PD model has been thoroughly evaluated and critiqued by several sources, including publication of the model in peer-reviewed journals (Gearhart et al., 1990; Timchalk et al., 2002a; Timchalk et al., 2002b; Timchalk et al., 2006; Lowe et al., 2009; Hinderliter et al., 2011; Smith et al., 2011; Poet, 2013; Poet et al., 2014; Smith et al., 2014). It has also been reviewed by the SAP (US EPA/SAP, 2010; US EPA/SAP, 2012; US EPA/SAP, 2016)and US EPA (2014a). Because the PBPK-PD model is based on human data obtained through dosing studies and metabolic factors derived from human tissues, US EPA has designated an interspecies uncertainty factor (UF) = 1x (US EPA, 2014b), which HHA also used. Therefore, the PoDs for acute oral CPF exposures are as follows:

PoD for infants < 1 year old = 0.60 mg/kg/d
PoD for young children ages 1-2 years = 0.581 mg/kg/d
PoD for children aged 6-12 years = 0.53 mg/kg/d
PoD for youth aged 13-19 years old = 0.475mg/kg/d
PoD for females of childbearing age (13-49 years old) = 0.457 mg/kg/d

The lowest acute oral PoD was for females of childbearing age (13-49 years old) (0.457 mg/kg/d), and will be used for dietary exposure assessments (see Table 21 below).

For acute oral spray drift risk characterization, the steady-state PoD for children ages 1-2 years old was used (0.099 mg/kg/d). It is appropriate to use steady-state for California exposure scenarios in which crops are treated for a few hours every 10 days because AChE inhibition is slowly reversed over approximately 26 days. At 10 days, acetylcholinesterase inhibition is still 50% in plasma and approximately 20% in RBCs, resulting in accumulated inhibition in those exposed for the duration of the season of treatment (Nolan et al., 1984).

III.A.2. Acute Dermal Toxicity

Acute dermal CPF toxicity from a single administration was assessed in adult rats (M/F) and a decrease in plasma and RBC AChE was observed (Calhoun and Johnson, 1988). Multiple studies showed no AChE inhibition in human plasma ChE after a single treatment at a single dose (5.0 mg/kg/d) (Nolan *et al.*, 1982; Hoberman, 1998; Mattsson *et al.*, 1998; Maurissen *et al.*, 2000; Marty and Andrus, 2010; US EPA, 2011b). No overt effects were reported. The NOELs were 1.0 and $\geq$ 5.0 mg/kg/d for rats and humans, respectively. The rat dermal study performed by Chen et al. (1999)had the lowest NOEL of 1.0 mg/kg/d based on plasma and RBC AChE inhibition at the LOEL (10 mg/kg/d). This study was not performed according to US EPA Health Effects Test Guidelines. In addition, the toxicological significance of plasma and RBC AChE inhibition by itself is uncertain, especially in animals compared to humans. Therefore, HHA used the PBPK-PD-generated steady-state dermal PoD of 11.89 mg/kg/d for females of childbearing age and 134 mg/kg/d for children aged 1-2 years old to evaluate the acute spray drift dermal exposure scenarios.

III.A.3. Acute Inhalation Toxicity

Male and female rats were treated with CPF in an aerosol (nose only) in a single exposure and showed plasma, RBC and lung AChE inhibition (Hotchkiss et al., 2010). The LOEL was 3.7 mg/m^3 (1.0 mg/kg/d) based on ChE inhibition in plasma, RBC and lung at every dose. In another

study, female rats administered CPF as a vapor (to saturation) showed no effects on plasma, RBC, and brain AChE at the only dose tested via nose only (17.7 ppb/0.254 mg/m^3) (Hotchkiss et al., 2013). The study of greatest interest for risk assessment is the one performed with aerosols, since that is the most likely medium for human inhalation exposure in California as shown in this document. Poet and colleagues (2015)incorporated an inhalation exposure route into the PBPK-PD model. Inhalation parameters used in the model were from the aerosol study in rat by Hotchkiss et al. (2010). The PBPK-PD model provided good comparisons for the critical metabolic parameters (e.g., plasma chlorpyrifos, oxon, and TCPy concentrations; ChE in plasma, RBC and brain). In vivo rat data were then used to validate the PBPK-PD model. Poet (2015)indicated that the PBPK/PD predictions for aerosol (particulate) inhalation exposure with respect to CPF, CPF-oxon, and TCPy in plasma as well as ChE in plasma, RBC, and brain was validated with data from the rat acute CPF aerosol inhalation study (Hotchkiss *et al.*, 2013; Poet, 2015). US EPA did not anticipate acute inhalation exposure for their residential scenarios. They instead generated PoDs for steady-state inhalation exposure for two critical subpopulations, children aged 1-2 years-old (PoD = 2.37 mg/m3) and females of childbearing age (PoD = 6.15 mg/m3) (US EPA, 2014a).

III.B. Subchronic Toxicity

Subchronic CPF toxicity was described and reported in the US EPA 2007 RED, the 2011 US EPA Preliminary Human Health Risk Assessment, and the 2014 US EPA Revised Human Health Risk Assessments (US EPA, 2007; US EPA, 2011a; US EPA, 2014a), and in the HHA Summary of Toxicology Data (Appendix 1). Summaries of registrant-submitted studies used in consideration for developing the subchronic endpoints are listed in Table 19, below. All studies are considered acceptable according to US EPA Health Effects Test Guidelines except the supplemental (non-Guideline) 6-week dietary CPF study performed in Beagle Dogs (Marable et al., 2001) designed to evaluate clinical signs, metabolism, and/or AChE inhibition.

III.B.1. Subchronic Oral Toxicity

Overt subchronic effects from CPF treatment included reduced body weights and feed consumption, increased clinical signs, neurobehavioral effects in FOB and motor activity, changes in urinalysis, hematology, and clinical chemistry values, changes in organ weights, increased adrenal zona fasciculata fatty vacuolization and altered adrenal tinctorial properties in adults, and reduced pup weights and pup survival. However, the most sensitive endpoint from the five dietary and one gavage studies shown below is AChE inhibition. In some cases a NOEL was not observed. A $BMDL_{10}$ of 0.03 mg/kg/d was calculated by US EPA (2011b) based on a weight-of-evidence from 5 multidose studies performed in rats(Hoberman, 1998; Mattsson *et al.*, 1998; Maurissen *et al.*, 2000; Marty and Andrus, 2010; US EPA, 2011b).

US EPA calculated an oral steady-state (21-day) PoD of 0.078 mg/kg/d from the PBPK-PD model. As mentioned earlier, because the PBPK-PD model is based on human data obtained through dosing studies and metabolic factors derived from human tissues, US EPA has designated an interspecies uncertainty factor (UF) = 1x (US EPA, 2014a), which HHA also used. Therefore, the PoDs for steady-state oral CPF exposures are as follows:

PoD for infants < 1 year old = 0.103 mg/kg/d
PoD for young children ages 1-2 years = 0.099 mg/kg/d
PoD for children aged 6-12 years = 0.090 mg/kg/d
PoD for youth aged 13-19 years old = 0.080 mg/kg/d
PoD for females of childbearing age (13-49 years old) = 0.078 mg/kg/d

The lowest steady-state oral PoD (0.078 mg/kg/d for females of childbearing age) will be used for subchronic/chronic dietary. The oral steady-state PoD for children 1-2 yrs old (0.099 mg/kg/d) was used to assess acute spray drift risk.

III.B.2. Subchronic Dermal Toxicity

No NOEL was achieved after 5 mg/kg/d CPF dermal treatment in rats (the only dose tested) (Calhoun and Johnson, 1988)(Table 19). Nor was a NOEL achieved in another CPF dermal study performed in mice (Krishnan et al., 2012), although a LOEL was established at 101 mg/kg/d based on reduced plasma ChE in adults and pups. Therefore, animal data for subchronic dermal exposure was not available for critical NOEL selection. The PBPK-PD model used by US EPA predicted steady-state 10% RBC AChE inhibition based on TCPy as a biomarker for CPF exposure in humans (Poet et al., 2003; Timchalk et al., 2007; Timchalk and Poet, 2008; Lowe et al., 2009; Smith et al., 2011; Smith et al., 2014). The modeled steady-state dermal PoDs are therefore useful to HHA for risk characterization since an animal NOEL is not available and because the PBPK-PD model is well described for the relevant subpopulations at risk. Females aged 13-49 years old (ss PoD = 23.6 mg/kg/d) and children ages 1-2 years old (ss PoD = 134 mg/kg/d) were used as the critical NOELs to assess dermal steady-state spray-drift risk. These PoDs were selected as the critical NOELs to evaluate subchronic spray drift inhalation exposure to CPF (see Table 19).

III.B.3. Subchronic Inhalation Toxicity

A 13-week study in rats established a NOEL of 0.010 ppm(0.143 mg/m^3) based on decreased AChE activity (Newton, 1988). It is important to note that the study was performed with CPF vapor and not aerosol. US EPA reported PoDs for steady-state (subchronic 21-day) inhalation exposure for two critical subpopulations: children 1-2 years-old (PoD = 2.37 mg/m^3) and females 13-49 years-old (PoD = 6.15 mg/m^3) (US EPA, 2014a). These PoDs were selected as the critical NOELs to evaluate subchronic spray drift inhalation exposure to CPF (see Table 21). As discussed earlier, the inhalation steady-state PoDs for females of childbearing age and children 1-2 years old were used to assess acute spray drift risk.

Table 21. Subchronic AChE and Overt Effects of Chlorpyrifos and the Respective NOELs and LOELs

Species	Exposure Duration	Effects	NOEL mg/kg/d	LOEL mg/kg/d	Ref[a]
Oral					
Rat F-344 M/F	Diet 28 d	↓ plasma ChE ↓body weights, body weight gains, feed consumption; ↑clinical signs & urinalysis, hematology, clinical chemistry & organ weight effects; ↑fatty vacuolization of the adrenal zona fasciculata	**Overt 1.0** **Plasma ChE 0.05**	Overt 5.0 AChE 0.1	1*

Species	Exposure Duration	Effects	NOEL mg/kg/d	LOEL mg/kg/d	Ref[a]
Rat SD M/F	Diet 2-Gen Repro	Parental:↑ vacuolation in zona fasciculate, altered tinctorial properties in this tissue; ↓ plasma and RBC AChE Pup: ↓pup weights & pup survival	**Overt Parental/Pup: 1.0** **ChE: 0.1**	Overt Parental/Pup: 5.0 AChE: 1.0	2*
Rat F-344 M/F	Diet 13 wk Neurotoxicity	↓ plasma and RBC AChE ↑ clinical signs, ↑FOB, motor activity effects	**Overt: 1.0** **ChE: 0.1**	Overt: 5.0 AChE: 1.0	3*
Rat Long-Evans F	Gavage c.o. 4 wk	↓ plasma, RBC and brain ChE ↑miosis & clinical signs; motor slowing and/or ↓ motivation (↑actual total delay, ↑ void trials, ↓#'s nose-pokes/trial).	Overt: 1.0 ChE: --	Overt: 3.0 AChE: 1.0	4*
Rat SD M/F	Gavage c.o. GD 6-20	↓RBC, Plasma & Brain ChE	**ChE $BMDL_{10}$: 0.03**	BMD_{10}[t] 0.06	7
Beagle Dog M/F	Diet 6 wk	↓RBC AChE	ChE: --	AChE: 0.5	6
Dermal					
Rat F-344 M/F	21d, 6hr/d, 5d/wk	No effects	--	No LOEL > 5.0	8
Mice Balb/c M Adult (150 d) Pup (18 d)	4 hr/d, 2 weeks: 1 dose level administered on the tail	Pup/Adult: ↓ plasma ChE	Pup/Adult: --	Pup/Adult: 101	9
Inhalation					
Rat CD(SD): Crl M/F	Vapor, Nose-only; 6 hr/d, 5d/wk 2 wks	No RBC, plasma, or brain ChE inhibition	--	LOEL >12 ppb	10
Rat F-344 M/F	Vapor, Nose-only; 6 hr/d, 5d/wk, 13 weeks	No RBC, plasma, or brain ChE inhibition	--	LOEL>20.6 ppb (0.295 mg/m^3)	11
Rat -344 M/F	Aerosol, Nose-only; 6 hr/d, 5 d/wk, 13 wk	↓Plasma ChE	10 ppb (0.143 mg/m^3)	20 ppb (0.286 mg/m^3)	12

[a] References: 1. Szabo et al. (1988); 2. Breslin et al. (1991); 3. Shankar et al. (1993); 4. Maurissen et al. (1996); 5. Boverhof et al. (2010); 6. Marable et al. (2001); 7. Mattsson *et al.* (1998); Maurissen *et al.* (2000); Marty and Andrus (2010); US EPA (2011b) 8. Calhoun and Johnson (1988); 9. Krishnan et al. (2012); 10. Landry et al. (1986); 11. Corley et al. (1986); 12. Newton (1988). *The study was acceptable to HHA based on FIFRA guidelines.

III.C. Chronic Toxicity

Chronic CPF toxicity was described and reported in the US EPA RED and Revised Human Health Risk Assessments (US EPA, 2007; US EPA, 2011a; US EPA, 2014a) and in the HHA Summary of Toxicology Data (Appendix 1). Registrant-submitted studies under consideration for the chronic endpoints are summarized in Table 21. All are considered acceptable according to US EPA Health Effects Test Guidelines (US EPA, 2000b).

III.C.1. Chronic Oral Toxicity

Chronic studies available for CPF endpoint determination show that the most sensitive endpoint in rats (Young and Grandjean, 1988; Crown, 1990; US EPA, 2000b), mice (Gur, 1992), and Beagle dogs (McCollister et al., 1971) was ChE inhibition (Table 10 and Table 11). An

BMD_{10}/$BMDL_{10}$ for RBC AChE inhibition was estimated for pregnant female rats ($BMDL_{10}$ = 0.03 mg/kg/d) by US EPA in their 2011 Preliminary Human Health Risk Assessment (US EPA, 2011a) based on data from Hoberman (1998), Mattsson et al. (1998), Maurissen et al. (2000)and Marty and Andrus (2010)Marty and Andrus (2010).

Overt chronic effects from CPF treatment included reduced body weight, reduced food and water consumption, yellow perineal stain, and increased clinical signs such as hepatocytic fatty centrolobular vacuolation, ulcerative dermatitis, panophthalmitis or endophthalmitis keratitis, accumulation of alveolar macrophages in lungs and septal thickening, cystic bulbourethral gland, vacuolation of the adrenal zona fasciculate, diffuse retinal degeneration/atrophy, and cataracts (Young and Grandjean, 1988; Crown, 1990)(Crown 1990; Young and Grandjean 1988a). The NOELs for these overt effects were at doses higher than those for AChE inhibition.

The PBPK-PD steady-state PoDs described earlier was also applied to chronic exposure (Table 11). Although steady-state values are higher than the $BMDL_{10}$ (estimated at 0.03 mg/kg/d), they are based on human data in a well-vetted model. Since RBC AChE reaches steady-state within 2-3 weeks, the use of a steady-state value for a chronic PoD can be rationalized (US EPA, 2014a). HHA used same steady-state PoDs described for subchronic oral toxicity here to describe chronic oral CPF exposures:

PoD for infants < 1 year old = 0.103 mg/kg/d
PoD for young children ages 1-2 years = 0.099 mg/kg/d
PoD for children aged 6-12 years = 0.090 mg/kg/d
PoD for youth aged 13-19 years old = 0.080 mg/kg/d
PoD for females of childbearing age (13-49 years old) = 0.078 mg/kg/d

The lowest steady-state oral PoD (0.078 mg/kg/d) for females 13-49 years old will be used for subchronic/chronic dietary characterization. Steady-state for oral PoDs for children (1-2 yrs old) was used for spray drift exposure assessments.

III.C.2. Chronic Dermal Toxicity

There were no chronic dermal toxicity studies available for CPF (Table 20). The US EPA PBPK-PD model estimated PoDs for steady-state dermal exposure (21-day) for several critical subpopulations (children 1-2 years-old: 0.13425 mg/kg/d; children 6-11 years-old: 0.02575 mg/kg/d; youths 11-16 years-old: 0.01395 mg/kg/d; females 13-49 years-old: 0.0236 mg/kg/d [highest dermal exposure]) (US EPA, 2014a). Since CPF RBC AChE inhibition reaches a steady-state within a 21 d period, HHA selected PoDs from children 1-2 years old and females 13-49 yrs-old (134.25 mg/kg/d and 23.6 mg/kg/d, respectively) to evaluate chronic dermal exposure to CPF spray drift.

III.C.3. Chronic Inhalation Toxicity

There were also no chronic inhalation toxicity studies available for CPF (Table 20). US EPA (2014a) reported a 10% RBC AChE inhibition PoD for steady-state (subchronic 21-day) inhalation exposure based on the PBPK-PD model for two critical subpopulations (children 1-2 years-old: 2.37 mg/m^3; females 13-49 years-old: 6.15 mg/m^3). Steady-state for ChE inhibition is

achieved within 21 days. Therefore, the steady-state modeled PoDs were selected by HHA to evaluate chronic inhalation exposure from CPF spray drift (Table 22).

Table 22. Chronic AChE and Overt Effects of CPF and the Respective NOELs and LOELs

Species	Exposure Duration	Effects	NOEL mg/kg/d	LOEL mg/kg/d	Ref [a]
Oral					
Rat F-344 M/F	Diet 2 yr	↓ plasma ChE; ↓body weight; perineal yellow; vacuolation of the adrenal zona fasciculate; ↑diffuse retinal degeneration	Overt: 1.0 ChE: 0.05	Overt: 10 ChE: 0.1	1*
Rat F-344M/F	Diet 2 yr	↓ plasma, RBC & brain ChE; ↓body weight; diffuse retinal atrophy & cataracts	Overt: 1.25 ChE: 0.01	Overt: 50 ChE: 0.1	2*
Rat SD F	Gavage c.o. GD 6-20 (DNT)	↓ RBC and brain ChE	ChE BMDL10: 0.03	ChE BMD10: 0.06	3*
Mouse CD-1	Diet 79 wks	↓ plasma, RBC and brain ChE; ↓body weight & food & water consumption; ↑clinical signs; ↑Hepatocytic fatty vacuolation: centrilobular, Ulcerative dermatitis; Keratitis, panophthalmitis or endophthalmitis; accumulation of alveolar macrophages in lungs & septal thickening; bulbourethral gland cystic dilatation	Overt: 0.78 ChE: <0.078	Overt: 7.9 ChE: 0.078	4*
Dog Beagle M/F	Diet 2 yr	↓ plasma (0.03), RBC (1.0) and brain AChE (0.03): only ChE tested, no overt effects.	Overt: >3.0 ChE: 0.03	Overt: 3.0 ChE: 0.1	3*

[a] No chronic dermal or inhalation studies.

[b] References: 1. Young and Grandjean (1988); 2. Crown (1990); 3. McCollister *et al.* (1971); US EPA (2011a); 4. Gur (1992); 7. Hoberman (1998); Mattsson *et al.* (1998); Maurissen *et al.* (2000); Marty and Andrus (2010); US EPA (2011b). *The study was acceptable to HHA based on FIFRA guidelines

III.D. Summary of Critical NOELs Used for HHA Risk Assessment

Table 23 summarizes the critical NOELs and endpoints selected for evaluating oral, dermal, and inhalation exposure from diet and spray drift. The PBPK-PD model is advantageous for risk assessment because 1) the uncertainties and lack of NOELs for various animal studies make it difficult to use their data for PoD estimation; 2) the PBPK-PD model has been peer reviewed and published in the open literature; and, 3) the PBPK-PD model can be adjusted based on the subpopulation exposed and the duration of exposure in a standardized manner (e.g., the model incorporates acute oral, steady-state oral, dermal, and inhalation exposure parameters designed to simulate human exposure scenarios for given age or gender groups expected to result in 10% RBC AChE inhibition) (US EPA, 2014a). As such, the PBPK-PD modeled values from US EPA 2014 Revised Human Health Risk Assessment were used for HHA's dietary and drinking water MOE calculations primarily for females (13-49 yrs old) and children (1-2 yrs old). Note that steady state values were used for acute oral, dermal, and inhalation bystander spray drift exposure.

Table 23. Summary of Critical NOELs for All Exposure Durations

Exposure Route[a]	PBPK-PD PoDs (US EPA, 2014a)							
	Infants < 1 yr old		Children 1-2 yrs old		Children 6-12 yrs old		Females 13-49 yrs old	
	Acute	SS[b]	Acute	SS[b]	Acute	SS[b]	Acute	SS[b]
Dietary (food only) and Drinking Water Exposures								
Drinking H_2O (oxon ppb)	1,183	217	3,004	548	7,700	1,358	5,285	932
Food (mg/kg/d)	0.600	0.103	0.581	0.099	0.530	0.090	0.467	0.078
Non-Dietary Exposures								
Incidental Oral (mg/kg/d)	--	--	--	0.101	--	--	--	--
Dermal (mg/kg/d)	--	--	--	134.25	--	--	--	23.60
Inhalation (mg/m^3)	--	--	--	2.37	--	--	--	6.15

a-PoDs are human equivalent doses derived from PBPK/PD model based on 10% inhibition of the RBC AChE activity after an acute (single day, 24 hr) or steady-state (21-day) exposure to CPF in humans (US EPA, 2014a).PoD from parent compound CPF was used for all exposure routes except for drinking water where PoD from CPF-oxon was used.
b- This assessment used SS oral (non-dietary), dermal, and inhalation PoDs to estimate the risk from spray drift and aggregate exposures.
c- Acute PoDs for CPF-oxon in ppb (µg/L) were converted into internal doses (mg/kg/d) using default drinking water consumption and body weight values
d- Steady-state dermal PoDs were developed assuming exposure duration of 1.5 hours per day for 21 days (US EPA, 2014a).
e- Steady-state inhalation PoDs were developed assuming exposure duration of 1 hour per day for 21 days (US EPA, 2014a).

IV. EXPOSURE ASSESSMENT

IV.A. Exposure Assessment of Non-Occupational Bystanders

IV.A.1. Introduction

The purpose of this exposure assessment is to evaluate non-occupational bystanders' exposure to CPF due to off-site movement (i.e., spray drift) of the product from agricultural applications in California. Other exposure scenarios will be addressed in an addendum, if needed. In California, field applications of CPF are made by both aerial and ground-based methods, and the latter includes ground boom and airblast (Dawson et al., 2012). For agricultural applications, 24 products with the aerial and (or) ground-based application methods are currently registered in California; their formulations include aqueous concentrate, emulsifiable concentrate, and wettable power (Table 24). In this exposure assessment, granular products are omitted because the focus is on spray drift following application of a liquid.

Table 24. CPF Products Labeled for Use in the Production of an Agricultural Commodity in California

Product Name	EPA Registration No.	Formulation
Bolton Insecticide	279-3581-AA	Emulsifiable Concentrate
Bolton Insecticide	67760-112-AA	Aqueous Concentrate
Chlorpyrifos 4E Ag	66222-19-AA	Emulsifiable Concentrate
Cobalt	62719-575-AA	Emulsifiable Concentrate
Cobalt Advanced	62719-615-AA	Emulsifiable Concentrate
CPF 4E	83222-20-AA	Emulsifiable Concentrate
Drexel Chlorpyrifos 4E-Ag	19713-520-AA	Emulsifiable Concentrate
Drexel Lambdafos Insecticide	19713-671-AA	Emulsifiable Concentrate

Product Name	EPA Registration No.	Formulation
Dursban 50W	62719-72-ZA	Wettable Powder
Eraser	62719-220-AA-71058	Emulsifiable Concentrate
Govern 4E Insecticide	62719-220-AA-55467	Emulsifiable Concentrate
Hatchet	62719-220-ZC	Emulsifiable Concentrate
Lock-On Insecticide	62719-79-ZA	Emulsifiable Concentrate
Lorsban Advanced	62719-591-AA	Aqueous Concentrate
Lorsban-4E	62719-220-ZA	Emulsifiable Concentrate
Nufos 4E	67760-28-AA	Emulsifiable Concentrate
Quali-Pro Chlorpyrifos 4E	66222-19-ZA	Emulsifiable Concentrate
Stallion Brand Insecticide	279-9545-ZA	Emulsifiable Concentrate
Stallion Insecticide	279-9545-AA	Emulsifiable Concentrate
Vulcan	66222-233-AA	Emulsifiable Concentrate
Warhawk	34704-857-AA	Aqueous Concentrate
Warhawk Clearform	34704-1077-AA	Emulsifiable Concentrate
Whirlwind	62719-220-AA-5905	Emulsifiable Concentrate
Yuma 4E	62719-220-ZA-1381	Emulsifiable Concentrate

IV.A.2. Exposure Scenarios Development

IV.A.2.a. Exposure Duration

Based on the number of applications allowed and the application intervals for high-use crops on the CPF product labels, short-term exposure is determined to be the focus of this bystander exposure assessment due to spray drift. DPR defines short-term exposure as lasting seven days or less (Andrews, 2001). The rationale for this determination is presented below.

For aerial applications, crops predominantly involved are alfalfa, cotton, corn (forage/fodder), and sugar-beets. Alfalfa is the crop with the most frequent repeated applications allowed, a total of 4 per season by some labels (e.g., Lorsban Advanced [62719-591-AA]) and Bolton Insecticide [67760-112-AA]]. Other labels allow 4 applications per year, with a single application allowed per cutting (e.g., Nufos 4E [67760-68-AA]). The minimum interval between applications is 10 days. The University of California (UC) Cost and Return Study for Alfalfa grown in Sacramento County assumes an average cutting of 7 times per year: "April, May, June, July (twice), August, and September" (Long et al., 2015). This suggests that with the exception of July, the shortest interval anticipated between applications is about a month. Even in July, the applications are probably spaced far enough apart to consider bystanders exposed to a series of acute exposures. Corn, cotton, and sugar-beets are each allowed 3 applications per season, with a minimum interval of 10 days.

For airblast applications, crops predominantly involved are tree fruits, nuts, and grapes. Foliar applications to citrus are limited to twice per year. Minimum application intervals are 30 days. Foliar applications to tree nuts are limited to 3 times per season. Minimum application intervals are 10 days. Grapes are only permitted one application per season with no potential of repeated exposure. For groundboom applications, the predominant crop is broccoli. According to the UC Cost and Return study for broccoli, there are normally 2 crops per year (Dara et al., 2012). This suggests that there could be as many as 6 applications to a field per year, and the minimum application interval is 10 days.

Based on the analysis above, exposure to CPF due to off-site product movement is considered to be a series of short-term exposures. For a given crop treatment, the exposure interval is no more frequent than 10 days.

IV.A.2.b. Spray Drift Exposure Assessment Approach

For assessing the short-term exposure due to off-site movement of CPF, this exposure assessment adopted the method of US EPA (Dawson et al., 2012): spray drift modeling coupled with the post-application assessment of dermal and inhalation exposures. For the spray drift modeling, two computer models were employed: AgDRIFT (spray drift regression model version 2.0.05) for ground boom and orchard airblast applications and AGDISP (AGricultural DISPersal near-wake Lagrangian model version 8.28) for aerial applications (Barry, 2017). For the post-application assessment, US EPA standard operating procedures (SOP) for residential exposure assessment were followed (US EPA, 2013).

Technical description of these models has been detailed elsewhere (Teske et al., 2002a; Teske et al., 2002b; Barry, 2017). Both AgDRIFT and AGDISP models were used to estimate off-site horizontal deposition of CPF at different distances downwind: 1000 feet for the aerial and 300 feet for ground boom and airblast applications. Table 25 shows the application types and model parameter values for use in estimating the drift deposition. These scenarios and parameter values were chosen to represent the reasonable worst case application conditions so that spray drift is not underestimated for the application scenarios assessed. To ensure horizontal deposition estimates are consistent with the application methods of airblast and ground boom in California, the number of swaths modeled was 40 for airblast and 60 for ground boom instead of the AgDRIFT default of 20 swaths. AGDISP was used to estimate horizontal deposition and 1 hour time-weighted average air concentrations (mg/m^3) of CPF at vertical heights of 1.7 ft and 5 ft. The vertical heights of 1.7 ft and 5 ft represent the breathing zones of children 1-2 years old and females 13-49 years old, respectively. The aerial application exposure scenarios evaluated in this exposure assessment used the estimated air concentrations for each specific scenario. For airblast and ground boom, the AGDISP model was used to produce surrogate air concentrations using a default aerial application (AT802A with a finished spray volume of 2 gal/acre) and the specific application rates for each airblast and ground boom scenario evaluated in this exposure assessment. Similar to the deposition estimates, these time-weighted air concentrations are the reasonable worst case air concentrations based on the parameters listed in Table 25.

Table 25. Application Type Scenarios for Chlorpyrifos Deposition Estimates

Application Type	Sub-Type	Parameter Value	Nozzle Droplet	No. of Swaths[b] (Coverage)[c]
Aerial	Fixed-Wing (AT802A)	10 mph wind; 20% RH; 90°F[a]	Medium	50 (206.6)
	Rotor-Wing (Bell 205)	10 mph wind; 20% RH; 90°F[a]	Medium	50 (190.4)
Ground Boom	Low Boom (20 inches above the canopy)	regression equation	M-to-C	40 (37.2)
	High Boom (50	regression equation	M-to-C	40 (37.2)

	inches above the canopy)			
Orchard Airblast	Sparse/Young	regression equation	NS	60 (7.05)
	Dormant Apple	regression equation	NS	60 (7.05)

Abbreviations: M-to-C, medium to coarse; NS, not specified; RH, relative humidity
[a] Meteorological conditions contributed to the highest drift deposition (i.e., worst case condition).
[b] Number of swaths to cover the field sizes in California.
[c] Equivalent square acreage covered by the total number of swaths.
Reference: Barry (2017)

Table 26 shows the single application rate (unit: pound per active ingredient per acre [lb AI/acre]) grouping of CPF products registered in California. This table is adapted from the US EPA spray drift exposure assessment document (Dawson et al., 2012). Application rates were used for translating the drift fraction outputs of AgDRIFT and AGDISP models into exposure estimates.

Table 26. Application Rates Grouping of Chlorpyrifos Usages in California

Single Application [a] (lb AI/acre)	**Example Use Site**	**Example Product**	**Comments**
6[b,c]	citrus fruits	Nufos 4E	Permitted use to control California red scale in Fresno, Tulare, Kern, Kings & Madera Counties only
4[b]	citrus fruits	Vulcan	Not specific to California
2.3	citrus fruits	Lorsban Advanced	Control of Citrus Psylla in California
2	tree fruits (e.g., apple), broccoli	Warhawk	Not specific to California
1	alfalfa, corn, cotton	Chlorpyrifos 4E AG	Not specific to California

[a] Modified from Dawson et al. (2012).
[b] Application rate of >2.3 lb AI/acre is not allowed for aerial equipment.
[c] An application rate higher than 6 lb AI/acre (i.e., 8 lb AI/acre) is identified in one product for use in pre-plant soil treatment. Because of the assumption employed for estimating inhalation exposure (i.e., ground based method results in the same air concentrations from aerial method at a the same ground-based application rate) and because of a much lower maximum aerial application allowed (i.e., 2.3 lb A.I./acre), exposure assessment based on 8 lb AI/acre application rate would greatly exaggerate the health risk estimated and, therefore, is not included in this exposure assessment. However, this application rate will be included in the future exposure assessment once the method of assessing inhalation exposure from the ground-based application methods is refined.

Evaluation of dermal and inhalation exposures of non-occupational/residential bystanders to spray drift was based on a modified US EPA residential SOP which incorporated off-site movement of pesticide from the results of AgDRIFT and AGDISP models (US EPA, 2013). Briefly, non-occupational/residential bystander exposure to spray drift is built on the assumption that CPF application may occur near residential sites or areas (e.g., schools) that the general public routinely access. Accordingly, the bystander exposures could occur indirectly via contact (e.g., dermal exposure) with the areas contaminated with the spray drift deposit and via inhalation of the airborne materials (e.g., aerosol) that may be transported off-site beyond the labeled buffer zone distance. It is important to note that direct exposures (via inhalation or

dermal contact) are prohibited by the product labels. Additionally, the California Code of Regulation §6614 also makes any direct exposure to humans a violation that may result in legal actions by the county or the State. DPR risk assessments only address legal application scenarios.

For assessing indirect exposure to spray drift for adults and small children, the US EPA residential lawns/turf post-application SOP is considered as the standard method (US EPA, 2013). That is, activities of adults and children on the contaminated lawn may result in transfer of spray drift deposition from different surfaces to their skin. In addition to the contact exposure via skin, exposure to spray drift deposition may occur via different mouthing activities, such as hand-to-mouth, object-to-mouth, and incidental soil ingestion for small children. In this exposure assessment, females 13-49 years old are a primary focus because of their potential increase in susceptibility to the toxicological effects of CPF during pregnancy. For children 1-2 years old, the US EPA Residential SOP (Addenda 1: Consideration of Spray Drift) indicates that children at this lifestage exhibit the highest exposure potential to pesticide contaminated lawn from spray drift due to dermal contact and different mouthing activities: hand-to-mouth, object-to-mouth, and incidental soil ingestion.

For estimating the dermal exposure from contaminated lawn, the following equation is employed.

$$\text{Dermal Dose} = \frac{\text{TTR} \times \text{TC} \times \text{ED} \times \text{AF} \times \text{CF}}{\text{BW}}$$

where:
TTR: turf transferable residue (μg/cm^2)
TC: transfer coefficient (cm^2/hr): 180000 for adults and 49000 for children
ED: exposure duration (hr/day): 1.5 for both adults and children
AF: absorption factor (dermal): 1 for computational purpose
CF: conversion factor of 0.001 mg/μg
BW: body weight (kg): 70 kg for females 13-49 years old; 13 kg for 1-2 years old (Andrews and Patterson, 2000)

According to the 2012 US EPA residential SOP, chemical-specific TTR on the day of application ($TTR_{Day\ 0}$) should be used for assessing individual exposure of pesticide on turf if available. A TTR study on CPF was conducted in three states including California, and the mean TTR values on the day of application were 0.124 μg/cm^2 in California and 0.12 μg/cm^2 as an average of the three states (Stafford and Robb, 1999).

Using the results of TTR study conducted in California (TTR_{expt}) (i.e., California-specific value), $TTR_{Day\ 0}$ for use in the drift exposure assessment can be estimated using the following equation:

$$\text{TTR}_{\text{Day 0}} = \left(\frac{\text{TTR}_{\text{expt}} \times \text{AppRate}_{\text{target}}}{\text{AppRate}_{\text{expt}}}\right) \times \text{F}$$

where:
TTR_{expt}: Experimentally measured mean turf transferable residue (μg/cm^2) of CPF in California (Dawson et al., 2012)

$AppRate_{expt}$: CPF application rate employed in the CA study (3.8 lb AI/A)
$AppRate_{target}$: CPF application rate(s) employed for assessing drift exposure
F: Fraction of nominal application rate (e.g., 6, 4, 2.3, 2, or 1 lb AI/acre) produced by AgDRIFT or AGDISP models as transferable residue following application

For estimating exposures to spray drift horizontal deposition through mouthing activities of small children (i.e., hand-to-mouth, object-to-mouth, and incidental soil ingestion), computational methods as defined in the US EPA residential SOP were strictly followed (US EPA, 2012). Hence, these computational methods are not reproduced in this exposure assessment.

For evaluating the inhalation exposure, breathing zone exposure concentrations of CPF in adults and small children are needed for the three application types: aerial, ground boom, and airblast. However, the empirical nature of the modules in the AgDRIFT for ground boom and airblast precludes the estimation of the needed breathing zone air concentrations. Accordingly, inhalation exposure calculations for all scenarios were performed using CPF air concentrations estimated using AGDISP.

IV.A.2.c. Spray Drift Exposure Estimates

V.A.2.c.i. Aerial Applications

Tables 27 and 28 show the drift deposition exposure (in µg/kg/day) and inhalation exposure estimates (as 1 hour time-weighted average air concentrations in mg/m^3) of CPF for children 1-2 years old and females 13-49 years old, respectively, due to aerial applications at two application volumes and three application rates with two types of aircraft: fixed-wing (AT802A airplane) and rotor-wing (Bell 205 helicopter). As can be seen in Tables 25 and 26, increases in CPF application rate resulted in a corresponding increase in the spray drift exposure estimates (regardless of the exposure route) at different distances downwind from the edge of the treated field.

For aerial applications, some CPF-containing products specify a minimum spray volume of not less than 2 gallons per acre (GPA). However, there appears to be no maximum spray volume specified. To evaluate the effect of spray volume on the horizontal deposition and inhalation exposure estimates, additional AGDISP simulations were performed. For a given application rate, the dermal exposure estimates are lower for the higher spray volume and the estimated 1 hour time-weighted average air concentrations increase with the spray volume. Further discussion of the effect of spray volume on the air concentrations of CPF can be found in (Barry, 2017) (Appendix 2).

Table 27. Dermal and Oral Doses and Inhalation Concentration for Children (1-2 years old) at Various Distances Downwind from the Fields Treated with CPF by Aircraft or Helicopter

Application Scenario	Appl. Vol. (gallon/acre)	Exposure Route	Appl. Rate (lb/acre)	Dose at Various Distance Downwind from the Treated Fields (µg/kg/d)						
				10 feet	25 feet[c]	50 feet	100 feet	250 feet	500 feet	1000 feet
Dermal and Oral Exposure: Aircraft or Helicopter (Children 1-2 years old)										
AT802A Fixed Wing Aircraft	2[a]	Dermal	1	35.46	30.24	23.80	16.03	8.36	4.98	2.66
			2	71.18	60.51	47.45	31.70	15.87	8.63	3.39
			2.3	81.85	69.55	54.48	36.32	18.16	9.63	3.73
		Object-to-Mouth	1	0.023	0.019	0.015	0.010	0.005	0.003	0.002
			2	0.046	0.039	0.030	0.020	0.010	0.006	0.002
			2.3	0.052	0.044	0.035	0.023	0.012	0.006	0.002
		Hand-to-Mouth	1	0.738	0.629	0.495	0.334	0.174	0.104	0.055
			2	1.481	1.259	0.987	0.659	0.330	0.180	0.071
			2.3	1.703	1.447	1.134	0.756	0.378	0.200	0.078
		Soil Ingestion	1	0.0055	0.0047	0.0037	0.0025	0.0013	0.0008	0.0004
			2	0.0111	0.0094	0.0074	0.0049	0.0025	0.0013	0.0005
			2.3	0.0127	0.0108	0.0085	0.0056	0.0028	0.0015	0.0006
Bell 205 Helicopter	2	Dermal	1	45.28	28.65	17.55	10.66	6.81	4.04	1.97
			2	91.18	58.08	35.76	22.25	12.32	6.31	2.77
			2.3	104.90	66.83	41.16	25.67	13.92	7.00	3.01
		Object-to-Mouth	1	0.0289	0.0183	0.0112	0.0068	0.0043	0.0026	0.0013
			2	0.0582	0.0371	0.0228	0.0142	0.0079	0.0040	0.0018
			2.3	0.0670	0.0427	0.0263	0.0164	0.0089	0.0045	0.0019
		Hand-to-Mouth	1	0.9419	0.5961	0.3650	0.2219	0.1416	0.0841	0.0411
			2	1.897	1.208	0.744	0.463	0.256	0.131	0.058
			2.3	2.182	1.390	0.856	0.534	0.290	0.146	0.063
		Soil Ingestion	1	0.0070	0.0044	0.0027	0.0017	0.0011	0.0006	0.0003
			2	0.0142	0.0090	0.0056	0.0035	0.0019	0.0010	0.0004
			2.3	0.0163	0.0104	0.0064	0.0040	0.0022	0.0011	0.0005
AT802A Fixed Wing Aircraft	15[b]	Dermal	1	30.83	26.00	20.79	13.91	7.14	4.43	3.30
			2	64.13	54.32	43.76	29.81	15.68	10.00	7.27
			2.3	74.05	62.80	50.67	34.50	18.20	11.58	8.40
		Object-to-Mouth	1	0.020	0.017	0.013	0.009	0.005	0.003	0.002
			2	0.041	0.035	0.028	0.019	0.010	0.006	0.005
			2.3	0.047	0.040	0.032	0.022	0.012	0.007	0.005
		Hand-to-Mouth	1	0.64	0.54	0.43	0.29	0.15	0.09	0.07
			2	1.33	1.13	0.91	0.62	0.33	0.21	0.15

			2.3	1.54	1.31	1.05	0.72	0.38	0.24	0.17
		Soil Ingestion	1	0.005	0.004	0.003	0.002	0.001	0.001	0.001
			2	0.010	0.008	0.007	0.005	0.002	0.002	0.001
			2.3	0.011	0.010	0.008	0.005	0.003	0.002	0.001
Bell 205 Helicopter	15	Dermal	1	42.08	25.88	15.02	8.71	6.05	4.54	2.97
			2	86.45	53.91	32.10	19.00	13.28	9.45	5.72
			2.3	99.93	62.46	37.30	22.15	15.36	10.78	6.53
		Object-to-Mouth	1	0.027	0.017	0.010	0.006	0.004	0.003	0.002
			2	0.055	0.034	0.021	0.012	0.008	0.006	0.004
			2.3	0.064	0.040	0.024	0.014	0.010	0.007	0.004
		Hand-to-Mouth	1	0.88	0.54	0.31	0.18	0.13	0.09	0.06
			2	1.80	1.12	0.67	0.40	0.28	0.20	0.12
			2.3	2.08	1.30	0.78	0.46	0.32	0.22	0.14
		Soil Ingestion	1	0.007	0.004	0.002	0.001	0.001	0.001	0.000
			2	0.013	0.008	0.005	0.003	0.002	0.001	0.001
			2.3	0.016	0.010	0.006	0.003	0.002	0.002	0.001
1-Hour Air Concentration at Various Distance Downwind from the Treated Fields (mg/m^3)										
				10 feet	**25 feet**	**50 feet**	**100 feet**	**250 feet**	**500 feet**	**1000 feet**
AT802A	2	Inhalation	1	0.0318	0.0292	0.0264	0.022	0.0161	0.0117	0.0065
			2	0.0546	0.0493	0.0437	0.0350	0.0237	0.0153	0.0072
			2.3	0.0583	0.0526	0.0464	0.0371	0.0250	0.0159	0.0075
	15	Inhalation	1	0.0443	0.0413	0.0391	0.0348	0.0289	0.0243	0.0190
			2	0.0758	0.0703	0.0660	0.0579	0.0468	0.0381	0.0279
			2.3	0.0841	0.0779	0.0730	0.0637	0.0513	0.0415	0.0299
Bell 205 Helicopter	2	Inhalation	1	0.0409	0.0336	0.0274	0.0219	0.0153	0.0102	0.0058
			2	0.0728	0.0580	0.0458	0.0345	0.0215	0.0130	0.0068
			2.3	0.0771	0.0611	0.0482	0.0362	0.0222	0.0133	0.0069
	15	Inhalation	1	0.0685	0.0592	0.0517	0.0448	0.0367	0.0288	0.0202
			2	0.0967	0.0828	0.0715	0.0612	0.0488	0.0373	0.0252
			2.3	0.1074	0.0917	0.0789	0.0671	0.0532	0.0402	0.0269

[a] Minimum spray volume as specified on some CPF product labels for the aerial application.
[b] Spray volume of 15 GPA is chosen in exercise for illustrative purpose.
[c] Buffer zone of 25 feet is required for aerial application of CPF.

Table 28. Estimated Dermal Doses and Inhalation Concentrations for Females (13-49 years old) at Various Distances from a Field Treated with Chlorpyrifos Using Aerial Equipment

Aircraft	Spray Volume (gallon/acre)	Application Rate (lb/acre)	Dose at Various Distance Downwind from the Treated Fields (µg/kg/day)						
			10 (feet)	25 (feet)[c]	50 (feet)	100 (feet)	250 (feet)	500 (feet)	1000 (feet)
AT802A	2[a]	1	24.19	20.63	16.24	10.94	5.70	3.40	1.81
		2	48.56	41.28	32.37	21.62	10.82	5.89	2.32
		2.3	55.84	47.45	37.17	24.78	12.39	6.57	2.55
	15[b]	1	21.03	17.73	14.18	9.49	4.87	3.02	2.25
		2	43.75	37.05	29.86	20.34	10.70	6.82	4.96
		2.3	50.52	42.84	34.56	23.54	12.42	7.90	5.73
Bell 205 Helicopter	2[a]	1	30.89	19.55	11.97	7.27	4.64	2.76	1.35
		2	62.20	39.62	24.39	15.18	8.41	4.30	1.89
		2.3	71.56	45.59	28.08	17.51	9.50	4.78	2.06
	15[b]	1	28.71	17.66	10.25	5.94	4.13	3.10	2.03
		2	58.98	36.78	21.90	12.96	9.06	6.44	3.90
		2.3	68.17	42.61	25.45	15.11	10.48	7.35	4.46
1-Hour Air Concentration at Various Distance Downwind from the Treated Fields (mg/m^3)									
			10 (feet)	**25 (feet)**	**50 (feet)**	**100 (feet)**	**250 (feet)**	**500 (feet)**	**1000 (feet)**
AT802A	2	1	0.0234	0.0218	0.0194	0.0163	0.0118	0.0085	0.0047
		2	0.0399	0.0367	0.0320	0.0259	0.0174	0.0111	0.0052
		2.3	0.0428	0.0394	0.0341	0.0275	0.0183	0.0115	0.0054
	15	1	0.0323	0.0306	0.0287	0.0256	0.0212	0.0177	0.0138
		2	0.0553	0.0522	0.0484	0.0426	0.0342	0.0278	0.0202
		2.3	0.0614	0.0579	0.0536	0.0469	0.0375	0.0303	0.0217
Bell 205 Helicopter	2[a]	1	0.0288	0.0240	0.0197	0.0158	0.0111	0.0074	0.0042
		2	0.0500	0.0404	0.0322	0.0246	0.0154	0.0093	0.0049
		2.3	0.0538	0.0435	0.0345	0.0260	0.0160	0.0096	0.0050
	15[b]	1	0.0487	0.0426	0.0373	0.0325	0.0266	0.0209	0.0147
		2	0.0686	0.0596	0.0516	0.0443	0.0353	0.0270	0.0183
		2.3	0.0762	0.0659	0.0569	0.0485	0.0385	0.0291	0.0195

[a] Minimum spray volume as specified on some CPF product labels for the aerial application.
[b] Spray volume of 15 GPA is chosen in exercise for illustrative purpose.
[c] Buffer zone of 25 feet is required for aerial application of CPF.

IV.A.2.c.ii. Ground-Based Applications

Table 29 shows the drift deposition exposure estimates (in µg/kg/day) of CPF for females 13-49 years old at four allowable application rates with two ground-based application methods, ground boom and airblast. For ground boom, spray drift deposition estimates were derived using two swath percentiles: 50th and 90th percentiles (see Appendix 2). Tables 30 and 31 show the spray drift exposure estimates of chlorpyrifos for children 1-2 years old: ground boom 90th percentile and ground boom 50th percentile deposition estimates. Table 32 shows the spray drift exposure estimates of chlorpyrifos for children 1-2 years old for orchard airblast. As expected for both ground boom and orchard airblast application methods and population subgroups, the spray drift exposure estimates increase with the application rates of chlorpyrifos. The higher horizontal deposition exposure estimates of the high-boom compared with the low-boom are consistent with the difference in the spray release height above the target between high- and low-boom (50 and 20 inches above the target, respectively). All other factors held constant, horizontal deposition increases as a function of boom height above the target. The higher near-field horizontal deposition exposure estimates of orchard airblast compared to ground boom are consistent with the much finer droplet spectrum of airblast sprayer application and the upward direction by the airblast sprayer of fine spray into the orchard canopy. Table 33 shows the drift inhalation concentration estimate (in mg/m3) for both children 1-2 years old (1.7 ft height) and females 13-49 years old (5 ft height).

Table 29. Estimated Dermal Doses for Females (13-49 years old) at Various Distances from a Field Treated with Chlorpyrifos Using Ground-Based Equipment: Ground Boom and Airblast

Application Scenarios	Swaths (Percentile)	Appl. Rate (lb/acre)	Dose at Various Distance Downwind from the Treated Fields (µg/kg/day)						
			25 (feet)	50 (feet)	75 (feet)	100 (feet)	150 (feet)	200 (feet)	250 (feet)
Ground boom									
High boom	40 (50th)[a]	1	1.1957	0.7929	0.5916	0.4657	0.3398	0.2643	0.2140
		2	2.3914	1.5859	1.1831	0.9314	0.6797	0.5286	0.4279
		4	4.7829	3.1718	2.3663	1.8628	1.3593	1.0573	0.8559
		6	7.1743	4.7577	3.5494	2.7942	2.0390	1.5859	1.2838
High boom	40 (90th)[a]	1	1.6992	1.2209	0.9440	0.7552	0.5664	0.4531	0.3776
		2	3.3983	2.4418	1.8880	1.5104	1.1328	0.9062	0.7552
		4	6.7967	4.8835	3.7759	3.0208	2.2656	1.8125	1.5104
		6	10.1950	7.3253	5.6639	4.5311	3.3983	2.7187	2.2656
Low boom	40 (50th)[a]	1	0.6293	0.4279	0.3272	0.2517	0.1888	0.1510	0.1259
		2	1.2586	0.8559	0.6545	0.5035	0.3776	0.3021	0.2517
		4	2.5173	1.7118	1.3090	1.0069	0.7552	0.6042	0.5035
		6	3.7759	2.5676	1.9635	1.5104	1.1328	0.9062	0.7552
Low boom	40 (90th)[a]	1	1.0699	0.7804	0.6042	0.4909	0.3650	0.3021	0.2517
		2	2.1397	1.5607	1.2083	0.9817	0.7300	0.6042	0.5035
		4	4.2794	3.1214	2.4166	1.9635	1.4600	1.2083	1.0069
		6	6.4191	4.6822	3.6249	2.9452	2.1900	1.8125	1.5104
Orchard Airblast									
Dormant Apples	60	1	6.9666	2.6507	1.3002	0.7388	0.3121	0.1649	0.0994
		2	13.9332	5.3014	2.6004	1.4777	0.6243	0.3298	0.1989
		4	27.8664	10.6028	5.2007	2.9553	1.2486	0.6595	0.3977
		6	41.7997	15.9043	7.8011	4.4330	1.8729	0.9893	0.5966
Sparse Orchard	60	1	5.6488	2.5727	1.4449	0.9226	0.4695	0.2832	0.1901
		2	11.2976	5.1454	2.8899	1.8452	0.9390	0.5664	0.3801
		4	22.5952	10.2907	5.7797	3.6904	1.8779	1.1328	0.7602
		6	33.8928	15.4360	8.6696	5.5355	2.8169	1.6992	1.1403

a-Horizontal deposition estimates were derived using a 50th percentile or 90th percentile horizontal deposition.

Table 30. Estimated Dermal and Mouthing Doses for Children (1-2 years old) at Various Distances from a Field Treated with Chlorpyrifos Using Ground Boom Equipment (High Boom)

Scenarios	Swaths (percentile)	Exposure Route	Appl. Rate (lb/acre)	Dose at Various Distance Downwind from the Treated Fields (µg/kg/day)						
				25 (feet)	50 (feet)	75 (feet)	100 (feet)	150 (feet)	200 (feet)	250 (feet)
High boom	40 (50^{th})[a]	Dermal	1	1.7527	1.1623	0.8671	0.6826	0.4981	0.3874	0.3136
			2	3.5054	2.3246	1.7342	1.3653	0.9963	0.7749	0.6273
			4	7.0108	4.6492	3.4685	2.7305	1.9925	1.5497	1.2546
			6	10.5162	6.9739	5.2027	4.0958	2.9888	2.3246	1.8818
		Object-to-Mouth	1	0.0011	0.0007	0.0006	0.0004	0.0003	0.0002	0.0002
			2	0.0022	0.0015	0.0011	0.0009	0.0006	0.0005	0.0004
			4	0.0045	0.0030	0.0022	0.0017	0.0013	0.0010	0.0008
			6	0.0067	0.0045	0.0033	0.0026	0.0019	0.0015	0.0012
		Hand-to-Mouth	1	0.0365	0.0242	0.0180	0.0142	0.0104	0.0081	0.0065
			2	0.0729	0.0484	0.0361	0.0284	0.0207	0.0161	0.0130
			4	0.1459	0.0967	0.0722	0.0568	0.0415	0.0322	0.0261
			6	0.2188	0.1451	0.1082	0.0852	0.0622	0.0484	0.0391
		Soil Ingestion	1	0.0003	0.0002	0.0001	0.0001	0.0001	0.0001	0.00005
			2	0.0005	0.0004	0.0003	0.0002	0.0002	0.0001	0.0001
			4	0.0011	0.0007	0.0005	0.0004	0.0003	0.0002	0.0002
			6	0.0016	0.0011	0.0008	0.0006	0.0005	0.0004	0.0003
High boom	40 (90^{th})[a]	Dermal	1	2.4907	1.7896	1.3837	1.1070	0.8302	0.6642	0.5535
			2	4.9813	3.5792	2.7674	2.2139	1.6604	1.3284	1.1070
			4	9.9627	7.1584	5.5348	4.4279	3.3209	2.6567	2.2139
			6	14.9440	10.7375	8.3022	6.6418	4.9813	3.9851	3.3209
		Object-to-Mouth	1	0.0016	0.0011	0.0009	0.0007	0.0005	0.0004	0.0004
			2	0.0032	0.0023	0.0018	0.0014	0.0011	0.0008	0.0007
			4	0.0064	0.0046	0.0035	0.0028	0.0021	0.0017	0.0014
			6	0.0095	0.0069	0.0053	0.0042	0.0032	0.0025	0.0021
		Hand-to-Mouth	1	0.0518	0.0372	0.0288	0.0230	0.0173	0.0138	0.0115
			2	0.1036	0.0745	0.0576	0.0461	0.0345	0.0276	0.0230
			4	0.2073	0.1489	0.1151	0.0921	0.0691	0.0553	0.0461
			6	0.3109	0.2234	0.1727	0.1382	0.1036	0.0829	0.0691
		Soil Ingestion	1	0.0004	0.0003	0.0002	0.0002	0.0001	0.0001	0.0001
			2	0.0008	0.0006	0.0004	0.0003	0.0003	0.0002	0.0002
			4	0.0015	0.0011	0.0009	0.0007	0.0005	0.0004	0.0003
			6	0.0023	0.0017	0.0013	0.0010	0.0008	0.0006	0.0005

a-Horizontal deposition estimates were derived using a 50^{th} percentile or 90^{th} percentile horizontal deposition.

Table 31. Estimated Dermal and Mouthing Doses for Children (1-2 years old) at Various Distances from a Field-Treated with Chlorpyrifos Using Ground Boom Equipment (Low Boom)

Scenarios	Swaths (percentile)	Exposure Route	Appl. Rate (lb/acre)	Dose at Various Distance Downwind from the Treated Fields (µg/kg/day)						
				25 (feet)	50 (feet)	75 (feet)	100 (feet)	150 (feet)	200 (feet)	250 (feet)
Low boom	40 (50th)[a]	Dermal	1	0.9225	0.6273	0.4797	0.3690	0.2767	0.2214	0.1845
			2	1.8449	1.2546	0.9594	0.7380	0.5535	0.4428	0.3690
			4	3.6899	2.5091	1.9187	1.4760	1.1070	0.8856	0.7380
			6	5.5348	3.7637	2.8781	2.2139	1.6604	1.3284	1.1070
		Object-to-Mouth	1	0.0006	0.0004	0.0003	0.0002	0.0002	0.0001	0.0001
			2	0.0012	0.0008	0.0006	0.0005	0.0004	0.0003	0.0002
			4	0.0024	0.0016	0.0012	0.0009	0.0007	0.0006	0.0005
			6	0.0035	0.0024	0.0018	0.0014	0.0011	0.0008	0.0007
		Hand-to-Mouth	1	0.0192	0.0130	0.0100	0.0077	0.0058	0.0046	0.0038
			2	0.0384	0.0261	0.0200	0.0154	0.0115	0.0092	0.0077
			4	0.0768	0.0522	0.0399	0.0307	0.0230	0.0184	0.0154
			6	0.1151	0.0783	0.0599	0.0461	0.0345	0.0276	0.0230
		Soil Ingestion	1	0.0001	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000
			2	0.0003	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001
			4	0.0006	0.0004	0.0003	0.0002	0.0002	0.0001	0.0001
			6	0.0009	0.0006	0.0004	0.0003	0.0003	0.0002	0.0002
Low boom	40 (90th)[a]	Dermal	1	1.5682	1.1439	0.8856	0.7195	0.5350	0.4428	0.3690
			2	3.1364	2.2877	1.7711	1.4391	1.0701	0.8856	0.7380
			4	6.2728	4.5754	3.5423	2.8781	2.1401	1.7711	1.4760
			6	9.4092	6.8632	5.3134	4.3172	3.2102	2.6567	2.2139
		Object-to-Mouth	1	0.0010	0.0007	0.0006	0.0005	0.0003	0.0003	0.0002
			2	0.0020	0.0015	0.0011	0.0009	0.0007	0.0006	0.0005
			4	0.0040	0.0029	0.0023	0.0018	0.0014	0.0011	0.0009
			6	0.0060	0.0044	0.0034	0.0028	0.0021	0.0017	0.0014
		Hand-to-Mouth	1	0.0326	0.0238	0.0184	0.0150	0.0111	0.0092	0.0077
			2	0.0652	0.0476	0.0368	0.0299	0.0223	0.0184	0.0154
			4	0.1305	0.0952	0.0737	0.0599	0.0445	0.0368	0.0307
			6	0.1957	0.1428	0.1105	0.0898	0.0668	0.0553	0.0461
		Soil Ingestion	1	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001
			2	0.0005	0.0004	0.0003	0.0002	0.0002	0.0001	0.0001
			4	0.0010	0.0007	0.0005	0.0004	0.0003	0.0003	0.0002
			6	0.0015	0.0011	0.0008	0.0007	0.0005	0.0004	0.0003

a-Horizontal deposition estimates were derived using a 50th percentile or 90th percentile horizontal deposition

Table 32. Estimated Dermal and Mouthing Doses for Children (1-2 years old) at Various Distances from Chlorpyrifos Treated Apple Orchards

Scenarios	Swaths	Exposure Route	Appl. Rate (lb/acre)	Dose at Various Distance Downwind from the Treated Fields (µg/kg/day)						
				25 (feet)	50 (feet)	75 (feet)	100 (feet)	150 (feet)	200 (feet)	250 (feet)
Dormant Apple	60	Dermal	1	10.2117	3.8854	1.9058	1.0830	0.4575	0.2417	0.1458
			2	20.4235	7.7709	3.8116	2.1660	0.9151	0.4834	0.2915
			4	40.8470	15.5418	7.6233	4.3319	1.8302	0.9667	0.5830
			6	61.2704	23.3127	11.4349	6.4979	2.7453	1.4501	0.8745
		Object-to-Mouth	1	0.0065	0.0025	0.0012	0.0007	0.0003	0.0002	0.0001
			2	0.0130	0.0050	0.0024	0.0014	0.0006	0.0003	0.0002
			4	0.0261	0.0099	0.0049	0.0028	0.0012	0.0006	0.0004
			6	0.0391	0.0149	0.0073	0.0041	0.0018	0.0009	0.0006
		Hand-to-Mouth	1	0.2124	0.0808	0.0396	0.0225	0.0095	0.0050	0.0030
			2	0.4249	0.1617	0.0793	0.0451	0.0190	0.0101	0.0061
			4	0.8498	0.3233	0.1586	0.0901	0.0381	0.0201	0.0121
			6	1.2747	0.4850	0.2379	0.1352	0.0571	0.0302	0.0182
		Soil Ingestion	1	0.0016	0.0006	0.0003	0.0002	0.0001	0.0000	0.0000
			2	0.0032	0.0012	0.0006	0.0003	0.0001	0.0001	0.0000
			4	0.0063	0.0024	0.0012	0.0007	0.0003	0.0002	0.0001
			6	0.0095	0.0036	0.0018	0.0010	0.0004	0.0002	0.00014
Sparse Orchard	60	Dermal	1	8.2801	3.7711	2.1180	1.3523	0.6882	0.4151	0.2786
			2	16.5602	7.5421	4.2360	2.7047	1.3763	0.8302	0.5572
			4	33.1203	15.0842	8.4720	5.4094	2.7526	1.6604	1.1143
			6	49.6805	22.6263	12.7079	8.1140	4.1290	2.4907	1.6715
		Object-to-Mouth	1	0.0053	0.0024	0.0014	0.0009	0.0004	0.0003	0.0002
			2	0.0106	0.0048	0.0027	0.0017	0.0009	0.0005	0.0004
			4	0.0212	0.0096	0.0054	0.0035	0.0018	0.0011	0.0007
			6	0.0317	0.0145	0.0081	0.0052	0.0026	0.0016	0.0011
		Hand-to-Mouth	1	0.1723	0.0785	0.0441	0.0281	0.0143	0.0086	0.0058
			2	0.3445	0.1569	0.0881	0.0563	0.0286	0.0173	0.0116
			4	0.6890	0.3138	0.1763	0.1125	0.0573	0.0345	0.0232
			6	1.0336	0.4707	0.2644	0.1688	0.0859	0.0518	0.0348
		Soil Ingestion	1	0.0013	0.0006	0.0003	0.0002	0.0001	0.0001	0.0000
			2	0.0026	0.0012	0.0007	0.0004	0.0002	0.0001	0.0001
			4	0.0051	0.0023	0.0013	0.0008	0.0004	0.0003	0.0002
			6	0.0077	0.0035	0.0020	0.0013	0.0006	0.0004	0.00026

Table 33. Estimated Air Concentrations at Various Distances from a Field Treated with Chlorpyrifos Using Aerial Equipment

Aircraft	Spray Volume (gallon/acre)	Height of Air Concentration (ft)	Application Rate (lb/acre)	1-Hour Air Concentration at Various Distance Downwind from the Treated Fields[a] (mg/m^3)						
				25 (feet)	50 (feet)	75 (feet)	100 (feet)	150 (feet)	200 (feet)	250 (feet)
AT802A	2	1.7 ft	1	0.0292	0.0264	0.0239	0.0220	0.0194	0.0175	0.0161
			2	0.0493	0.0437	0.0386	0.0350	0.0300	0.0264	0.0237
			4	0.0795	0.0688	0.0594	0.0526	0.0431	0.0367	0.0315
			6	0.1042	0.0884	0.0752	0.0650	0.0508	0.0414	0.0348
		5 ft	1	0.0218	0.0194	0.0176	0.0163	0.0143	0.0129	0.0118
			2	0.0367	0.0320	0.0285	0.0259	0.0221	0.0195	0.0174
			4	0.0596	0.0503	0.0439	0.0389	0.0319	0.0269	0.0230
			6	0.0781	0.0643	0.0550	0.0479	0.0377	0.0305	0.0253

a-These estimated doses are used as surrogate inhalation doses for orchard airblast and ground boom applications.

IV.A.2.d. Exposure from House Dust

Inhalation of airborne material, dermal contact with contaminated surfaces, and non-dietary oral ingestion (e.g., pica) are potential exposure of chlorpyrifos associated with spray drift. In addition to these outdoor post-application exposure pathways, exposure to chlorpyrifos may occur via incidental ingestion of contaminated indoor dust especially in young children in agricultural families (Buck et al., 1999; Quiros-Alcala et al., 2011). Prior to the restrictions of indoor chlorpyrifos use, house dust contained chlorpyrifos residues derived from the indoor chlorpyrifos applications (e.g., in home insect control) (Lewis et al., 2001) or from "take-home" exposure from occupational settings (Fenske et al., 2013; Smith et al., 2017). In 2000, US EPA heavily restricted indoor use of chlorpyrifos, leaving only roach baits in child resistant packaging registered for indoor use. Therefore, sources outside of the home can now be assumed to be the sole contributors to chlorpyrifos residues in house dust. Figure 11 shows the pounds of chlorpyrifos applied in California two years before and one year after the US EPA action. Also shown in Figure 11 is the maximum concentrations of chlorpyrifos measured on house dust samples collected from the same farmworker community at Salinas Valley, CA in 1999 and 2002 (Bradman et al., 2007; Harnly et al., 2009). Similar to the reduction in amounts of chlorpyrifos applied over the time period of 1999-2002, the maximum chlorpyrifos concentrations in house dust decreased from 9810 ng/g in 1999 to 1200 ng/g in 2002. Because these household dust samples were collected from homes of farmworkers within the same agricultural area, the substantial decrease (i.e., a factor of ~8) in the maximum house dust concentrations over this time period suggests that the indoor uses may have been the major source of chlorpyrifos in contaminated house dust. In other words, after the restrictions of home use, outdoor sources such as "take-home" by farmworkers from their occupations become the dominant source of chlorpyrifos in house dust in these agricultural families.

Studies showed that chlorpyrifos concentrations in house dust are higher in farmworker homes than non-farmworker homes (Smith et al., 2017). Accordingly, assessing house dust exposure in farmworker homes with a life stage that has the highest estimate of soil ingestion rate (i.e., children <2 years old) would constitute a reasonable "worst case" estimate of chlorpyrifos exposure in children. For evaluating children's exposure to chlorpyrifos via house dust, this assessment employs house dust concentration of chlorpyrifos after the indoor use cancellation. Specifically, in the study by (Bradman *et al.*, 2007), organophosphate pesticides including chlorpyrifos were measured in house dust samples collected from 20 farmworker families in 2002 at Salinas Valley, CA. Combining the highest measured chlorpyrifos house dust concentration (i.e., 1200 ng/g) with a daily dust ingestion rate for children 0 - 2 years old (i.e., 304 mg/day [at the 95th percentile]) (OEHHA, 2012), and assuming an infant body (i.e., <1 yr old) weight of 7.6 kg (Andrews and Patterson, 2000), and 100% oral absorption, a short term absorbed daily dose can be estimated as 0.048 μg/kg/day.

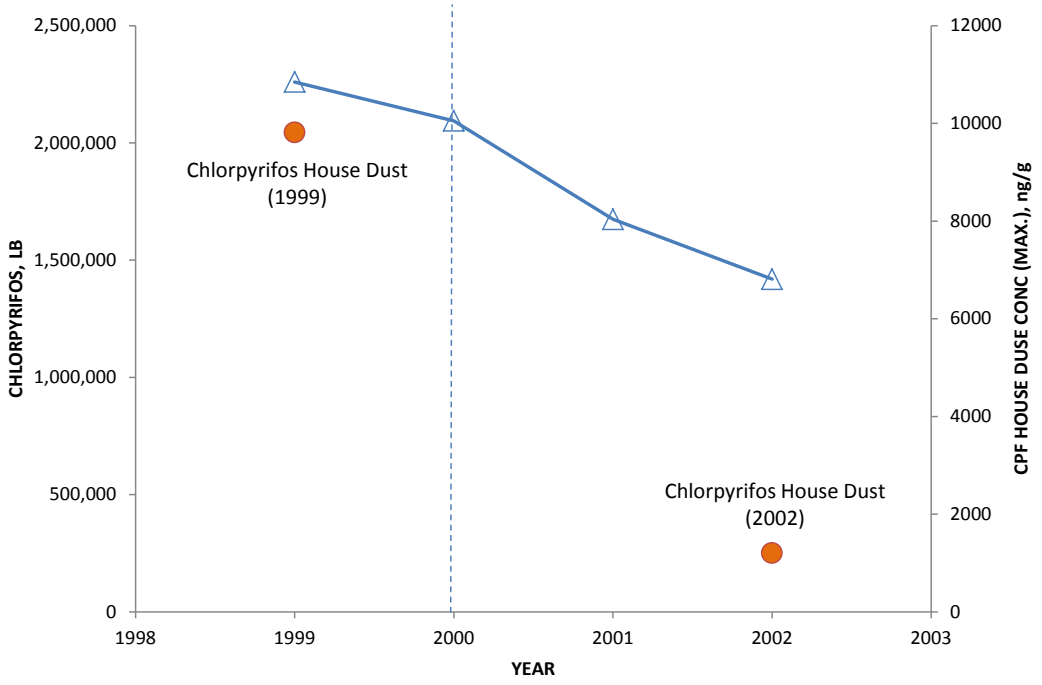


Figure 11. Pounds of chlorpyrifos applied in California from 1999 to 2002 and maximum concentrations of chlorpyrifos measured in house dust samples collected from Salinas Valley, CA in 1999 and 2002
(Bradman et al., 2007; Harnly et al., 2009)

IV.B. Dietary Exposure (Food and Drinking Water)

Below is a brief description of the CPF dietary (food only) and drinking water (DW: refined, ground water and surface water) risk assessment for California. The subpopulations of concern for both dietary (food only) and DW acute and steady-state exposures were infants (< 1 year old), children (1-2 years old), children (6-12 years old), and females (13-49 years old). The PoDs for these subgroups were presented in the 2014 US EPA Revised Human Health Risk Assessment for CPF (2014a) and in the Hazard Identification, above.

IV.B.1. Food-Only Exposure Assessment

IV.B.1.a. Summary of the 2014 US EPA Food-Only Exposure Assessment

Acute food-only exposures were calculated for every standard subpopulation and steady-state exposures were calculated for four sentinel subpopulations identified in the US EPA risk assessment: infants (< 1 year old), children 1-2 years, children 6-12 years, and females 13-49 years (US EPA, 2014b).

IV.B.2. Description of Dietary Exposure Assessment Models

1) DEEM-FCID

DEEM-FCID is a computer program for estimating exposure and/or risk to human health from pesticides in food (US EPA, 2015). The software incorporates food consumption data from the National Health and Nutrition Examination Survey/"What We Eat in

America" (NHANES/WWEIA) dietary survey. Individual dietary consumption records reported in the survey are translated into more than 500 US EPA-defined food commodities using the Food Commodity Intake Database. Dietary consumption data, expressed in units of food commodities (kg food/kg body weight), are combined with pesticide residue data in a probabilistic analysis to estimate pesticide exposure levels. Exposure can be calculated for specific segments of the population based on age, gender, or ethnicity, and for periods of time corresponding to acute (≤ 1 day), chronic, or lifetime effects.

2) Calendex-FCID

Calendex-FCID is a component DEEM-FCID that allows the analysis of variations in exposure during the calendar year as well the ability to aggregate exposures from multiple routes and pathways, such as oral, dermal, and inhalation exposures resulting from residues in food as well as residential and/or occupational exposure. In US EPA's 2014 dietary exposure assessment, Calendex-FCID was used because it allowed the estimation of 21-day average dietary exposure, which corresponded to the period of time required for steady-state cholinesterase inhibition by CPF (US EPA, 2015).

IV.B.3. Residue Data and Refinements

CPF is used on a wide variety of food crops, including some of the most important commodities in California. Based on the most recent five years of use data (2011-2015), the top agricultural uses in the state were almond, alfalfa, walnut, orange, and cotton. Average annual use for all sites, including all agricultural and non-agricultural uses, was 1.3 million lbs/year.

US EPA tolerances for residues of CPF are presently established on a large number of crops. There are 79 individual tolerances and three crop group tolerances ranging from 0.1 to 20 ppm (CFR 40 §180.342, updated August 12, 2015). Two of the tolerances, for grape and asparagus, are regional. CPF-oxon residues are not included in the tolerances established for CPF residues because it is generally not found in food. US EPA's 2014 dietary exposure assessment incorporated the latest residue data from USDA's Pesticide Data Program (PDP) (through 2012) and updated usage information (2004-2012). Steady-state exposure was analyzed as a 21-day rolling average throughout the year. The assessment used an extensive set of processing factors including those for cooking and peeling, as well as default factors for dried or juice food types. The factors from the cooking study were summarized in the 2011 preliminary dietary exposure assessment.

The metabolite CPF-oxon was not included in the food-only exposure assessment because field trial and metabolism studies showed that it was not present in crops. Also, it was not detected by the PDP program from 2007 through 2012, except in one potato sample. CPF in not registered for use on potatoes in the US (US EPA, 2014b).

Seventy residue data files were used in the probabilistic analysis. The same data files were used in the acute and steady state exposure assessments. For crops not sampled by PDP, data were translated from similar crops where appropriate. The following commodities had no detects of

CPF residues: sugar beet; dried peas and beans; dried peach, banana, and plantain; field corn; popcorn; sorghum (syrup); triticale and wheat flour; sunflower; cottonseed; most meat, milk and egg food types; fig; peanut; peppermint; and spearmint. For those commodities, US EPA's analysis used anticipated residues, tolerance values, or point estimates of residues, depending on consumption rate of the commodity, and the availability of either field trial data or residue data from similar commodities.

Acute exposures were calculated for the general US population and eight subpopulations: infants, children 1-2 years, children 3-5 years, children 6-12 years, youth 13-19 years, adults 20-49 years, adults 50-99 years, and females 13-49 years. Steady state exposures were calculated for four sentinel populations characterized in the PBPK-PB model: infants, children 1-2 years, children 6-12 years, and females 13-49 years.

The 2014 US EPA exposure values were estimated on a per capita basis (all individuals surveyed). HHA selects per user-day basis (consumers only or the population that is exposed) for the acute exposure rather than the entire population (per capita) (CDPR, 2009). In many exposure scenarios, per capita risks would be lower than per user risks. Therefore, HHA conducted a sensitivity analysis of food consumption by infant population subgroups in DEEM-FCID v3.16 to determine if consumption was significantly different among them. Residue levels for all commodities excluding water, was set at 1 ppm (point estimate). Table 34 shows the number of users compared to number of persons surveyed in each population subgroup. Because so many commodities were included, most persons surveyed were users. The exposure estimates at the 95th percentile were slightly higher for non-nursing infants compared to all infants, but at the 99.9th percentile, the exposure estimates for non-nursing infants and all infants were essentially the same. Nevertheless, we recognize that non-nursing infants on formula can have higher exposures to CPF on average, but at the higher exposure levels the difference in exposure estimates between non-nursing infants and all infants is small.

Table 34. Comparison of Consumption of Food Commodities for Infant Population

Population Subgroup	Persons Surveyed	Users Surveyed	Exposure (mg/kg/day) per capita		
			Mean	95th percentile	99.9th percentile
Nursing infants	792	604	0.019639	0.069205	0.181581
Non-nursing infants	1708	1707	0.046784	0.125402	0.222562
All infants	2500	2311	0.038403	0.111445	0.221506

HHA also examined the potential for CPF exposure through formula or breast milk in infants. Infant formulas are prepared using heat and other purification procedures to reduce potential pesticide residues from application on crops used in formula ingredients. Infant formulas are mainly based on cow's milk or soy protein and soy oil. Monitoring studies over the years have confirmed that pesticides are rarely detected in infant formulas (National Research Council Committee on Pesticides in the Diets of Infants and Children, NRC, 1993). For CPF and CPF-oxon, PDP (2013 and 2014) analyzed 705 samples of cow milk and 706 samples of soy-based infant formula and found no detectable residues (LOD ranged from 0.001 and 0.01 ppm). PDP monitoring of cow's milk in 2012 resulted in 3 chlorpyrifos detects out of 792 samples (0.4%), with a LOD of 0.5 ppb.

Presently, there are very few studies that measured chlorpyrifos concentrations in breast milk of mothers in the US. A 2011 pilot study from the CHAMACOS Cohort measured chlorpyrifos concentrations in the breast milk of women residing in urban and agricultural regions in CA (Weldon et al., 2011). The study detected chlorpyrifos residues in breast milk in a relatively small number of subjects (21 urban women and 13 agricultural women) . The residues ranged from 13 to 1,000 pg/g milk. The median values between urban and agricultural women were similar (24.5 and 28.0 pg/g, respectively). The LOD's in this study were very low, ranging from 0.1-0.5 pg/g. In a study in India, Bedi *et al.* (2013) found much higher residues than in the Weldon study, although the LOD was not reported. The number of subjects was also relatively small (primiparate and 19 multiparate women). While not referring to this particular study by Bedi et al., Weldon and colleagues suggested a hypothesis that higher residues in breast milk from Indian women was associated with non-compliance of re-entry intervals after applications (Weldon et al., 2011). In a dissertation from the University of Tennessee (Casey, 2005), the author used ELISA to detect residues of chlorpyrifos in breast milk from mothers in Tennessee. This method has not been validated, although initial results were approximately 40 times higher in 26 lactating and 26 non-lactating females than levels reported in Weldon et al. (2011). The former has not yet been published as a peer-reviewed manuscript. Lastly, as mentioned earlier, PDP monitoring of cow's milk reported only 3 chlorpyrifos detects out of 792 samples with a LOD of 0.0005 ppm or 0.5 ppb (PDP 2015).

Taken as a whole these studies reported chlorpyrifos residues in breast milk, but the magnitude of them is uncertain. The Weldon *et al.* (2011) appears to be the most reliable estimate of breast milk residues in US women with the legal uses of chlorpyrifos and the residues were low. HHA will continue to follow the literature on pesticides residues in human milk and will evaluate children's exposure to chlorpyrifos via the lactational pathway as data become available.

Exposure estimates were compared to population-adjusted doses (PADs) from US EPA's evaluation. PADs were based on PoDs that were estimated from PBPK-PD modeling of RBC cholinesterase inhibition in humans.

IV.B.4. Results of Dietary (food-only) Exposure Assessment

Exposure estimates from the 2014 US EPA assessment are shown in Table 35 and Table 36. Children 1-2 years old were identified as the highest exposed population subgroup. At the 99.9th percentile, their exposure was estimated at 0.000423 mg/kg. Although a commodity contribution analysis was not included in either the 2011 or 2014 US EPA exposure assessments, residues in peaches, peppers, apples, plums, grapefruit juice, grape juice, soy milk, cranberry juice, and orange juice were described as drivers of acute food exposure.

Table 35. Acute Dietary Exposure for CPF

Population Subgroup	Oral aPoD (mg/kg)[a]	Residues at 99.9th Percentile Exposure (mg/kg/d)
All Infants < 1 year old	0.600	0.000273
Children 1-2 years old	0.581	0.000423
Children 6-12 years old	0.530	0.000189
Females 13-49 years old	0.469	0.000150

[a] aPoD = acute point of departure; Reference: US EPA (2014a)

Table 36. Steady-State Dietary Exposure for CPF

Population Subgroup	Oral ssPoD (mg/kg)[a]	Residues at 99.9th Percentile Max Exposure (mg/kg/d)
All Infants < 1 year old	0.103	0.000186
Children 1-2 years old	0.099	0.000242
Children 6-12 years old	0.090	0.000128
Females 13-49 years old	0.078	0.000075

[a] ssPoD = Steady State point of departure
Reference: US EPA (2014a)

IV.B.5. HHA Drinking Water Assessment

IV.B.5.a. Summary of US EPA Drinking Water Assessments

US EPA conducted a preliminary drinking water assessment (DWA) in 2011 and updated it with additional analyses in 2014 (US EPA, 2011a; US EPA, 2014c). CPF is rapidly oxidized to the oxon during the chlorination process of drinking-water treatment. Since more than 75% of community water systems in the US use chlorination to disinfect drinking water, the DWA assumed that CPF is converted 100% to CPF-oxon during water treatment processes. A drinking water level of concern (DWLOC) of 3.9 ppb was calculated for exposure to CPF-oxon based on the ssPoD, uncertainty factors, and estimated food exposure for infants.

Several use scenarios were expected to result in surface water concentrations that exceed the DWLOC, based on computer modeling. Concentrations in ground water were not expected to exceed the DWLOC. The updated DWA examined water monitoring programs across the country, including DPR's program, and found that none (except a registrant study of Orestimba Creek in Stanislaus County) were capable of detecting peak or 21-day average concentrations of CPF or CPF-oxon because the frequency of monitoring did not coincide with either the exposure period of interest or the timing of CPF applications.

- **Drinking water derived from ground water (i.e., wells) is predicted[3] to have acceptable levels** of CPF and CPF-oxon. Even for a use scenario with 5 applications per year totaling 14.5 lbs CPF per acre, the 21-day average concentration of CPF-oxon in drinking water derived from ground water is not expected to be greater than 0.15 µg / L (US EPA, 2014c).

[3] **For drinking water derived from ground water, source of predictions for Estimated Drinking Water Concentrations (EDWC):** For drinking water derived from ground water, USEPA (2014c) used the higher prediction from either of two models: Screening Concentration in Ground water (SCI-GROW) version 2.3, and Pesticide Root Zone Model for Ground Water (PRZM-GM). A previous evaluation by US EPA showed that, "In a few cases PRZM-GM underestimated pesticide concentration observed in ground water", especially "pesticide concentrations with high sorption coefficients (i.e., K_{OC} > 1,000 mL/g_{OC}) and low persistence (i.e., soil half-life < 30 days)." Quote is from: http://www.epa.gov/oppefed1/models/water/przm_gw/wqtt_przm_gw_guidance.htm Chlorpyrifos and chlorpyrifos-oxon both have lower K_{OC} values and longer soil half-lives that fall outside of those problematic ranges.

That is less than 4% of the Drinking Water Level of Concern (DWLOC) of 3.9 µg / L for CPF-oxon[4].

- **Drinking water derived from surface water is predicted[5] to pose an exposure concern** (Table 37). According to US EPA, several CPF uses may exceed the DWLOC at rates lower than maximum labeled rates (both single as well as yearly), including an application rate of one pound per acre per year (US EPA, 2014c). Uses that may exceed the DWLOC include scenarios for certain California cropping systems, such as wheat, rangeland, cole crops, and wine grapes.

- **Exceedances in drinking water derived from surface water are predicted to be highly localized.** Highest exposures are predicted in small watersheds where there is a high percent cropped area on which CPF is applied. Similarly, evaluation of surface water monitoring data illustrates that exposures are highly localized. Overall, model predictions agree well with surface water monitoring data, despite limitations of monitoring[6].

- **Routine treatment of drinking water is not expected to mitigate the risk.** According to US EPA, drinking water treatment processes in general are not efficient in removing pesticide residues. The exceptions may be granular activated carbon filtration or water softening, which may alter the water pH or provide a substrate for binding or deposition (US

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[4] **Calculation of Drinking Water Level of Comparison (DWLOC):** The average 21-day concentration of chlorpyrifos-oxon necessary to cause 10% AChE inhibition was determined by the US EPA Office of Pesticide Programs Health Effects Division to be 217 ppb. This value was divided by the safety factors (50x), resulting in a value of 4.3 ppb; and then the contribution from food (0.4 ppb) was subtracted out to give a DWLOC of 3.9 ppb. Source: USEPA 2014c, page 4, footnote 12. Though never stated by US EPA (2014c), the value 217 ppb corresponds to infants, the most susceptible population; see US EPA 2014a chlorpyrifos risk assessment Table 4.8.4. The 50x "safety factors" used by Bohaty (US EPA 2014a) comprises a 10x uncertainty factor as required by Food Quality Protection Act (FQPA) multiplied by a 5x uncertainty factor for intraspecific extrapolation. The intraspecific value is 5x for most populations, including infants; but for adult females, the intraspecific factor is 10x. Source: US EPA 2014a,b .

[5] **For drinking water derived from surface water, source of predictions for Estimated Drinking Water Concentrations (EDWC):** "Tier II surface water EDWCs for chlorpyrifos and chlorpyrifos-oxon were calculated using the Surface Water Concentration Calculator (SWCC) version 1.106. The SWCC uses Pesticide Root Zone Model for Ground Water version 5.0+ (PRZM5) and the Variable Volume Water Body Model (VVWM). PRZM5 is used to simulate pesticide transport as a result of runoff and erosion from an agricultural field. VVWM estimates environmental fate and transport of pesticides in surface water. The input parameters used in SWCC simulations are presented in Table 10" US EPA (2014c)

[6] **Limitations of surface-water monitoring to date:** " None of the monitoring programs examined to date were specifically designed to target chlorpyrifos use (except the Registrant Monitoring Program MRID 44711601); therefore, peak concentrations (and likely 21-day average concentrations) of chlorpyrifos and chlorpyrifos-oxon likely went undetected in these programs. In general, sampling frequency needs to be approximately equal to the duration of exposure concern. The chlorpyrifos monitoring data evaluated thus far also show that as sample frequency increases, so does the detection frequency" US EPA. 2014c. Chlorpyrifos: Updated Drinking Water Assessment for Registration Review, December 23, 2014. PC Code: 059101. DP Barcode: D424487, pp. 7-8).

EPA 2014c). Additionally, all CPF that enters a drinking water treatment facility is assumed to be converted to CPF-oxon during chlorination. And while CPF-oxon has a hydrolysis half-life of 5 days, the drinking water treatment simulation half-life for CPF-oxon is approximately 12 days. Therefore, once CPF-oxon forms during treatment, little transformation is expected to occur before consumption (during drinking water distribution) (US EPA 2014c).

IV.B.5.b. Risk Assessment Section (RAS) Evaluation of the Exposure to CPF in Drinking Water in California

In the absence of modeling data specific for California, the assessment utilized residue data from PDP's drinking water study and from the testing of surface and ground water in California to evaluate the potential exposure to CPF through drinking water.

IV.B.5.c. Analysis of Drinking Water Exposure Using PDP Residue Data

The PDP Drinking Water Project began in 2001 and ended in 2013 (PDP, 2015). The data include samples collected from water treatment plants located in agricultural areas, paired pre-treatment and post-treatment samples from water treatment plants, bottled water, and potable ground water. A total of 1835 samples were analyzed for CPF and/or CPF-oxon and no residues were detected. LODs ranged from 3 to 30 ppt for CPF and 12 to 510 ppt for CPF-oxon (Table 37). The average LOD for CPF-oxon in finished (treated) water samples (n = 706) was 38.2 ppt. Exposure to CPF-oxon in drinking water was estimated by assuming that each of the 706 samples of finished (treated) water contained CPF-oxon at concentrations equivalent to the LOD for CPF-oxon in each sample. The 95th and 99.9th percentile exposures for all infants, the most highly exposed subpopulation, were 0.000004 and 0.000108 mg/kg respectively (Table 38).

Table 37. PDF Monitoring Data for CPF and CPF-oxon in Ground Water, Untreated Drinking Water, Finished Drinking Water, and Bottled Water in California (2001-2013)

YEAR	CHEMICAL	SAMPLE TYPE	SAMPLES	DETECTS	LOD (PPT)
2001	CPF	Finished	134	0	11
	CPF-oxon	Finished	134	0	20
2002	CPF	Finished	267	0	6
	CPF-oxon	Finished	265	0	12
2003	CPF	Finished	272	0	9
	CPF-oxon	Finished	272	0	12
2004	-- NO DATA --				
2005	CPF	Bottled	93	0	30
	CPF	Finished	26	0	11
	CPF	Untreated	28	0	11
	CPF-oxon	Finished	26	0	510
	CPF-OXON	Untreated	28	0	510
2006	CPF	Bottled	88	0	30
	CPF	Finished	9	0	11

YEAR	CHEMICAL	SAMPLE TYPE	SAMPLES	DETECTS	LOD (PPT)
	CPF	Untreated	9	0	11
	CPF-oxon	Finished	9	0	510
	CPF-oxon	Untreated	9	0	510
2007	CPF	Ground water	4	0	30
2008	CPF	Ground water	2	0	30
2009	CPF	Ground water	13	0	30
2010	CPF	Ground water	27	0	30
2012	CPF	Untreated	26	0	30
	CPF	Finished	26	0	30
	CPF-oxon	Untreated	26	0	12
	CPF-oxon	Finished	26	0	12
2013	CPF	Ground water	8	0	30
	CPF-oxon	Ground water	8	0	12

LOD = limit of detection.

Table 38. DEEM-FCID (v. 3.18) Acute Exposure Estimates for CPF-Oxon in Drinking Water Based on 2001-2013 PDP Residue Data for CPF-Oxon in Treated (Finished) Water

Probabilistic Estimate With All Non-Detects at the LOD[a]			
Population Subgroup	Exposure (mg/kg/d)[b]		
	95th Percentile (Users)	99th Percentile (Users)	99.9th Percentile (Users)
All Infants (< 1 year old)	0.000004	0.000061	0.000108
Children 1-2 years old	0.000002	0.000025	0.000057
Children 6-12 years old	0.000002	0.000015	0.000036
Females 13-49 years old	0.000001	0.000017	0.000036

a- Residue data were assigned to commodities: "Water, direct, all sources", "Water, indirect, all sources".

b- 706 samples, no detections. LODs ranged 12-510 ppt (mean = 38.2 ppt).

IV.B.5.d. Analysis of Drinking Water Exposure Using EMON Surface Water Residue Data

DPR's Environmental Monitoring Branch collects residue data from surface water samples within California by a number of government agencies including the US Geologic Survey, the State Water Resources Control Board, and CALFED Bay-Delta Program, as well DPR sampling. The samples may be collected from water sources that are ultimately treated and used for drinking water as well as from irrigation ponds, sloughs, and agricultural drains that are either not used for drinking water or are located far from water bodies that may ultimately be used for drinking water, and therefore highly diluted before use. A total of 7154 samples of California surface water were analyzed for CPF from 2005 to 2014 and the range of detected residues was 0.000572 to 3.7 ppb. A total of 794 samples were analyzed for CPF-oxon and there were no detected residues (average detection limit ranged from 0.05 to 0.08 ppb) (Table 39) (CDPR, 2015a).

Exposure to CPF-oxon in drinking water was estimated by conducting a probabilistic analysis using either the detected CPF residue in surface water or the detection limit (in the case of non-detects) together with all individual water consumption records for each subpopulation. The DEEM-FCID residue data file (RDF) contained 7048 residue values (either the measured residue or LOD). The 95th and 99.9th percentile exposures for all infants, the most highly exposed subpopulation, were 0.000008 and 0.000419 mg/kg, respectively (Table 40). These exposures were up to 4-fold higher than the exposures estimated based on the PDP monitoring data.

Table 39. Summary of DPR Surface Water Monitoring for CPF in California (2005-2014)

YEAR	CHEMICAL	SAMPLE COUNT	DETECTS	DETECTION FREQUENCY (%)	RANGE (PPB)	AVG. AVG. DETECTION LIMIT FOR NON-DETECTS (PPB)
2005	CPF	702	59	8.4%	0.0058 - 1.4	0.0619
	CPF-oxon	14	0	0.0%	n/a	0.0562
2006	CPF	545	57	10.5%	0.0092 - 0.72	0.0728
	CPF-oxon	45	0	0.0%	n/a	0.0562
2007	CPF	804	82	10.2%	0.0079 - 3.7	0.0280
	CPF-oxon	59	0	0.0%	n/a	0.0562
2008	CPF	965	146	15.1%	0.0010 - 1.8	0.0232
	CPF-oxon	71	0	0.0%	n/a	0.0548
2009	CPF	628	79	12.6%	0.000572 - 2.377	0.0266
	CPF-oxon	66	0	0.0%	n/a	0.0500
2010	CPF	857	138	16.1%	0.00248 - 1.988	0.0211
	CPF-oxon	57	0	0.0%	n/a	0.0519
2011	CPF	985	122	12.4%	0.0022 - 1.4	0.0129
	CPF-oxon	60	0	0.0%	n/a	0.0650
2012	CPF	393	66	16.8%	0.0027 - 0.2940	0.0640
	CPF-oxon	52	0	0.0%	n/a	0.0800
2013	CPF	905	60	6.6%	0.0024 - 1.59	0.0925
	CPF-oxon	0	n/a	n/a	n/a	n/a
2014	CPF	370	51	13.8%	0.0027 - 1.75	0.0853
	CPF-oxon	0	n/a	n/a	n/a	n/a

CPF = chlorpyrifos, CPF-oxon = chlorpyrifos-oxon

Table 40. DEEM-FCID (v. 3.18) Acute Exposure Estimates for CPF-oxon in Drinking Water Based on 2005-2014 Surface Water Residue Data

Probabilistic Estimate With All Non-Detects at the Detection Limit[a,b]			
Population Subgroup	Exposure (mg/kg/d)[c]		
	95th Percentile (Users)	99th Percentile (Users)	99.9th Percentile (Users)
All Infants (< 1 year old)	0.000008	0.000049	0.000419
Children 1-2 years old	0.000004	0.000023	0.000177
Children 6-12 years old	0.000002	0.000014	0.000110
Females 13-49 years old	0.000002	0.000015	0.000119

a- Residue data were assigned to commodities: "Water, direct, all sources", "Water, indirect, all sources".
b- 7048 samples, 860 detections (range, 0.000572-3.7; mean 0.125 ppb). LODs ranged 0.001-4 ppb, mean 0.045 ppb).
c- CPF exposure values were converted to CPF-oxon by applying a molecular weight correction factor (0.9541).

IV.B.6. Analysis of Drinking Water Exposure Using DPR Ground Water Residue Data

The Environmental Monitoring Branch of DPR collects residue data from sampling of ground water within California by a number of government agencies including US Geological Survey, CA State Water Resources Control Board, CA Department of Water Resources, CA Department of Public Health, as well as sampling by DPR. The samples are collected from a variety of wells including municipal, community, domestic and irrigation. A total of 2055 samples were analyzed for CPF from 2004 to 2013 and only two samples had detectible residues (in 2006, 0.006 and 0.008 ppb). The average detection limit for non-detects ranged from 0.005 to 1 ppb each year. A total of 1903 samples were analyzed for CPF-oxon on and there were no detected residues (average detection limit ranged from 0.05 to 0.06 ppb) (Table 41) (CDPR, 2015b).

Exposure to CPF-oxon in drinking water was estimated by conducting a probabilistic analysis using either the detected CPF residue in ground water or the detection limit (in the case of non-detects) together with all individual water consumption records for each subpopulation. The DEEM-FCID residue data file (RDF) contained 2055 residue values (either the measured residue or detection limit). The 95th and 99.9th percentile exposures for all infants, the most highly exposed subpopulation, were 0.000018 and 0.000222 mg/kg, respectively (Table 42).

Table 41. Summary of Ground Water Monitoring for CPF in California, 2004-2013

YEAR	CHEMICAL	SAMPLE COUNT	DETECTS	DETECTION FREQUENCY (%)	RANGE (PPB)	AVG. DETECTION LIMIT FOR NON-DETECTS (PPB)
2004	CPF	152	0	0.0%	n/a	0.0181
	CPF-oxon	151	0	0.0%	n/a	0.0560
2005	CPF	388	0	0.0%	n/a	0.0050
	CPF-oxon	388	0	0.0%	n/a	0.0560
2006	CPF	478	2	0.0%	0.006 - 0.008	0.0071
	CPF-oxon	477	0	0.0%	n/a	0.0560
2007	CPF	354	0	0.0%	n/a	0.0107
	CPF-oxon	352	0	0.0%	n/a	0.0560
2008	CPF	437	0	0.0%	n/a	0.0921
	CPF-oxon	395	0	0.0%	n/a	0.0553
2009	CPF	94	0	0.0%	n/a	0.0837
	CPF-oxon	78	0	0.0%	n/a	0.0500
2010	CPF	65	0	0.0%	n/a	0.0862
	CPF-oxon	60	0	0.0%	n/a	0.0500
2011	CPF	46	0	0.0%	n/a	0.9393
	CPF-oxon	2	0	0.0%	n/a	0.0600
2012	CPF	22	0	0.0%	n/a	1.0000
	CPF-oxon	0	n/a	n/a	n/a	n/a
2013	CPF	25	0	0.0%	n/a	1.0000
	CPF-oxon	0	n/a	n/a	n/a	n/a

CPF = chlorpyrifos, CPF-oxon = chlorpyrifos-oxon

Table 42. DEEM-FCID Acute Exposure Estimates for CPF-Oxon in Drinking Water Based on 2004-2013 Ground Water Residue Data

Probabilistic Estimate With All Non-Detects at the Detection Limit[a,b]			
Population Subgroup	**Exposure (mg/kg/d)[c]**		
	95th Percentile (Users)	**99th Percentile (Users)**	**99.9th Percentile (Users)**
All Infants (< 1 year old)	0.000018	0.000127	0.000222
Children 1-2 years old	0.000012	0.000054	0.000115
Children 6-12 years old	0.000008	0.000031	0.000075
Females 13-49 years old	0.000009	0.000036	0.000073

a- Residue data were assigned to commodities: "Water, direct, all sources", "Water, indirect, all sources".
b- 2055 samples, 2 detects (0.006, 0.008 ppb). Detection limit for non-detects ranged 0.004-1 ppb (mean 0.072 ppb).
c- CPF exposure values were converted to CPF-oxon by applying a molecular weight correction factor (0.9541).

V. RISK CHARACTERIZATION

The critical NOELs or toxicological points of departure (PoDs) for characterizing the risk from exposures to CPF were PBPK-PD-estimated human equivalent doses. Risks were calculated as margins of exposure (MOE), a quotient of the NOEL and the human exposure level. A MOE of 100 was considered prudent for protection against the CPF toxicity. The target of 100 includes an uncertainty factor of 1 for interspecies sensitivity, an uncertainty factor of 10 for intraspecies variability, and an UF of 10 fold for potential neurodevelopmental effects.

V.A. Risk Characterization (Margins of Exposure) for a Single Route (oral, dermal, inhalation)

In the assessment of single routes of exposure, the risk for non-oncogenic effects is characterized in terms of a margin of exposure (MOE), defined as the ratio of the critical human equivalent PoD to the estimated human exposure levels. The calculation is shown below:

$$\text{Single Route MOE} = \frac{\text{PoD (e.g., oral, dermal, inhalation)}}{\text{Exposure Dosage (route specific: oral, dermal, inhalation)}}$$

V.B. Spray-Drift Bystander (Non-Occupational/Residential) Risk Characterization

Using the allowable application rates and methods specified on the product labels of currently registered CPF-containing products in California, the risk estimates (i.e., MOE) of different exposure routes associated with spray drift were evaluated: exposures through dermal contact and inhalation for females 13-49 years old and children 1-2 years old and exposures due to different mouthing activities associated with the small children (hand-to-mouth, object-to-mouth, and incidental soil ingestion). Because different portal-of-entries (dermal, inhalation, and oral) are involved, route-specific MOEs are used to characterize the risks associated with different exposure routes.

For females 13-49 years old, under the current buffer zone requirement of 25 feet, risks were estimated, for exposures associated with aerial applications via fixed-winged and rotor-wing aircraft at rates of 1, 2, or 2.3 lb AI/acre (Table 43) or ground boom and airblast at application rates of 1, 2, 4, or 6 lb AI/acre (Table 44). For aerial applications, aggregate risk at 10 ft for the Bell 205 helicopter scenario at 2 and 2.3 lb/ac application rates showed MOEs below 100. Inhalation and aggregated MOEs were less than 100 for all the 6 lb/acre ground boom and airblast applications at 25ft and 50 ft distances. The airblast 4 lb/acre aggregate MOEs were less than 100 at 25 ft.

For children 1-2 years old, risk estimates are of concern for exposures from inhalation routes at the lowest application rate of 1 lb AI/acre at 50 feet away from the edge of a treated field via aerial application (Table 45). When inhalation, dermal, and oral exposures associated with aerial applications are aggregated for children, risks of concern occur as far as 250 feet from the application. For dermal and oral exposures, no risks of concern were identified for children as close as 25 feet downwind of a ground boom application (Table 46), even at the highest allowed rate of 6 lb AI/acre. For inhalation and aggregate risk associated with ground boom applications, the MOEs were below 100 at 75 ft for 1 lb/ac, at 200 ft for 2 lb/ac aggregate, and 250 ft for 4 lb/ac to 6 lb/aggregate (Table 47). A risk of concern occurs for 1-2 year-old children 75 feet downwind of an airblast application at the rate of 6 lb AI/acre due to hand-to-mouth exposure (Table 48). Airblast inhalation and aggregate risk both show MOEs less than 100 at 75 ft for 1 lb/ac. Airblast inhalation MOEs were less than 100 at 200 ft for 2 lb/ac and 250 ft for 4 lb/ac and 6 lb/ac. Airblast Aggregate MOEs were below 100 at 75 ft for 1 lb/ac and 250 ft for 2 lb/ac, 4 lb/ac, and 6 lb/ac.

Table 43. MOEs for Females (13-49 years old) Associated with Spray Drift at Various Distances from a Field Treated with CPF Using Aerial Equipment

Scenarios	Spray Vol (gallon/acre)	Exposure Route	Appl. Rate	MOE at Various Distance Downwind from the Treated Fields						
			(lb/acre)	10 (feet)	25 (feet)	50 (feet)	100 (feet)	250 (feet)	500 (feet)	1000 (feet)
AT802A	2	Dermal	1	976	1144	1454	2158	4139	6945	13021
			2	486	572	729	1091	2180	4006	10190
			2.3	423	497	635	952	1905	3591	9264
		Inhalation	1	263	282	317	377	521	724	1309
			2	154	168	192	237	353	554	1183
			2.3	144	156	180	223	336	533	1139
		Aggregated MOE (Dermal & Inhalation Routes)	1	207	226	260	321	463	655	1189
			2	117	130	152	195	304	487	1060
			2.3	107	119	140	181	285	464	1014
Bell 205	2	Dermal	1	764	1207	1972	3244	5081	8562	17524
			2	379	596	968	1555	2807	5483	12500
			2.3	330	518	840	1347	2485	4941	11482
		Inhalation	1	214	256	312	389	554	831	1464
			2	123	152	191	250	399	661	1255
			2.3	114	141	179	236	385	641	1237
		Aggregated MOE (Dermal & Inhalation Routes)	1	167	211	270	348	500	758	1351
			2	93	121	160	215	350	590	1141
			2.3	85	111	147	201	333	567	1117

Table 44. MOEs for Females (13-49 years old) Associated with Spray Drift at Various Distances from a Field Treated with CPF Using Ground-based Equipment Ground Boom and Airblast

Scenarios	Swaths (percentile)	Exposure Route	Appl. Rate (lb/acre)	MOE at Various Distance Downwind from the Treated Fields						
				25 (feet)	50 (feet)	75 (feet)	100 (feet)	150 (feet)	200 (feet)	250 (feet)
Ground boom										
High boom	40 (50th)	Dermal	1	19737	29762	39894	50676	69446	89287	110296
			2	9869	14881	19947	25338	34723	44644	55148
			4	4934	7441	9974	12669	17361	22322	27574
			6	3290	4960	6649	8446	11574	14881	18383
		Inhalation	1	282	317	349	377	429	477	521
			2	168	192	216	237	278	316	353
			4	103	122	140	158	193	228	267
			6	79	96	112	128	163	202	243
		Aggregated MOE (Dermal & Inhalation Routes)	1	278	314	346	375	427	474	519
			2	165	190	213	235	276	314	351
			4	101	120	138	156	191	226	265
			6	77	94	110	126	161	199	240
High boom	40 (90th)	Dermal	1	13889	19330	25000	31250	41667	52084	62501
			2	6945	9665	12500	15625	20834	26042	31250
			4	3472	4833	6250	7813	10417	13021	15625
			6	2315	3222	4167	5208	6945	8681	10417
		Inhalation	1	282	317	349	377	429	477	521
			2	168	192	216	237	278	316	353
			4	103	122	140	158	193	228	267
			6	79	96	112	128	163	202	243
		Aggregated MOE (Dermal & Inhalation Routes)	1	276	312	344	373	425	472	517
			2	164	188	212	234	274	312	349
			4	100	119	137	155	189	224	263
			6	76	93	109	125	159	197	238
Low boom	40 (50th)	Dermal	1	37501	55148	72117	93751	125002	156252	187503
			2	18750	27574	36058	46876	62501	78126	93751
			4	9375	13787	18029	23438	31250	39063	46876
			6	6250	9191	12019	15625	20834	26042	31250
		Inhalation	1	282	317	349	377	429	477	521
			2	168	192	216	237	278	316	353
			4	103	122	140	158	193	228	267
			6	79	96	112	128	163	202	243
		Aggregated MOE (Dermal & Inhalation Routes)	1	280	315	347	376	428	475	520
			2	166	191	214	236	276	315	352
			4	102	121	139	157	192	227	266
			6	78	95	111	127	162	200	241
Low boom	40 (90th)	Dermal	1	22059	30242	39063	48078	64656	78126	93751
			2	11030	15121	19532	24039	32328	39063	46876
			4	5515	7561	9766	12019	16164	19532	23438
			6	3677	5040	6511	8013	10776	13021	15625
		Inhalation	1	282	317	349	377	429	477	521
			2	168	192	216	237	278	316	353
			4	103	122	140	158	193	228	267
			6	79	96	112	128	163	202	243
		Aggregated MOE (Dermal & Inhalation Routes)	1	279	314	346	374	426	474	518
			2	165	190	213	235	275	313	351
			4	101	120	138	156	191	226	264
			6	77	94	110	126	161	199	239

Scenarios	Swaths (percentile)	Exposure Route	Appl. Rate (lb/acre)	MOE at Various Distance Downwind from the Treated Fields						
				25 (feet)	50 (feet)	75 (feet)	100 (feet)	150 (feet)	200 (feet)	250 (feet)
Airblast										
Dormant Apples	60	Dermal	1	3388	8903	18151	31943	75606	143132	237346
			2	1694	4452	9076	15971	37803	71566	118673
			4	847	2226	4538	7986	18902	35783	59336
			6	565	1484	3025	5324	12601	23855	39558
		Inhalation	1	282	317	349	377	430	477	521
			2	168	192	216	237	278	315	353
			4	103	122	140	158	193	229	267
			6	79	96	112	128	163	202	243
		Aggregated MOE (Dermal & Inhalation Routes)	1	260	306	343	373	428	475	520
			2	152	184	211	234	276	314	352
			4	92	116	136	155	191	227	266
			6	69	90	108	125	161	200	242
Sparse Orchard	60	Dermal	1	4178	9173	16333	25580	50269	83335	124174
			2	2089	4587	8167	12790	25134	41667	62087
			4	1044	2293	4083	6395	12567	20834	31044
			6	696	1529	2722	4263	8378	13889	20696
		Inhalation	1	282	317	349	377	430	477	521
			2	168	192	216	237	278	315	353
			4	103	122	140	158	193	229	267
			6	79	96	112	128	163	202	243
		Aggregated MOE (Dermal & Inhalation Routes)	1	264	306	342	372	426	474	519
			2	155	184	210	233	275	313	351
			4	94	116	135	154	190	226	265
			6	71	90	107	125	160	199	240

Table 45. MOEs for Children (1-2 years old) Associated with Spray Drift at Various Distances from a Field Treated with CPF Using Aerial Equipment

Scenarios	Spray Vol. (gallon/acre)	Exposure Route	Appl. Rate (lb/acre)	MOE at Various Distance Downwind from the Treated Fields						
				10 (feet)	25 (feet)	50 (feet)	100 (feet)	250 (feet)	500 (feet)	1000 (feet)
AT802A	2	Dermal	1	3786	4440	5641	8374	16063	26951	50532
			2	1886	2218	2829	4236	8461	15548	39547
			2.3	1640	1930	2464	3696	7392	13937	35952
		Object-to-Mouth	1	4460	5230	6645	9864	18922	31747	59526
			2	2222	2613	3333	4989	9967	18316	46585
			2.3	1932	2274	2903	4354	8708	16418	42350
		Hand-to-Mouth	1	137	161	204	303	581	975	1827
			2	68	80	102	153	306	562	1430
			2.3	59	70	89	134	267	504	1300
		Soil Ingestion	1	18347	21515	27335	40578	77842	130601	244877
			2	9140	10751	13710	20525	41003	75347	191643
			2.3	7948	9354	11940	17911	35821	67539	174221
		Inhalation	1	75	81	90	108	147	203	365
			2	43	48	54	68	100	155	329
			2.3	41	45	51	64	95	149	318
		Aggregated MOE (Dermal, Oral & Inhalation Routes)	1	47	53	61	78	116	166	300
			2	26	29	35	46	74	120	264
			2.3	23	27	32	42	69	113	252
Bell 205	2	Dermal	1	2965	4686	7652	12589	19720	33227	68006

Scenarios	Spray Vol. (gallon/acre)	Exposure Route	Appl. Rate (lb/acre)	MOE at Various Distance Downwind from the Treated Fields						
				10 (feet)	25 (feet)	50 (feet)	100 (feet)	250 (feet)	500 (feet)	1000 (feet)
			2	1472	2312	3755	6034	10893	21277	48511
			2.3	1280	2009	3262	5229	9646	19174	44560
		Object-to-Mouth	1	3493	5519	9013	14830	23230	39140	80109
			2	1734	2723	4423	7108	12832	25063	57145
			2.3	1508	2366	3842	6160	11362	22587	52491
		Hand-to-Mouth	1	107	169	277	455	713	1202	2459
			2	53	84	136	218	394	769	1754
			2.3	46	73	118	189	349	693	1611
		Soil Ingestion	1	14369	22706	37079	61007	95562	161015	329554
			2	7135	11201	18195	29239	52788	103106	235082
			2.3	6202	9734	15806	25341	46742	92918	215936
		Inhalation	1	58	71	86	108	155	232	409
			2	33	41	52	69	110	182	349
			2.3	31	39	49	65	107	178	345
		Aggregated MOE (Dermal, Oral & Inhalation Routes)	1	37	49	65	86	126	192	347
			2	20	27	37	51	85	145	287
			2.3	18	25	34	48	80	140	280

Table 46. MOEs for Children (1-2 years old) Associated with Spray Drift at Various Distances from a Field Treated with CPF Using Ground Boom

Scenarios	Swaths (Percentile)	Exposure Route	Appl. Rate (lb/acre)	MOE at Various Distance Downwind from the Treated Fields						
				25 (feet)	50 (feet)	75 (feet)	100 (feet)	150 (feet)	200 (feet)	250 (feet)
High Boom	40 (50^{th})	Dermal	1	76596	115503	154823	196667	269506	346508	428039
			2	38298	57751	77411	98333	134753	173254	214019
			4	19149	28876	38706	49167	67377	86627	107010
			6	12766	19250	25804	32778	44918	57751	71340
		Object-to-Mouth	1	90229	136059	182377	231668	317471	408177	504218
			2	45114	68029	91188	115834	158735	204088	252109
			4	22557	34015	45594	57917	79368	102044	126055
			6	15038	22676	30396	38611	52912	68029	84036
		Hand-to-Mouth	1	2770	4177	5599	7112	9746	12531	15479
			2	1385	2088	2799	3556	4873	6265	7739
			4	692	1044	1400	1778	2436	3133	3870
			6	462	696	933	1185	1624	2088	2580
		Soil Ingestion	1	371182	559719	750261	953035	1306011	1679156	2074252
			2	185591	279859	375131	476517	653005	839578	1037126
			4	92795	139930	187565	238259	326503	419789	518563
			6	61864	93286	125044	158839	217668	279859	345709
		Inhalation	1	81	90	99	108	122	135	147
			2	48	54	61	68	79	90	100
			4	30	34	40	45	55	65	75
			6	23	27	32	36	47	57	68
		Aggregated MOE (Dermal, Oral & Inhalation Routes)	1	79	88	97	106	121	134	146
			2	46	53	60	66	78	88	99
			4	29	33	39	44	54	63	74
			6	22	26	30	35	45	56	66
High Boom	40 (90^{th})	Dermal	1	53901	75017	97022	121278	161704	202130	242555
			2	26951	37509	48511	60639	80852	101065	121278

Scenarios	Swaths (Percentile)	Exposure Route	Appl. Rate (lb/acre)	MOE at Various Distance Downwind from the Treated Fields						
				25 (feet)	50 (feet)	75 (feet)	100 (feet)	150 (feet)	200 (feet)	250 (feet)
			4	13475	18754	24256	30319	40426	50532	60639
			6	8984	12503	16170	20213	26951	33688	40426
		Object-to-Mouth	1	63494	88368	114289	142862	190482	238103	285724
			2	31747	44184	57145	71431	95241	119052	142862
			4	15874	22092	28572	35715	47621	59526	71431
			6	10582	14728	19048	23810	31747	39684	47621
		Hand-to-Mouth	1	1949	2713	3509	4386	5848	7309	8771
			2	975	1356	1754	2193	2924	3655	4386
			4	487	678	877	1096	1462	1827	2193
			6	325	452	585	731	975	1218	1462
		Soil Ingestion	1	261202	363529	470164	587705	783606	979508	1175410
			2	130601	181764	235082	293852	391803	489754	587705
			4	65301	90882	117541	146926	195902	244877	293852
			6	43534	60588	78361	97951	130601	163251	195902
		Inhalation	1	81	90	99	108	122	135	147
			2	48	54	61	68	79	90	100
			4	30	34	40	45	55	65	75
			6	23	27	32	36	47	57	68
		Aggregated MOE (Dermal, Oral & Inhalation Routes)	1	78	87	96	105	120	133	145
			2	46	52	59	66	77	87	98
			4	28	33	38	43	53	62	73
			6	21	25	30	35	44	54	65

Table 47. MOEs for Children (1-2 years old) Associated with Spray Drift at Various Distances from a Field Treated with CPF Using Low Boom Ground Boom

Scenarios	Swaths (Percentile)	Exposure Route	Appl. Rate (lb/acre)	MOE at Various Distance Downwind from the Treated Fields						
				25 (feet)	50 (feet)	75 (feet)	100 (feet)	150 (feet)	200 (feet)	250 (feet)
Low Boom	40 (50^{th})	Dermal	1	145533	214019	279872	363833	485111	606389	727666
			2	72767	107010	139936	181917	242555	303194	363833
			4	36383	53505	69968	90958	121278	151597	181917
			6	24256	35670	46645	60639	80852	101065	121278
		Object-to-Mouth	1	171434	252109	329681	428585	571447	714309	857171
			2	85717	126055	164841	214293	285724	357155	428585
			4	42859	63027	82420	107146	142862	178577	214293
			6	28572	42018	54947	71431	95241	119052	142862
		Hand-to-Mouth	1	5263	7739	10121	13157	17543	21928	26314
			2	2631	3870	5060	6579	8771	10964	13157
			4	1316	1935	2530	3289	4386	5482	6579
			6	877	1290	1687	2193	2924	3655	4386
		Soil Ingestion	1	705246	1037126	1356242	1763114	2350819	2938524	3526229
			2	352623	518563	678121	881557	1175410	1469262	1763114
			4	176311	259282	339060	440779	587705	734631	881557
			6	117541	172854	226040	293852	391803	489754	587705
		Inhalation	1	81	90	99	108	122	135	147
			2	48	54	61	68	79	90	100

Scenarios	Swaths (Percentile)	Exposure Route	Appl. Rate (lb/acre)	MOE at Various Distance Downwind from the Treated Fields						
				25 (feet)	50 (feet)	75 (feet)	100 (feet)	150 (feet)	200 (feet)	250 (feet)
			4	30	34	40	45	55	65	75
			6	23	27	32	36	47	57	68
		Aggregated MOE (Dermal, Oral & Inhalation Routes)	1	80	89	98	107	122	134	146
			2	47	53	61	67	78	89	99
			4	29	34	39	44	54	64	74
			6	22	26	31	36	46	56	67
Low Boom	40 (90th)	Dermal	1	85608	117366	151597	186581	250919	303194	363833
			2	42804	58683	75799	93291	125460	151597	181917
			4	21402	29341	37899	46645	62730	75799	90958
			6	14268	19561	25266	31097	41820	50532	60639
		Object-to-Mouth	1	100844	138253	178577	219787	295576	357155	428585
			2	50422	69127	89289	109894	147788	178577	214293
			4	25211	34563	44644	54947	73894	89289	107146
			6	16807	23042	29763	36631	49263	59526	71431
		Hand-to-Mouth	1	3096	4244	5482	6747	9074	10964	13157
			2	1548	2122	2741	3374	4537	5482	6579
			4	774	1061	1371	1687	2268	2741	3289
			6	516	707	914	1125	1512	1827	2193
		Soil Ingestion	1	414850	568747	734631	904161	1215941	1469262	1763114
			2	207425	284373	367315	452081	607970	734631	881557
			4	103713	142187	183658	226040	303985	367315	440779
			6	69142	94791	122438	150694	202657	244877	293852
		Inhalation	1	81	90	99	108	122	135	147
			2	48	54	61	68	79	90	100
			4	30	34	40	45	55	65	75
			6	23	27	27	36	27	27	68
		Aggregated MOE (Dermal, Oral & Inhalation Routes)	1	79	88	97	106	121	134	145
			2	47	53	60	66	78	88	98
			4	29	33	39	44	54	63	73
			6	22	26	30	35	45	55	66

Table 48. MOEs for Children (1-2 years old) Associated with Spray Drift at Various Distances from a Field Treated with CPF Using Airblast

Scenarios	Swaths	Exposure Route	Appl. Rate (lb/acre)	MOE at Various Distance Downwind from the Treated Fields						
				25 (feet)	50 (feet)	75 (feet)	100 (feet)	150 (feet)	200 (feet)	250 (feet)
Dormant Apples	60	Dermal	1	13147	34552	70442	123964	293414	555470	921096
			2	6573	17276	35221	61982	146707	277735	460548
			4	3287	8638	17611	30991	73353	138868	230274
			6	2191	5759	11740	20661	48902	92578	153516
		Object-to-Mouth	1	15486	40701	82979	146026	345633	654329	1085027
			2	7743	20351	41489	73013	172817	327164	542513
			4	3872	10175	20745	36506	86408	163582	271257
			6	2581	6784	13830	24338	57606	109055	180838
		Hand-to-	1	475	1249	2547	4483	10611	20087	33309

Scenarios	Swaths	Exposure Route	Appl. Rate (lb/acre)	MOE at Various Distance Downwind from the Treated Fields						
				25 (feet)	50 (feet)	75 (feet)	100 (feet)	150 (feet)	200 (feet)	250 (feet)
		Mouth	2	238	625	1274	2241	5305	10044	16655
			4	119	312	637	1121	2653	5022	8327
			6	79	208	425	747	1768	3348	5552
		Soil Ingestion	1	63708	167437	341358	600720	1421866	2691777	4463580
			2	31854	83719	170679	300360	710933	1345889	2231790
			4	15927	41859	85340	150180	355467	672944	1115895
			6	10618	27906	56893	100120	236978	448630	743930
		Inhalation	1	81	90	99	108	122	135	147
			2	48	54	61	68	79	90	100
			4	30	34	40	45	55	65	75
			6	23	27	32	36	47	57	68
		Aggregated MOE (Dermal, Oral & Inhalation Routes)	1	69	83	95	105	121	134	147
			2	39	50	58	66	78	89	99
			4	23	31	37	43	54	64	75
			6	17	24	29	35	45	56	67
Sparse Orchard	60	Dermal	1	16214	35600	63386	99272	195085	323407	481898
			2	8107	17800	31693	49636	97542	161704	240949
			4	4053	8900	15846	24818	48771	80852	120475
			6	2702	5933	10564	16545	32514	53901	80316
		Object-to-Mouth	1	19099	41936	74666	116940	229805	380965	567663
			2	9550	20968	37333	58470	114902	190482	283831
			4	4775	10484	18667	29235	57451	95241	141916
			6	3183	6989	12444	19490	38301	63494	94610
		Hand-to-Mouth	1	586	1287	2292	3590	7055	11695	17427
			2	293	644	1146	1795	3527	5848	8713
			4	147	322	573	897	1764	2924	4357
			6	98	215	382	598	1176	1949	2904
		Soil Ingestion	1	78570	172516	307163	481068	945370	1567213	2335251
			2	39285	86258	153581	240534	472685	783606	1167625
			4	19643	43129	76791	120267	236342	391803	583813
			6	13095	28753	51194	80178	157562	261202	389208
		Inhalation	1	81	90	99	108	122	135	147
			2	48	54	61	68	79	90	100
			4	30	34	40	45	55	65	75
			6	23	27	32	36	47	57	68
		Aggregated MOE (Dermal, Oral & Inhalation Routes)	1	71	84	95	104	120	134	146
			2	41	50	58	65	77	88	99
			4	24	31	37	43	53	63	74
			6	18	24	29	34	45	55	66

V.C. Comparison of Spray Drift Exposure Assessment modeling for CPF with US EPA

Both US EPA and HHA produced the CPF horizontal deposition estimates using computer simulation models. Inputs for some scenarios modeled were similar. For other scenarios, the

inputs were quite different. Details about the models, the modeling process, and estimates that this risk assessment produced can be found in Appendix 2 (Barry, 2017).

V.C.1. Orchard Airblast and Ground Boom

For orchard airblast and ground boom downwind deposition, this exposure assessment used AgDRIFT 2.0.05 because we did not have access to AgDRIFT 2.1.1 regulatory version before the analysis was completed. For orchard airblast and ground boom, AgDRIFT 2.0.05 yielded results identical to AgDRIFT 2.1.1 regulatory. This is expected because the empirical models that produce the orchard airblast and ground boom results have not changed since the earliest versions of AgDRIFT following the expert panel review in the mid-1990s.

V.C.1.a. Orchard Airblast

This exposure assessment includes inhalation exposures using surrogate air concentrations from AGDISP model runs for the AT802A aircraft with 2 GPA finished spray. US EPA did not include inhalation in the exposure assessment for orchard airblast. However, with respect to horizontal deposition, US EPA and this exposure assessment for orchard airblast are consistent. The only differences are due to US EPA rounding up to 2 decimal places for the horizontal deposition. US EPA presented only the sparse orchard scenario. This exposure assessment presented sparse orchard and dormant apples. A side-by-side comparison for sparse orchard and 2 lb ai/ac application rate is shown in Table 49.

Table 49. Comparison of 50th Percentile Sparse Orchard Horizontal Deposition (pounds per active ingredient per acre [lb AI/ac] Across a 50 ft Wide Lawn for 20 Swaths and 2 lb AI/ac Application Rate as Estimated Using the AgDRIFT Model

Distance Downwind (ft)	This Exposure Assessment	US EPA
0	*[a]	0.57[b]
10	*	0.16
25	0.0886	0.09
50	0.04	0.04
75	0.022	0.02
100	0.0136	0.01
125	0.009	0.01
150	0.0064	0.01
200	0.0036	0.00
250	0.0022	0.00
300	0.0016	0.00

a- This exposure assessment did not report estimates for empirical model fits between 0 and 25 feet because no field measurements were made within that distance range. The empirical model fit starts at 25 ft downwind of the treated field.

b- These horizontal deposition estimates are in error (References: Personal Communication with Charles Peck; (US EPA, 2014a)).

V.C.1.b. Ground Boom

This exposure assessment includes inhalation exposures using surrogate air concentrations from AGDISP model runs for the AT802A aircraft with 2 GPA finished spray. US EPA did not include inhalation in the exposure assessment for ground boom. With respect to the inputs for

horizontal deposition estimation, US EPA and this exposure assessment for ground boom are consistent. Both used the same AgDRIFT Fine to Medium/Coarse droplet spectra category for low and high boom applications. However, US EPA reported the 90th percentile estimates. This exposure assessment reported the 50th percentile estimates because the orchard airblast and aerial are both 50th percentile estimates. The use of the 50th percentile estimate puts ground boom on the same estimation basis as orchard airblast and aerial. Table 50 shows a side-by-side comparison of ground boom horizontal deposition (lb ai/ac) across a 50 ft wide lawn for 20 swaths and 2 lb ai/ac application rate as estimated using the AgDRIFT model.

Table 50. Comparison of Ground Boom Horizontal Deposition (lb AI/ac) across a 50ft Wide Lawn for 20 Swaths and 2 lb AI/ac Application Rate as Estimated Using the AgDRIFT Model

Distance Downwind (ft)	Low Boom[a] 50th Percentile	Low Boom 90th Percentile (US EPA)	High Boom[b] 50th Percentile	High Boom 90th Percentile (US EPA)
0	*[c]	0.46[d]	*	0.54[d]
10	*	0.02	*	0.04
25	0.0094	0.02	0.0184	0.03
50	0.0064	0.01	0.0118	0.02
75	0.0048	0.01	0.009	0.02
100	0.0040	0.01	0.0074	0.01
125	0.0034	0.01	0.0062	0.01
150	0.0030	0.01	0.0054	0.01
200	0.0024	0.00	0.0042	0.01
250	0.0020	0.00	0.0034	0.01
300	0.0018	0.00	0.0028	0.01

a- Low boom height is 20 inches above the target.
b- High boom is 50 inches above the target.
c-This exposure assessment did not report estimates for empirical model fits between 0 and 25 feet because no field measurements were made within that distance range. The empirical model fit starts at 25 ft downwind of the treated field.
d-These horizontal deposition estimates are in error (References: Personal Communication with Charles Peck; (US EPA, 2014a)).

V.C.2. Aerial Application

There are differences between US EPA and this exposure assessment for aerial modeling inputs. Thus, the horizontal deposition and air concentration estimates differ between US EPA and this exposure assessment. The most important difference is that this exposure assessment used AGDISP 8.28 (Teske and Curbishley, 2013) to simulate the aerial application scenarios while US EPA used AgDRIFT 2.1.1 regulatory version. The Tier I aerial default values are shown in the AgDRIFT user's manual (Teske et al., 2002b). For this comparison, the US EPA Tier II modeling inputs will be compared. Table 51 shows the input comparisons for the fixed wing aircraft scenario and follows the format of the tables shown in the AgDRIFT 2.0.05 user's manual (Teske et al., 2002b). The format of the AgDRIFT user's manual does not change with model version and the Tier I default parameter are the same between AgDRIFT 2.0.05 and AgDRIFT 2.2.1. AgDRIFT Tier I inputs are shown for the US EPA inputs, which were not changed by US EPA from the defaults.

Table 51. Details of Aerial Application Inputs for AgDRIFT and AGDISP used by US EPA and this Exposure Assessment

Parameters	DPR AGDISP	US EPA AgDRIFT
Aircraft Model	AT802A	AT401
Weight	11160 lbs	6000 lbs
Wing Semi-span	29 ft	24.5 ft
Flight Speed	144.99 mph	119.99 mph
Release Height	10 ft	10 ft
Number of Nozzles	39	42
Vertical Offset	-0.6601 ft	-1.51 ft
Horizontal Offset	-0.5 ft	-0.83 ft
Boom Span	76.3%	76.32%
Spacing (even)	14 inches	11 inches
ASABE[a] Droplet Spectra Classification	Medium	Tier I Fine to Medium Tier II Medium
Wind Speed at 2 m	10 mph	10 mph
Wind Direction	Perpendicular to Flight Path	Perpendicular to Flight Path
Surface Roughness	0.12 ft (low crops)	0.0246 ft (bare soil)
Stability	Overcast (Neutral)	Overcast (Neutral)
Relative Humidity	20%	50%
Temperature	90 deg F	86 deg F
Specific Gravity	1.0	1.0
Spray Volume Rate	2 gal/ac and 15 gal/ac	2 gal/ac
Application Rate	2 lb/ac[b]	2 lb/ac
Nonvolatile Rate	2 lb/ac	3 lb/ac[c]
Active Solution % of Tank Mix	12%	12%
Additive Solution % of Tank Mix	0%	5%
Nonvolatile Active	12%	12%
Volatile Fraction	0.88	0.83
Nonvolatile Fraction	0.12	0.17
Swath Width	60 ft	60 ft
Swath Displacement	37%	37%
Number of Flight Lines	50	20

a- American Society of Agricultural and Biological Engineers (formerly American Society of Agricultural Engineers [ASAE]); the organization changed its name in 2005.

b- Application rates of 1, 2, 2.3, 4, and 6 lb/ac were simulated at both 2 gal/ac and 15 gal/ac spray volumes. Although 4 and 6 lb/ac are not allowed for aerial application by the current product labels of CPF, these application rates were included in the US EPA analyses (Dawson et al., 2012). The employment of 15 gallons/acre for AGDISP simulation is to evaluate the effect of spray volume on the drift exposure estimates.

c- US EPA indicates in D3399483. Appendix F. CPOSDrift.xlsx: "…DAS Error Correction Comments/Meetings" for this tank mix but there is no accompanying documents to explain the "correction." Not all CPF products are manufactured by a single registrant and therefore, this exposure assessment does not include the 1 lb/ac of non-active ingredient-nonvolatile material in the tank mix. Available at https://www.regulations.gov/document?D=EPA-HQ-OPP-2008-0850-0107

Deposition estimates for 2 lb ai/ac application rate are compared in Table 52 and shown in Figure 12. US EPA AgDRIFT estimates were extended to 1000 ft downwind for comparison to DPR AGDISP estimates. In addition, the US EPA AgDRIFT inputs were used in AGDISP to provide a

comparison of AgDRIFT and AGDISP horizontal deposition estimate for the AT401 aircraft. The AgDRIFT 2.1.1 aerial algorithm does not include an evaporation time-step refinement that was incorporated into AGDISP 8.28 to improve mass accountancy (Per. Comm. Harold Thistle, 2014). AgDRIFT horizontal deposition is higher than AGDISP for the same scenario (AT401 aircraft) due to the lack of the refined evaporation time-step. Thus, for the same inputs, the AgDRIFT model will produce higher horizontal deposition estimates than AGDISP. For the same model (e.g., AGDISP), the horizontal deposition estimates of this exposure assessment are also higher than US EPA for several additional reasons: 1) the AT802A was selected as the California aircraft based on common use in California and higher horizontal deposition estimates, 2) this exposure assessment used 50 swathes to reflect the largest application sizes in California, 3) the meteorological conditions used in this exposure assessment are California specific, and 4) the tank mix fractions are generic. In addition, US EPA used simple multiplication of a base application rate AgDRIFT run to obtain deposition estimates for a variety of application rates. Analysis shown in Barry (2015) indicates that simple multiplication of the horizontal deposition fraction from a base application rate to adjust for desired application rates will not yield the same results as if the AGDISP model is run for each of the desired application rates (Figure 12). The difference is small in the near-field, but increases in the far field. Because of this effect, this exposure assessment did not use the simple multiplication method for the application rate adjustments. Instead, each application rate scenario was simulated. There is also a nonlinear effect of spray volume (gal/ac) on deposition at the same application rate, as illustrated by the effect of a spray volume of 2 gal/ac versus a spray volume of 15 gal/ac on horizontal deposition. As with application rate, the effect is largest in the far field (greater than 300 ft). This exposure assessment included the spray volume analysis as part of the higher application rates scenarios. However, spray volume has an effect at all application rates (Barry, 2017). The AT802A aircraft was used for these simulations. The simulation inputs are shown in Appendix 2.

Table 52. Comparison of Aerial Horizontal Deposition (Fraction of Application Rate) Aross a 50 ft Wide Lawn for 2 lb AI/ac Application Rate as Estimated Using the AgDRIFT and AGDISP Models

Downwind Distance (ft)	US EPA AgDRIFT 2 gal/ac 20 swath AT401 Tier I	US EPA AgDRIFT 2 gal/ac 20 swath AT401 Tier II	US EPA AGDISP 2 gal/ac 20 swath AT401	DPR AGDISP 2 gal/ac 50 swath AT802A	DPR AGDISP 15 gal/ac 50 swath AT802A
10	0.20	0.1800	0.1374	0.1929	0.1859
25	0.17	0.1500	0.1170	0.1640	0.1580
50	0.13	0.1100	0.0914	0.1286	0.1240
75	0.10	0.0800	0.0742	0.1034	0.0955
100	0.08	0.0700	0.0627	0.0859	0.0833
125	0.06	0.0500	0.0546	0.0739	0.0717
150	0.05	0.0500	0.0483	0.0652	0.0634
200	0.04	0.0400	0.0394	0.0524	0.0515
250	0.03	0.0300	0.0327	0.0430	0.0435
300	0.03	0.0300	0.0275	0.0365	0.0387
500	0.02	0.0154	0.0155	0.0234	0.0286
1000	*[1]	0.0048	0.0054	0.0092	0.0203

[1]AgDRIFT Tier I does not estimate to 1000 ft.

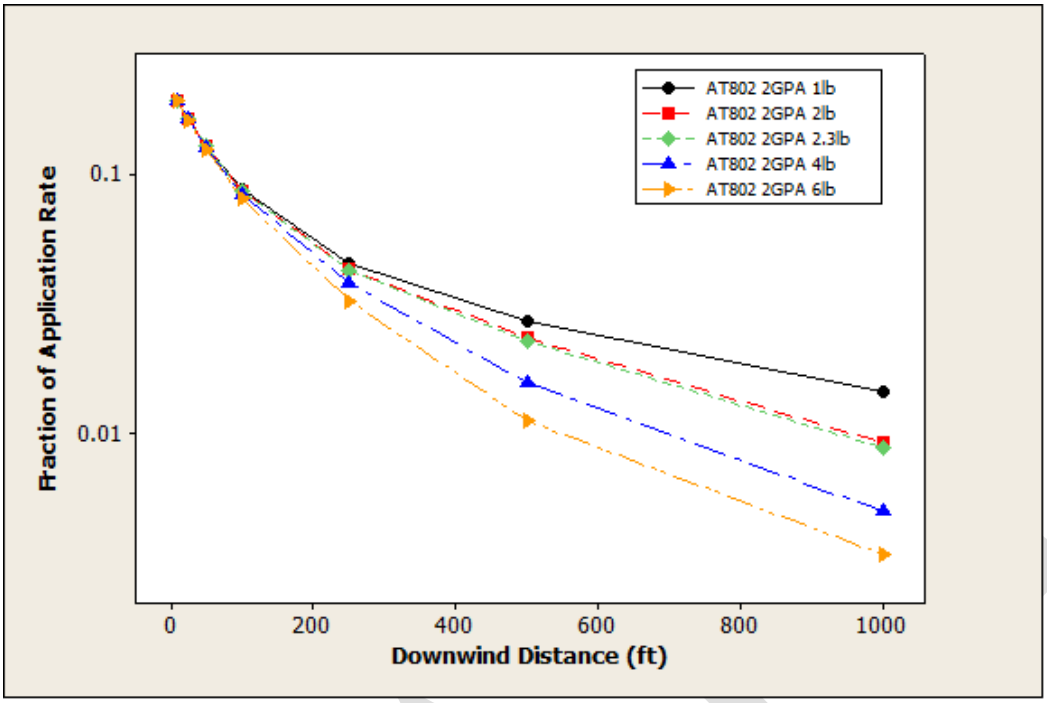

Figure 12. Effect of Application Rate on Aerial Application Downwind Horizontal Deposition Expresses as a Fraction of Application Rate

V.D. House Dust Risk Characterization

The short-term absorbed daily dose of chlorpyrifos via house dust is estimated to be 0.048 µg/kg/day in infant (i.e., <1 yr old). Comparing the estimated dose to an acute oral PoD (steady state) of 103 µg/kg/day for infants (US EPA, 2014a), the MOE of chlorpyrifos exposure due to house dust is 2146. Based on the results presented, chlorpyrifos exposure from house dust would not constitute more than 10% AChE inhibition in infants.

V.E. Dietary Risk Characterization

Dietary risk is characterized by the MOEs (calculation shown below) based on acute and steady-state PoDs for dietary CPF residues in the sensitive population subgroups (all infants <1 year old; children 1-2 years old, children 6-12 years old, and females 13-49 years old). The PoDs, residues, and MOEs for each population subgroup is shown below in Table 51.

V.E.1. Acute and Steady State Dietary (food only) Margins of Exposure

It is evident that using the PoDs from the PBPK-PD model for acute and steady-state oral (dietary: food only) exposures show that MOEs for CPF are all acceptable (Table 53). The MOEs were determined by using the oral acute PoD (aPoD) or the steady-state PoD (ssPoD) for each population subgroup and dividing it by the respective dietary exposures (MOE = aPoD or ssPoD ÷ exposure).

Table 53. Acute and Steady-state Dietary (food only) Exposure and Margins of Exposure for CPF

ACUTE DIETARY EXPOSURE[a]							
Population Subgroup	aPoD[b, c] (mg/kg)	95th Percentile		99th Percentile		99.9th Percentile	
		Exposure (mg/kg/d)	MOE[d]	Exposure (mg/kg/d)	MOE[d]	Exposure (mg/kg/d)	MOE[d]
All Infants:< 1 yr	0.600	0.000050	12,000	0.000088	6,818	0.000273	2,198
Children: 1-2 yrs	0.581	0.000082	7,085	0.000143	4,063	0.000423	1,374
Children: 6-12 yrs	0.530	0.000040	13,250	0.000072	7,361	0.000189	2,804
Females: 13-49 yrs	0.469	0.000021	22,333	0.000041	11,439	0.000150	3,127
STEADY STATE (21-DAY) DIETARY EXPOSURE[a]							
Population Subgroup	**ssPoD[b, e] (mg/kg)**	**70th Percentile**		**95th Percentile**		**99.9th Percentile**	
		Max. Exposure (mg/kg)	**MOE[d]**	**Exposure (mg/kg/d)**	**MOE[d]**	**Exposure (mg/kg/d)**	**MOE[d]**
All Infants:< 1 yr	0.103	0.000020	5,150	0.000045	2,289	0.000186	554
Children: 1-2 yrs	0.099	0.000038	2,605	0.000072	1,375	0.000242	409
Children: 6-12 yrs	0.090	0.000019	4,737	0.000039	2,308	0.000128	703
Females: 13-49 yrs	0.078	0.000009	8,667	0.000018	4,333	0.000075	1,040

a- Exposures are from the US EPA dietary exposure assessment to support registration review (US EPA, 2014b)
b- Point of Departures are PBPK-PD-estimated human equivalent doses
c- aPoD = acute point of departure
d- Margin of Exposure (MOE) = PoD ÷ Dietary Exposure. Target MOE is 100 for every population.
e- ssPoD = steady-state (21 day) point of departure

V.E.2. Drinking Water Exposure

V.E.2.a. Acute Drinking Water Margins of Exposure

It was necessary to perform a conversion from CPF to CPF-oxon values. Acute CPF PoDs from PBPK-PD modeling of dietary (food only) exposures were selected since they were the highest and because exposure to dietary residues is usually one event rather than continuous. As shown in Table 54, the CPF-oxon (ppb), water concentration (L) and body weights obtained from the US EPA 2014 Revised Human Health Risk Assessment were used to calculate the CPF-oxon PoD (µg/kg/d) (e.g., [CPF-oxon PoD (ppb) x water concentration (L)] ÷ body weight (kg) = CPF-oxon PoD µg/kg/d) (US EPA, 2014a). The ratio (Total Equivalent Residue: TEF) of CPF-oxon µg/kg/d to CPF µg/kg/d PoD yielded similar values among all population subgroups. Infants (<1 year old) and children (1-2 years old) had similar PoDs for CPF-oxon and similar TEFs (Table 54). The MOEs were calculated as follows: MOE_{DW} = (CPF-oxon PoD ÷ $DW_{PDP\ or\ EMON}$ Residue). DW MOEs indicate that there is no risk from drinking water exposure in California based on both PDP and EMON data.

Table 54. Acute CPF to CPF-Oxon Conversion for Drinking Water Residue Assessment

Population Subgroup	CPF-oxon PoD (ppb)	Water Cons. (L)	Body Weight (kg)[a]	CPF-Oxon PoD mg/kg/d	CPF PoD mg/kg/d	TEF[b]
Infants < 1 yr	1,183	0.688	4.8	0.170	0.600	3.53
Children 1-2 yrs	3,004	0.688	13	0.159	0.581	3.65
Children 6-12 yrs	7,700	0.688	37.1	0.143	0.530	3.71
Youth 13-19 yrs	4,988	1.71	67.31	0.127	0.475	3.74
Adult Females	5,285	1.71	70	0.129	0.467	3.62

a- Body weights were from US EPA (2014a)
b- TEF: Total Equivalent Residue calculated as the Ratio CPF-oxon PoD to CPF PoD.
c- MOE calculations: CPF-oxon PoD ÷ $DW_{PDP\ or\ EMON}$ Residue
Highlighted are populations of concern for spray drift and aggregate exposure and risk characterization.

V.E.2.b. Risk Characterization of the Drinking Water Exposure:

Table 55 shows acute MOEs for exposure to CPF-oxon in drinking water for the four sentinel populations based on the drinking water residue data from PDP and DPR surface and ground water residues. The MOEs were highest for PDP (18,856 – 47,636) and lowest for surface water (405 – 1,299). All MOEs for acute water-only exposure were greater than the target of 100.

Monitoring and modeling data were not available to estimate the steady-state (21-day) exposure to CPF-oxon in drinking water. If acute exposure estimates are compared to steady-state PoDs, the resulting MOEs would be lower than those shown in Table 55. However, lack of residue data precludes a steady-state drinking water assessment at this time.

Table 55. Acute Exposure Estimates and MOEs for CPF-oxon in Drinking Water; Surface and Ground Water

Acute Exposure Estimates for CPF-Oxon in Drinking Water Based on 2001-2013 PDP Residue Data						
Population Subgroup	Exposure (mg/kg/d)[a]			MOE[b]		
	95th	99th	99.9th	95th	99th	99.9th
All Infants (< 1 year old)	0.000004	0.000061	0.000108	42425	2782	1571
Children 1-2 years old	0.000002	0.000025	0.000057	79555	6364	2791
Children 6-12 years old	0.000002	0.000015	0.000036	71454	9527	3970
Females 13-49 years old	0.000001	0.000017	0.000036	129152	7597	3588
Acute Exposure Estimates for CPF-Oxon in Drinking Water Based on 2005-2014 Surface Water Residue Data						
Population Subgroup	Exposure (mg/kg/d)[a]			MOE[b]		
	95th	99th	99.9th	95th	99th	99.9th
All Infants (< 1 year old)	0.000008	0.000049	0.000419	19875	3469	406
Children 1-2 years old	0.000004	0.000023	0.000177	39750	6913	898
Children 6-12 years old	0.000002	0.000014	0.00011	71500	10214	1300
Females 13-49 years old	0.000002	0.000015	0.000119	63500	8467	1067
Acute Exposure Estimates for CPF-Oxon in Drinking Water Based on 2004-2013 Ground Water Residue Data						
Population Subgroup	Exposure (mg/kg/d)[a]			MOE[b]		
	95th	99th	99.9th	95th	99th	99.9th
All Infants (< 1 year old)	0.000018	0.000127	0.000222	9444	1339	766
Children 1-2 years old	0.000012	0.000054	0.000115	13250	2944	1478
Children 6-12 years old	0.000008	0.000031	0.000075	17875	4613	1907
Females 13-49 years old	0.000009	0.000036	0.000073	14111	3528	1740

a- CPF exposure values were converted to CPF-oxon by applying a molecular weight correction factor (0.9541).
b- MOE calculations: CPF-oxon PoD ÷ DW_{PDP} Residue
Highlighted indicates subgroup with the DW exposure but MOE was within acceptable range.

V.F. Aggregate Exposure: Combined MOEs (Dietary [food only], Drinking Water [PDP or Surface Water], Spray Drift)

When exposure occurs by more than one route and route-specific NOELs are used, a combined MOE for all routes can be calculated. This section is designed to show the acute aggregate MOEs for children (1-2 years old) for all routes (Appendix 2, Table 16) including: combined deposition (CD = dermal + object-to-mouth + hand-to-mouth + soil deposition); inhalation (I), in addition to dietary (D: food only; PoD = 0.581 mg/kg/d; Table 51) and drinking water (CPF-oxon PoD = 0.159 mg/kg/d).

$$\text{Aggregate MOE} = \frac{1}{\frac{1}{MOE_{CD}} + \frac{1}{MOE_{I}} + \frac{1}{MOE_{D}} + \frac{1}{MOE_{DW\ (PDP\ or\ EMON)}}}.$$

Aggregate exposure MOEs include the parameters described above for children (1-2 years old) as well as the acute drinking water PoD for CPF-oxon of 0.159 mg/kg/d and body weight of 13 kg described in the Exposure Assessment, Section IV.

V.F.1. Aggregate MOEs after Aircraft Exposure from Spray Drift (Children 1-2 years old)

Table 56 has the CPF to CPF-oxon conversion values used in the aggregate risk characterizations for spray drift bystander exposure. Table 56 indicates that once the values for inhalation are added, the aggregate MOEs fall below the target of 100. Additional factors that decrease the aggregate MOEs are increased application volume and increased application rate. As these are increased, the distances where aggregate MOEs are below the target of 100 extend to 1000 feet. Inhalation appears to drive the MOEs below the target value for children (1-2 years old).

Table 56. Dermal and Oral MOEs for Children (1-2 years old) at Various Distances Downwind from Fields Treated with CPF by Aircraft or Helicopter

Application Scenario	Appl. Vol. (gal/acre)	Exposure Route	Appl. Rate (lb/acre)	MOE at Various Distances Downwind from the Treated Fields						
				10 feet	25 feet	50 feet	100 feet	250 feet	500 feet	1000 feet
Aircraft or Helicopter (Children 1-2 years old)										
AT802A Fixed Wing Aircraft	2	CD[a]	1	127	149	190	282	541	907	1701
			2	63	75	95	143	285	523	1331
			2.3	55	65	83	124	249	469	1210
		CD + I[b]	1	47	53	61	78	116	166	300
			2	26	29	35	46	74	120	264
			2.3	23	27	32	42	69	113	252
		CD + I + D[c]	1	45	51	58	74	107	148	246
			2	25	29	34	44	70	110	221
			2.3	23	26	31	41	65	105	213
		CD + I + D + DW-PDP[e]	1	45	51	58	74	106	147	244
			2	25	29	34	44	70	110	220
			2.3	23	26	31	41	65	104	211
		CD + I + D + DW-EMON[d]	1	43	48	55	68	95	127	193
			2	25	28	32	42	65	98	178
			2.3	22	25	30	39	61	94	172
Bell 205 Helicopter	2	CD	1	100	158	258	424	664	1118	2289
			2	50	78	126	203	367	716	1633
			2.3	43	68	110	176	325	645	1500
		CD + I	1	37	49	65	86	126	192	347

			2	20	27	37	51	85	145	287
			2.3	18	25	34	48	80	140	280
		CD + I + D	1	36	47	62	81	115	169	277
			2	19	26	36	49	80	131	238
			2.3	18	24	33	46	76	127	233
		CD + I + D + DW-PDP	1	36	47	62	81	115	168	274
			2	19	26	36	49	80	131	236
			2.3	18	24	33	46	76	126	231
		CD + I + D + DW-EMON	1	34	45	58	74	102	142	212
			2	19	26	34	47	73	115	188
			2.3	17	24	32	44	70	111	185
AT802A Fixed Wing Aircraft	15	CD	1	147	174	217	325	633	1021	1368
			2	70	83	103	152	288	452	622
			2.3	61	72	89	131	248	390	538
		CD + I	1	39	43	47	56	73	89	115
			2	22	24	27	32	43	55	75
			2.3	19	21	24	29	39	50	69
		CD + I + D	1	38	42	46	54	69	84	106
			2	21	24	26	32	42	53	71
			2.3	19	21	23	28	38	48	66
		CD + I + D + DW-PDP	1	38	42	46	54	69	83	105
			2	21	24	26	31	42	52	71
			2.3	19	21	23	28	38	48	66
		CD + I + D + DW-EMON	1	37	40	44	51	64	77	95
			2	21	23	25	30	40	50	66
			2.3	19	21	23	28	36	46	61
Bell 205 Helicopter	15	CD	1	107	175	301	519	747	996	1521
			2	52	84	141	238	340	478	790
			2.3	45	72	121	204	294	419	692
		CD + I	1	26	33	40	48	59	76	109
			2	17	21	27	33	42	56	84
			2.3	15	19	24	30	39	52	78
		CD + I + D	1	26	32	39	46	57	72	101
			2	16	21	26	33	41	54	79
			2.3	15	19	24	29	38	50	74
		CD + I + D + DW-PDP	1	26	32	39	46	57	72	100
			2	16	21	26	32	41	54	79
			2.3	15	19	24	29	38	50	74
		CD + I + D + DW-EMON	1	25	31	37	44	54	67	91
			2	16	21	26	31	39	51	73
			2.3	14	18	23	29	36	47	68

Source: US EPA (2014a): Dermal PoD-Steady-state = 134.25 mg/kg/d; For calculations, Dermal Absorption (0-1) = 1; Oral PoD Steady-state: 0.099 mg/kg/d. Target MOE = 100

a- Combined Deposition (CD = Dermal + Object-to-Mouth + Hand-to-Mouth + Soil Ingestion)

b- Combined Deposition (CD = Dermal + Object-to-Mouth + Hand-to-Mouth + Soil Ingestion; inhalation (I))

c- Combined deposition (CD = dermal + object-to-mouth + hand-to-mouth + soil deposition; inhalation (I); dietary (D: food only; PoD = 0.581 mg/kg/d).

d- Combined deposition (CD = dermal + object-to-mouth + hand-to-mouth + soil deposition; inhalation (I); dietary (D: food only; PoD = 0.581 mg/kg/d); drinking Water (CPF-oxon PoD = 0.159 mg/kg/d from DW-PDP or DW-EMON).

V.F.2. Aggregate MOEs after Ground Boom Exposure from Spray Drift (Children 1-2 years old)

Aggregate MOEs for this exposure scenario are below the target of 100 for children (1-2 years old) from 75 feet for dermal plus inhalation at 1 lb/ac to 250 ft for all aggregate exposures at 2 lb/ac, 4 lb/ac, and 6 lb/ac (Table 57).

Table 57. Aggregate MOEs after Ground Boom Exposure from Spray Drift (Children 1-2 years old)

Application Scenario	Appl. Vol. (gallon/acre)	Exposure Route	Appl. Rate (lb/acre)	25 feet	50 feet	75 feet	100 feet	150 feet	200 feet	250 feet
Ground boom (Children 1-2 years old)										
High Boom	40 (50th percentile)	CD[a]	1	2578	3888	5211	6620	9072	11664	14408
			2	1289	1944	2606	3310	4536	5832	7204
			4	645	972	1303	1655	2268	2916	3602
			6	430	648	869	1103	1512	1944	2401
		CD + I[b]	1	79	88	97	106	121	134	146
			2	46	53	60	66	78	88	99
			4	29	33	39	44	54	63	74
			6	22	26	30	35	45	56	66
		CD + I + D[c]	1	74	82	91	98	111	122	132
			2	28	32	38	43	52	60	70
			4	28	32	38	43	52	60	70
			6	21	25	30	34	44	53	63
		CD + D + DW-PDP[d]	1	74	82	91	98	111	121	131
			2	45	51	57	63	73	83	92
			4	28	32	38	42	52	60	70
			6	21	25	30	34	44	53	63
		CD + D + DW-EMON[d]	1	69	76	83	89	99	107	115
			2	43	48	54	59	68	76	83
			4	27	31	36	41	49	57	65
			6	21	25	29	33	42	50	59
Low Boom	40 (50th percentile)	CD	1	4899	7204	9421	12247	16329	20411	24494
			2	2449	3602	4710	6123	8165	10206	12247
			4	1225	1801	2355	3062	4082	5103	6123
			6	816	1201	1570	2041	2722	3402	4082
		CD + I	1	80	89	98	107	122	134	146
			2	47	53	61	67	78	89	99
			4	29	34	39	44	54	64	74
			6	22	26	31	36	46	56	67
		CD + I + D	1	75	83	92	99	112	122	132
			2	46	51	58	64	74	83	93
			4	29	33	38	43	52	61	71
			6	22	26	30	35	44	54	64
		CD + D + DW-PDP	1	75	83	91	99	111	122	132
			2	46	51	58	64	74	83	92
			4	28	33	38	43	52	61	70
			6	22	26	30	35	44	54	64
		CD + D + DW-EMON	1	70	76	83	89	99	108	115
			2	43	49	55	60	68	76	84
			4	28	32	37	41	49	57	65
			6	21	25	29	34	42	51	60
High Boom	40 (90th percentile)	CD	1	1814	2525	3266	4082	5443	6804	8165
			2	907	1263	1633	2041	2722	3402	4082
			4	454	631	816	1021	1361	1701	2041
			6	302	421	544	680	907	1134	1361
		CD + I	1	78	87	96	105	120	133	145
			2	46	52	59	66	77	87	98
			4	28	33	38	43	53	62	73
			6	21	25	30	35	44	54	65
		CD + I + D	1	74	82	90	98	110	121	131
			2	44	50	57	63	73	82	91
			4	27	32	37	42	51	60	69
			6	21	25	29	34	43	52	62
		CD + D + DW-	1	73	81	90	97	110	121	130

		PDP	2	44	50	57	62	73	82	91
			4	27	32	37	42	51	59	69
			6	21	25	29	34	43	52	62
		CD + D + DW-EMON	1	68	75	82	88	98	107	114
			2	42	47	53	58	67	75	83
			4	27	31	36	40	48	56	64
			6	20	24	28	33	41	49	58
Low Boom	40 (90th percentile)	CD	1	2882	3951	5103	6280	8446	10206	12247
			2	1441	1975	2551	3140	4223	5103	6123
			4	720	988	1276	1570	2112	2551	3062
			6	480	658	850	1047	1408	1701	2041
		CD + I	1	79	88	97	106	121	134	145
			2	47	53	60	66	78	88	98
			4	29	33	39	44	54	63	73
			6	22	26	30	35	45	55	66
		CD + I + D	1	75	83	91	98	111	122	132
			2	45	51	57	63	73	83	92
			4	28	32	38	42	52	60	70
			6	21	25	30	34	44	53	63
		CD + D + DW-PDP	1	74	82	91	98	111	121	131
			2	45	51	57	63	73	83	92
			4	28	32	38	42	51	60	70
			6	21	25	30	34	44	53	63
		CD + D + DW-EMON	1	69	76	83	89	99	107	115
			2	43	48	54	59	68	76	83
			4	27	31	36	41	49	56	65
			6	21	25	29	33	42	50	59

Source: US EPA (2014a): Dermal PoD-Steady-state = 134.25 mg/kg/d; For calculations, Dermal Absorption (0-1) = 1; Oral PoD Steady-state: 0.099 mg/kg/d. Target MOE = 100

a- Combined Deposition (CD = Dermal + Object-to-Mouth + Hand-to-Mouth + Soil Ingestion)

b- Combined Deposition (CD = Dermal + Object-to-Mouth + Hand-to-Mouth + Soil Ingestion; inhalation (I))

c- Combined deposition (CD = dermal + object-to-mouth + hand-to-mouth + soil deposition; inhalation (I); dietary (D: food only; PoD = 0.581 mg/kg/d).

d- Combined deposition (CD = dermal + object-to-mouth + hand-to-mouth + soil deposition; inhalation (I); dietary (D: food only; PoD = 0.581 mg/kg/d); drinking Water (CPF-oxon PoD = 0.159 mg/kg/d from DW-PDP or DW-EMON).

V.F.3. Aggregate MOEs after Orchard Airblast Exposure from Spray Drift (Children 1-2 years old)

Both orchard airblast scenarios show that dermal MOES are below 100 only at the highest application rates (lb/acre). When inhalation is added the aggregate MOEs are below 100 at 75 ft for 1 lb/ac and at 250 ft for all other application rates (Table 58).

Table 58. Dermal and Oral MOEs for Children (1-2 years old) at Various Distances Downwind from Fields Treated with CPF by Orchard Airblast

Application Scenario	Appl. Vol. (gallon/acre)	Exposure Route	Appl. Rate (lb/acre)	25 feet	50 feet	75 feet	100 feet	150 feet	200 feet	250 feet
Orchard Airblast (Children 1-2 years old)										
Dormant Apples	60	CD[b]	1	443	1163	2371	4173	9876	18697	31005
			2	221	582	1186	2086	4938	9349	15502
			4	111	291	593	1043	2469	4674	7751
			6	74	194	395	695	1646	3116	5167
		CD + I[c]	1	69	83	95	105	121	134	147
			2	39	50	58	66	78	89	99
			4	23	31	37	43	54	64	75
			6	17	24	29	35	45	56	67
		CD + I + D[d]	1	65	79	89	98	111	122	132
			2	38	48	56	63	74	83	93
			4	23	30	36	42	52	61	71
			6	17	23	29	34	44	54	64
		CD + D + DW-PDP[e]	1	78	89	97	111	122	132	141
			2	38	48	56	62	73	83	92
			4	23	30	36	42	52	61	71
			6	17	23	29	34	44	54	64
		CD + D + DW-EMON[e]	1	61	72	81	88	99	108	115
			2	37	45	53	59	68	76	84
			4	23	29	35	40	49	57	66
			6	17	23	28	33	42	51	60
Sparse Orchard	60	CD	1	546	1198	2134	3342	6567	10886	16221
			2	273	599	1067	1671	3283	5443	8111
			4	136	300	533	835	1642	2722	4055
			6	91	200	356	557	1094	1814	2704
		CD + I	1	71	84	95	104	120	134	146
			2	41	50	58	65	77	88	99
			4	24	31	37	43	53	63	74
			6	18	24	29	34	45	55	66
		CD + I + D	1	67	79	89	97	111	122	132
			2	40	48	56	62	73	83	92
			4	24	30	36	41	51	60	70
			6	18	23	28	33	43	53	63
		CD + D + DW-PDP	1	67	79	88	97	110	121	131
			2	40	48	56	62	73	83	92

			4	24	30	36	41	51	60	70
			6	18	23	28	33	43	53	63
		CD + D + DW-EMON	1	63	72	81	88	98	107	115
			2	38	46	52	58	68	76	84
			4	23	29	35	40	48	57	65
			6	18	23	27	32	41	50	59

Source: US EPA (2014a): Dermal PoD-Steady-state = 134.25 mg/kg/d; For calculations, Dermal Absorption (0-1) = 1; Oral PoD Steady-state: 0.099 mg/kg/d. Target MOE = 100

a- Combined Deposition (CD = Dermal + Object-to-Mouth + Hand-to-Mouth + Soil Ingestion)

b- Combined Deposition (CD = Dermal + Object-to-Mouth + Hand-to-Mouth + Soil Ingestion; inhalation (I))

c- Combined deposition (CD = dermal + object-to-mouth + hand-to-mouth + soil deposition; inhalation (I); dietary (D: food only; PoD = 0.581 mg/kg/d).

d- Combined deposition (CD = dermal + object-to-mouth + hand-to-mouth + soil deposition; inhalation (I); dietary (D: food only; PoD = 0.581 mg/kg/d); drinking Water (CPF-oxon PoD = 0.159 mg/kg/d from DW-PDP or DW-EMON).

VI. RISK APPRAISAL

VI.A. Introduction

The risk assessment reported here evaluated the dietary, spray-drift, and aggregate risks that accompany exposure to chlorpyrifos. Every risk assessment has inherent limitations with the application of existing data to estimate potential risk to human health. Therefore, certain assumptions and extrapolations are incorporated into the hazard identification, dose-response assessment, and exposure assessment processes. These, in turn, result in uncertainty in the risk characterization which integrates all the information from the previous three processes. Qualitatively, risk assessments for all chemicals have similar uncertainties. However, the degree or magnitude of the uncertainty can vary depending on the availability and quality of the data, and the types of exposure scenarios being assessed. Specific areas of uncertainty associated with this risk assessment for chlorpyrifos are delineated in the following discussion.

Studies on potential adverse effects after acute, subchronic or chronic oral, dermal or inhalation exposure in animals have focused on ChE inhibition in plasma, RBCs, and the brain. Controlled dosing studies that measured RBC and plasma ChE in humans are available (Eaton et al., 2008). RBC AChE inhibition is commonly used as a surrogate of cholinesterase inhibition in target tissues in the central and peripheral nervous system (Furman, 2010; US EPA, 2014a). A 10% inhibition is the lowest level of cholinesterase inhibition which can be reliably measured. For this risk assessment, the PBPK-PD model which incorporates human data was used to estimate PoDs based on 10% RBC AChE inhibition. Other potentially noncholinergic effects and uncertainties in using the PBPK-PD model are discussed below.

VI.B. Uncertainties Associated with the Hazard Identification

VI.B.1. The PBPK-PD Model

HHA adopted the critical PoDs for CPF from the 2014 US EPA revised human health assessment. The PBPK-PD model was used to estimate these values for10% RBC AChE inhibition in various human populations, durations and routes. This model has been in development for the last 15 years and has undergone numerous scientific evaluations (US EPA/SAP, 2008; US EPA/SAP, 2010; US EPA/SAP, 2012; US EPA, 2014a)as well as publications (Timchalk et al., 2002a; Timchalk et al., 2002b; Timchalk et al., 2005; Timchalk et al., 2006; Timchalk and Poet, 2008; Smith et al., 2011; Poet et al., 2014; Smith et al., 2014; Poet et al., 2017a). The discussion below focuses mainly on the uncertainties with the model used by US EPA in 2014 (US EPA, 2014a), however, predictions by the updated 2017 model (Poet et al., 2017a) are included for comparison when appropriate.

The PBPK-PD model is based on the pharmacokinetics of CPF in two human dosing studies and a human dermal dosing study. Human liver microsomes and plasma were used to represent CPF metabolic variability across a broad range of ages (Nolan et al., 1984; Smith et al., 2011; Poet et al., 2014; Smith et al., 2014; US EPA, 2014a; Poet et al., 2017a).

The model predicts a time-course of CPF metabolism and RBC AChE inhibition, reactivation, and regeneration after oral, dermal, and inhalation exposure to CPF. It has been reviewed and validated with human data since publication of the original PBPK model (Timchalk et al., 2002b). One of the main advantages of this model is the availability of human volunteer dosing studies (Nolan et al., 1984; Vaccaro et al., 1993; Kisicki et al., 1999) and sources of well-characterized human tissues (Smith et al., 2011). The model incorporates life-stages for infants (6 months), children (3-year-olds), and adults (30 year olds) as well as pregnancy parameters (Smith et al., 2011; Smith et al., 2014; Poet et al., 2017) and multi-route human exposure parameters (oral, dermal and inhalation) (Poet et al., 2014). The 2017 updated model includes sensitivity analyses for each of the 120-160 parameters to determine those that drive the greatest variability within the model (e.g. chlorpyrifos activation and deactivation reactions) as well as uncertainty calculations (Poet et al., 2017a).

VI.B.1.a. Acute Oral PoDs from the PBPK-PD Model

The PBPK-derived acute oral PoDs ranged from 0.5-0.6 mg/kg/day for the evaluated population subgroups including infants, children and women of childbearing age. HHA used these values to characterize the human risk to CPF from acute exposure from food and drinking water. These PoDs were similar to the acute NOELs established in the available animal studies (0.4-0.5 mg/kg/day) for RBC AChE inhibition. The overall database for chlorpyrifos generally shows that the threshold dose for RBC AChE inhibition is around 1 mg/kg/day, including that for young rats.

VI.B.1.b. Steady-State Oral PoDs from the PBPK-PD Model

Separate subchronic and chronic oral PoDs were not specifically calculated in the PBPK-PD model reported in the current US EPA (2014a) IRED. Instead the model generated a 21-day steady-state oral PoD for 10% RBC AChE inhibition in humans. Repeated exposures result in a balance between inhibition and generation of new AChE. Studies of 14-21 day durations show AChE inhibition to the same degree as those of longer duration (US EPA, 2014a). The model-derived steady state human PoDs were in the range of the NOELs from repeated dosing from several weeks to 2 years (0.03-0.05 mg/kg/day) in animal studies.

VI.B.1.c. Steady-State Dermal, Non-Dietary Ingestion and Inhalation PoDs from the PBPK-PD Model

PoDs for steady-state dermal, non-dietary ingestion and inhalation exposures were adopted from the PBPK-PD model presented by US EPA (2014b). The US EPA model was based on the level of RBC ChE inhibition in humans achieved at or before 21 days of daily inhalation exposure. These values were used to calculate risks to children and females of childbearing age from spray drift near application sites, as well as risks associated from aggregate exposures.

Spray drift exposure is of short-term duration (1 – 1.5 hours) for which acute PoDs would normally be used to estimate relevant risks. However, this practice may underestimate risks to individuals residing in areas of high CPF use because acute PoDs do not by themselves account for the elevated level of AChE inhibition already present in such populations. Indeed, enzyme activities in children residing in high CPF use areas are decreased by about 30% compared to

children who live in non- or low-use agricultural areas. This is evident in a study by Kapka-Skrzypczak et al. (2015) who compared RBC AChE levels (adjusted for hemoglobin concentration, Hb) in a group of Polish children (8-12 years old) living in a high pesticide use area versus matched children in a lower pesticide use area. The study did not specify the pesticides involved however at least one AChE inhibiting pesticide was detected in sweat sorbents from the children.

AChE (mU/µmol Hb)			
n (sex)	**mean**	**SD**	**CV (%)**
Exposed			
49 (M)	243.40	28.17	11.6
59 (F)	240.02	25.52	10.6
Controls			
47 (M)	349.59	50.19	14.4
45 (F)	346.91	44.29	12.8

In addition, Suarez-Lopez et al. (2013) made a similar observation in children who lived with a household member who worked at a flower plantation but lived at varying distances from the plantations. This study also did not specify the pesticides involved.

AChE (U/ml)			
1st Tertile:			
67% cohabited with flower worker, 360m avg distance to flower plantation			
n (sex)	**mean**	**SD**	**CV (%)**
104 (M/F)	2.63	0.27	10.3
3rd Tertile:			
45% cohabited with flower worker, 501m avg distance to flower plantation			
n (sex)	**mean**	**SD**	**CV (%)**
102 (M/F)	3.67	0.29	7.9

Therefore, when evaluating the risk from short term exposures in the presence of concurrent background levels of inhibition likely to occur in populations from areas of high CPF use, we considered three factors to be critical: (1) AChE inhibition sustained by constant exposure is cumulative; (2) Complete recovery of enzyme activity in humans is not achieved even after 10 days of non-exposure; and (3) AChE inhibition in laboratory animals subjected to repeated doses of CPF reaches steady state levels after ~2-3 weeks of exposure. In this light, we concluded that the effect produced from short term drift exposures would be most prudently characterized by a PoD derived from repeated (21-day) dosing.

VI.C. Uncertainties Related to Exposure Assessment

VI.C.1. Acute CPF Spray Drift Exposure Uncertainty

This exposure assessment employed state-of-the-art computer models (AgDRIFT and AGDISP) coupled with the latest version of the US EPA Residential Exposure Assessment Standard Operating Procedures for characterizing the non-occupational bystanders' exposure to spray drift of CPF. Accordingly, the intrinsic uncertainties associated with these modeling and exposure computational methodologies (e.g., assumptions) will be translated into the bystanders' exposure

estimates of CPF based on the manner in which these computer models and SOPs were applied. The intrinsic uncertainties associated with these computer models and SOPs have been detailed in the original documentations (Teske *et al.*, 2002b; Teske and Curbishley, 2013)US EPA 2012c). Therefore, the focus of the following discussion is to evaluate the uncertainties of exposure estimates based on the approach of which these computer models and exposure computations were performed.

For modeling spray drift, the input parameters were tailored to match the actual field operation and meteorological conditions that are expected to result in the reasonable worst-case horizontal deposition and air concentration estimates under California use conditions (Appendix 2) (Barry, 2017). Hence, these aerial application exposure estimates of CPF can be considered as reasonable worst-case estimates of exposures under California conditions. Unlike the aerial application, the available spray drift computer models are unable to generate air concentrations of CPF associated with ground boom and orchard airblast applications. To account for inhalation exposures in the orchard airblast and ground boom application methods, this exposure assessment used surrogate air concentrations estimates obtained by modeling aerial applications using the AT802A aircraft. These surrogate air concentrations are likely reasonable worst case air concentration estimates for orchard airblast and ground boom. As a point of comparison, the California Air Resources Board (CARB) has conducted two CPF application site air monitoring studies: CARB (2016) and CARB (1998). The CARB (2016) study measured air concentration associated with a helicopter application. The results of the CARB (2016)study are not used for comparison for the following reasons: 1) the sampling method was best suited for collecting vapor so it was not optimal for collecting aerosols that comprised spray drift during an application (further discussed below), 2) the application period sampling interval did not match the actual application time, and 3) the maximum measured air concentration was not collected at the sampler located in the predominant wind direction. CARB (1998)measured air concentrations of CPF during and after an orchard airblast application to an orange orchard in Tulare, CA. This study measured air concentrations during two separate application periods using an air monitoring method best suited for collecting vapor. Spray drift is composed of aerosols and requires a different sampling method to adequately characterize air concentrations (Streicher et al., 1994). Therefore, the CARB (1998)air monitoring results cannot be definitively compared to the AGDISP air concentration estimates, but general observations can be made. The air concentrations in the study were measured over several days, with two application periods sampled. Those two application sampling periods are well described and correctly bracketed the actual application period. Therefore, they are the appropriate periods to compare to the AGDISP estimated air concentrations. The CARB measured air concentrations must be adjusted to the same averaging time as the modeled air concentrations using the peak-to-mean method as described in Barry (2000). The AGDISP model produces 1 hr time weighted average air concentration estimates. The CARB (1998) application sampling interval peak air concentrations adjusted to 1-hr time weighted average concentrations are 0.06 mg/m^3 and 0.08 mg/m^3 for application periods 1 and 2, respectively. These measured values are similar to the AGDISP female 13-49 year old air concentration of 0.06 mg/m^3 at 25 ft and 0.05 mg/m^3 at 50 ft and 1-2 year old child air concentration of 0.08 mg/m^3 at 25 ft and 0.07 mg/m^3 at 50 ft CARB (1998) measured air concentrations were sampled at 30 ft and 57 ft from the application edge. This general comparison suggests that the surrogate aerial air concentrations are reasonable estimates of inhalation exposures associated with orchard airblast applications. In general, it is likely that

the air concentrations estimated for the fixed-wing aircraft are as high or higher, than those associated with either ground boom or orchard airblast because of the higher ground speed and the higher release height of the spray from aircraft.

For the horizontal deposition exposure calculations, California-specific turf transferable residue (TTR) values obtained from the study by Stafford and Robb (1999)were used. In the same study by these investigators, the mean $TTR_{Day\ 0}$ data ($\mu g/cm^2$) were also obtained from two other states (mean values in parentheses): Indiana (0.09 ± 0.005) and Mississippi (0.146 ± 0.005). Although the value from Mississippi (i.e., the highest value) is not used in the horizontal deposition estimates, this value is comparable to the TTR value obtained in California (0.124 ± 0.004). In fact, risk estimates based on TTR data from Mississippi and California are essentially identical (see Tables 59 and 60).

Table 59. MOEs for Children (1-2 years old) Associated with Spray Drift at Various Distances from a Field Treated with CPF Using Aerial Equipment and the Mississippi turf transferable residue (TTR) value from Stafford and Robb (1999)

Application Scenario	Appl. Vol. (gallon/acre)	Exposure Route	Appl. Rate (lb/acre)	MOE at Various Distances Downwind from the Treated Fields						
				10 feet	25 feet	50 feet	100 feet	250 feet	500 feet	1000 feet
Aircraft or Helicopter (Children 1-2 years old)										
AT802A Fixed Wing Aircraft	2	CD[b]	1	109	128	163	242	463	777	1458
			2	54	64	82	122	244	448	1141
			2.3	47	56	71	107	213	402	1037
		CD + I[c]	1	44	50	58	74	112	161	292
			2	24	27	33	44	71	115	255
			2.3	22	25	30	40	66	109	243
		CD + I + D[d]	1	43	48	56	71	103	144	241
			2	24	27	32	42	67	106	215
			2.3	22	24	29	39	63	101	207
		CD + I + D + DW-PDP[e]	1	43	48	55	71	103	143	239
			2	24	27	32	42	67	106	214
			2.3	22	24	29	39	63	101	205
		CD + I + D + DW-EMON[e]	1	41	46	52	66	93	124	190
			2	23	26	31	40	63	95	174
			2.3	21	24	28	37	59	91	168
Bell 205 Helicopter	2	CD	1	86	135	221	363	569	958	1962
			2	42	67	108	174	314	614	1399
			2.3	37	58	94	151	278	553	1285
		CD + I	1	35	46	62	83	122	187	338
			2	18	25	35	49	82	141	279
			2.3	17	23	32	46	77	135	272
		CD + I + D	1	34	45	59	79	112	165	271
			2	18	25	34	48	77	128	232
			2.3	17	23	32	44	73	123	227
		CD + I + D + DW-PDP	1	34	45	59	78	111	164	269
			2	18	25	34	47	77	127	230
			2.3	17	23	32	44	73	122	225
		CD + I + D + DW-EMON	1	32	43	56	72	99	139	208
			2	18	24	33	45	71	112	184
			2.3	16	22	30	42	68	108	181
AT802A Fixed Wing Aircraft	15	CD	1	126	149	186	278	542	875	1173
			2	60	71	88	130	247	387	533
			2.3	52	62	76	112	213	334	461
		CD + I	1	38	41	46	55	71	88	113
			2	21	23	26	31	42	54	73

			2.3	18	20	23	28	38	49	68
		CD + I + D	1	37	40	44	53	68	83	104
			2	20	23	25	30	41	52	70
			2.3	18	20	22	27	37	47	65
		CD + I + D + DW-PDP	1	36	40	44	53	68	82	104
			2	20	23	25	30	41	51	69
			2.3	18	20	22	27	37	47	64
		CD + I + D + DW-EMON	1	35	38	42	50	63	76	94
			2	20	22	24	29	39	49	65
			2.3	18	20	22	27	35	45	60
Bell 205 Helicopter	15	CD	1	92	150	258	445	640	853	1304
			2	45	72	121	204	292	410	677
			2.3	39	62	104	175	252	359	593
		CD + I	1	25	32	39	47	59	75	107
			2	16	20	26	33	42	55	83
			2.3	14	18	23	29	38	51	77
		CD + I + D	1	25	31	38	46	56	71	100
			2	16	20	26	32	40	53	78
			2.3	14	18	23	29	37	49	73
		CD + I + D + DW-PDP	1	25	31	38	46	56	71	99
			2	16	20	26	32	40	53	78
			2.3	14	18	23	29	37	49	73
		CD + I + D + DW-EMON	1	24	30	36	43	53	66	90
			2	15	20	25	31	39	50	72
			2.3	14	18	22	28	35	46	67

a- From US EPA (2014a): Dermal PoD-Steady-state = 134.25 mg/kg/d; For calculations, Dermal Absorption (0-1) = 1; Oral PoD Steady-state: 0.099 mg/kg/d. Target MOE = 100

b- Combined Deposition (CD = Dermal + Object-to-Mouth + Hand-to-Mouth + Soil Ingestion)

c- Combined Deposition (CD = Dermal + Object-to-Mouth + Hand-to-Mouth + Soil Ingestion; inhalation (I))

d- Combined deposition (CD = dermal + object-to-mouth + hand-to-mouth + soil deposition; inhalation (I); dietary (D: food only; PoD = 0.581 mg/kg/d).

e- Combined deposition (CD = dermal + object-to-mouth + hand-to-mouth + soil deposition; inhalation (I); dietary (D: food only; PoD = 0.581 mg/kg/d); drinking Water (CPF-oxon PoD = 0.159 mg/kg/d from DW-PDP or DW-EMON).

Table 60. Aggregate MOEs for Children (1-2 years old) at Various Distances Downwind from Fields Treated with CPF by Aircraft or Helicopter Using California Turf Transferable Residue (TTR) from Stafford and Robb (1999)

Application Scenario	Appl. Vol. (gallon/acre)	Exposure Route	Appl. Rate (lb/acre)	MOE at Various Distances Downwind from the Treated Fields						
				10 feet	25 feet	50 feet	100 feet	250 feet	500 feet	1000 feet
Aircraft or Helicopter (Children 1-2 years old)										
AT802A Fixed Wing Aircraft	2	CD[b]	1	127	149	190	282	541	907	1701
			2	63	75	95	143	285	523	1331
			2.3	55	65	83	124	249	469	1210
		CD + I[c]	1	47	53	61	78	116	166	300
			2	26	29	35	46	74	120	264
			2.3	23	27	32	42	69	113	252
		CD + I + D[d]	1	45	51	58	74	107	148	246
			2	25	29	34	44	70	110	221
			2.3	23	26	31	41	65	105	213
		CD + I + D + DW-PDP[e]	1	45	51	58	74	106	147	244
			2	25	29	34	44	70	110	220
			2.3	23	26	31	41	65	104	211
		CD + I + D + DW-EMON[e]	1	43	48	55	68	95	127	193
			2	25	28	32	42	65	98	178
			2.3	22	25	30	39	61	94	172
Bell 205 Helicopter	2	CD	1	100	158	258	424	664	1118	2289
			2	50	78	126	203	367	716	1633
			2.3	43	68	110	176	325	645	1500
		CD + I	1	37	49	65	86	126	192	347
			2	20	27	37	51	85	145	287
			2.3	18	25	34	48	80	140	280
		CD + I + D	1	36	47	62	81	115	169	277
			2	19	26	36	49	80	131	238
			2.3	18	24	33	46	76	127	233
		CD + I + D + DW-PDP	1	36	47	62	81	115	168	274
			2	19	26	36	49	80	131	236
			2.3	18	24	33	46	76	126	231
		CD + I + D + DW-EMON	1	34	45	58	74	102	142	212
			2	19	26	34	47	73	115	188
			2.3	17	24	32	44	70	111	185
AT802A Fixed Wing Aircraft	15	CD	1	147	174	217	325	633	1021	1368
			2	70	83	103	152	288	452	622
			2.3	61	72	89	131	248	390	538
		CD + I	1	39	43	47	56	73	89	115
			2	22	24	27	32	43	55	75
			2.3	19	21	24	29	39	50	69
		CD + I + D	1	38	42	46	54	69	84	106
			2	21	24	26	32	42	53	71
			2.3	19	21	23	28	38	48	66
		CD + I + D + DW-PDP	1	38	42	46	54	69	83	105
			2	21	24	26	31	42	52	71
			2.3	19	21	23	28	38	48	66
		CD + I + D + DW-EMON	1	37	40	44	51	64	77	95
			2	21	23	25	30	40	50	66
			2.3	19	21	23	28	36	46	61
Bell 205 Helicopter	15	CD	1	107	175	301	519	747	996	1521
			2	52	84	141	238	340	478	790
			2.3	45	72	121	204	294	419	692
		CD + I	1	26	33	40	48	59	76	109
			2	17	21	27	33	42	56	84

			2.3	15	19	24	30	39	52	78
		CD + I + D	1	26	32	39	46	57	72	101
			2	16	21	26	33	41	54	79
			2.3	15	19	24	29	38	50	74
		CD + I + D + DW-PDP	1	26	32	39	46	57	72	100
			2	16	21	26	32	41	54	79
			2.3	15	19	24	29	38	50	74
		CD + I + D + DW-EMON	1	25	31	37	44	54	67	91
			2	16	21	26	31	39	51	73
			2.3	14	18	23	29	36	47	68

a- From US EPA (2014a): Dermal PoD-Steady-state = 134.25 mg/kg/d; For calculations, Dermal Absorption (0-1) = 1; Oral PoD Steady-state: 0.099 mg/kg/d. Target MOE = 100
b- Combined Deposition (CD = Dermal + Object-to-Mouth + Hand-to-Mouth + Soil Ingestion)
c- Combined Deposition (CD = Dermal + Object-to-Mouth + Hand-to-Mouth + Soil Ingestion; inhalation (I))
d- Combined Deposition (CD = dermal + object-to-mouth + hand-to-mouth + soil deposition; inhalation (I); dietary (D: food only; PoD = 0.581 mg/kg/d).
e- Combined deposition (CD = dermal + object-to-mouth + hand-to-mouth + soil deposition; inhalation (I); dietary (D: food only; PoD = 0.581 mg/kg/d); drinking Water (CPF-oxon PoD = 0.159 mg/kg/d from DW-PDP or DW-EMON). Target MOE = 100

VI.C.2. Dietary Exposure Uncertainties

Issues Related to Food Exposure:

Illegal Residues In Food Were Not Included In The Exposure Assessment: The PDP data indicate that chlorpyrifos residues are frequently detected on crops that lack chlorpyrifos tolerances. This could result from illegal applications on these crops, drift from applications to nearby fields, or soil residues remaining from applications to an earlier crop previously grown in the same field. From 2008 to 2012, PDP detected illegal chlorpyrifos residues on catfish, cilantro, cherry tomatoes, green onions, spinach, and five other crops.

From 2012 to 2014, DPR's California Pesticide Residue Monitoring Program (CPRMP) analyzed 2180 food samples and detected 63 (3% of total samples) illegal chlorpyrifos residues on the commodities shown in Table 61. A high proportion of illegal detections were on cactus (leaves or fruit), litchi, and longan. Most or all of these foods were imported. Certain population ethnic subgroups (e.g., Hispanic and Asian) in California have higher consumption of these foods. From 2015 to 2017, CPRMP analyzed over 2500 samples of fresh produce, of which 269 (11%) contained illegal CPF residues. Litchi, orange, oriental pear, cactus and tangelo were among the produce with frequent illegal detections. HHA evaluations of these cases concluded that 23 (about 1% of 2500 samples) were of potential health risk to consumers.

US EPA sets the legal limit (tolerance) for the amount of pesticide residues allowed in food. Over the years, DPR's residue monitoring program has detected illegal chlorpyrifos residues on various commodities, most or all of which were imported (Table 61 for residues detected from 2015-2017). Neither DPR nor US EPA assesses the health implications of illegal residues on agricultural commodities in their dietary exposure assessments, which are restricted to analyzing the health implications of legal residues. However, DPR's Enforcement Branch enforces US EPA tolerances under the California Pesticide Residue Monitoring Program, which collects domestic and imported produce samples throughout the channels of trade, including wholesale and retail outlets, distribution centers, and farmers markets. These samples are analyzed for

pesticide residues at laboratories run by the State of California's Department of Food and Agriculture (CDFA). When a pesticide residue is determined to be illegal by virtue of (a) its occurrence on a commodity for which there is no established tolerance; or (b) its level exceeding the established tolerance, HHA conducts a special dietary exposure assessment to determine if an acute health risk exists from consumption of that lot. The results are then communicated to the Enforcement Branch, which has the authority to remove affected produce from channels of trade

Table 61. Commodities Sampled by DPR's Pesticide Residue Monitoring Program that had Illegal Chlorpyrifos Residues from January 2015 to November 2017

Commodity Name	Samples Tested	Samples with Illegal Residues[b]	% with Illegal Residues	Samples with Illegal Residues[a]		
				Minimum Conc. (ppm)	Maximum Conc. (ppm)	Average Conc. (ppm)
ARROWHEAD (SAGITTARIA SPP.)	1	1 (1)	100	0.032	0.032	0.032
ASPARAGUS (SPEARS, FERNS, ETC.)	73	3	4	0.023	0.140	0.078
BANANA	151	22	15	0.010	0.090	0.031
BEANS (GREEN, STRING)	56	2	4	0.022	0.068	0.045
BOK CHOY (WONG BOK)	24	1	4	0.028	0.028	0.028
CHAYOTE (CHRISTOPHENES)	69	2	3	0.014	0.022	0.018
CHINESE RADISH/DAIKON (LOBOK, JAPANESE RADISH)	27	1	4	0.034	0.034	0.034
KALE	223	2	1	0.022	0.023	0.023
KIWI FRUIT	67	2	3	0.017	0.023	0.020
LEMON	78	7	9	0.013	0.100	0.046
LIME (MEXICAN LIME, ETC.)	81	4	5	0.026	0.039	0.033
LITCHI NUTS	25	15 (9)	60	0.029	0.370	0.117
LONGAN (LONGAN FRUIT)	30	7 (2)	23	0.022	0.110	0.059
NECTARINE	213	3	1	0.022	0.038	0.030
ORANGE (ALL OR UNSPEC)	219	56	26	0.013	0.120	0.048
ORANGE, SWEET	27	4	15	0.026	0.068	0.038
PASSION FRUIT (TAMARILLO, PURPLE GRANADILLA)	2	1 (1)	50	0.020	0.020	0.020
PEAR	55	1	2	0.047	0.047	0.047
PEAR, ASIAN (ORIENTAL PEAR)	63	18 (4)	29	0.022	0.220	0.069
PEPPERS (ALL OR UNSPEC)	2	1	50	0.025	0.025	0.025
PEPPERS (CHILI TYPE) (FLAVORING AND SPICE CROP)	214	26	12	0.011	0.270	0.059
PEPPERS (FRUITING VEGETABLE), (BELL,CHILI, ETC.)	285	20	7	0.011	0.290	0.099
PERSIMMON, COMMON	6	1	17	0.140	0.140	0.140
PINEAPPLE (FRESH MKT.	33	1	3	0.021	0.021	0.021

Commodity Name	Samples Tested	Samples with Illegal Residues[b]	% with Illegal Residues	Samples with Illegal Residues[a]		
				Minimum Conc. (ppm)	Maximum Conc. (ppm)	Average Conc. (ppm)
PINEAPPLE)						
PRICKLYPEAR (CACTUS PEAR)	31	10 (1)	32	0.012	0.130	0.044
PRICKLYPEAR CACTUS PADS	90	9 (5)	10	0.045	0.160	0.091
RADISH	27	1	4	0.023	0.023	0.023
RADISH TOPS	28	4	14	0.038	0.320	0.155
SUBTROPICAL AND TROPICAL FRUIT (ALL OR UNSPEC)	12	2	17	0.022	0.076	0.049
TANGELO	13	3	23	0.027	0.060	0.047
TANGERINE (MANDARIN, SATSUMA, MURCOTT, ETC.)	194	30	15	0.021	0.180	0.066
TARO (DASHEEN) (ROOT CROP) (WETLAND, UPLAND, ETC.)	8	1	13	0.024	0.024	0.024
TOMATILLO	111	5	5	0.020	0.073	0.042
TURNIP (TURNIP ROOTS)	4	1	25	0.027	0.027	0.027
TURNIPS (ALL OR UNSPEC)	5	2	40	0.028	0.160	0.094
Grand Total	**2547**	**269 (23)**	**11**			

[a] An illegal residue is one that either exceeds the US tolerance or is detected on a commodity that has no tolerance for the subject pesticide

[b] Deemed "potential health risk"

Dietary Risks Evaluated on a Per Capita Basis Rather than Per User: In this risk document, RAS calculated the risk from chlorpyrifos exposure from food using the 2014 US EPA exposure values which were estimated on a per capita basis (all individuals surveyed). RAS selects per user-day basis (consumers only or the population that is exposed) for the acute exposure rather than the entire population (per capita) (CDPR, 2009). In many exposure scenarios, per capita risks would be lower than per user risks. However, since chlorpyrifos is used on such a wide variety of crops, almost everyone in the population can potentially be exposed, so per capita dietary risk is expected to be close to per user dietary risk.

Per capita consumption rates may underestimate the CPF exposure from certain foods such as infant formula to non-nursing infants. The sensitivity analysis of food consumption by the various infant population subgroups in DEEM-FCID v3.16 revealed that the exposure estimates at the 95th percentile were slightly higher for non-nursing infants compared to all infants. However at the 99.9th percentile, the exposure estimates for non-nursing infants and all infant users were essentially the same.

Issues Related to Drinking Water Exposure: US EPA modeling of surface water residues predicted that certain chlorpyrifos uses may result in residue levels exceeding the DWLOC at labeled application rates, including scenarios for California grown crops. Surface water modeling results also suggested that the highest exposures may be localized in small watersheds where

high percent crop treated area could occur. However, EDWC of chlorpyrifos was not modeled under California-specific conditions.

HHA estimated drinking water probabilistic exposures using 1) PDP residue data for chlorpyrifos oxon in treated drinking water in California or 2) monitoring data for chlorpyrifos in surface and ground water in California, and drinking water consumption records in DEEM-FCID. The analyses showed that exposures estimated from residues in surface water could be up to 4-fold higher than exposures estimated from residues in treated drinking water.

PDP is not designed to detect peak concentrations of chlorpyrifos or chlorpyrifos-oxon in drinking water and the estimated exposures were based entirely on LODs. Overall, use of PDP data may lead to an underestimation of actual drinking water exposure.

The DPR surface and ground water programs monitor pesticide residues in water, identify the sources of the contamination, and develop mitigation options for protection of aquatic and human health. These programs are designed to capture higher concentrations coinciding with runoff timing, storm events, high-use regions, and application timing. The DPR monitoring programs detected high residue levels in samples collected from various water sources including irrigation ponds, sloughs, and agricultural drains that are not normally used as sources for drinking water. Consequently, a drinking water exposure based on these residues would likely represent a conservative high end potential exposure. Regardless of the residue database, all acute drinking water MOEs at the 99.9^{th} percentile exposure were substantially higher than the target of 100, ranging between 405 and 3,970. As such, a health concern is not indicated. In conclusion, the actual exposure to chlorpyrifos in the California drinking water is likely to be somewhere between the high end exposure scenario based on the DPR surface and ground water detections and the scenario based on LOD for chlorpyrifos oxon from the PDP monitoring.

Assessing exposures via the lactational pathway: Presently, there are very few studies that have measured CPF concentrations in breast milk of mothers in the US. Each of these studies has its limitations. The results from Weldon et al. (2011) were considered to be the most reliable estimate of breast milk residues for US women. These data can be used to evaluate exposure to CPF from human breast milk to nursing infants when consumption data from NHANES or other sources become available. HHA will continue to follow the literature on pesticide residues in human milk and consumption to address pesticide exposure via the lactational pathway.

Assessing risk from aggregate exposure: In this draft assessment, the aggregate MOE associated with dietary and drinking water exposures was calculate using acute PoD values. As detailed in section VI.B.1.c. of this document, it is evident that people living in high pesticide use area have lower levels of RBC AChE activity than those living in low or no use areas. Therefore, the use of acute PoD may underestimate the aggregate risk.

VI.D. Uncertainties in the Risk Characterization

VI.D.1 Interspecies UF:

The input parameters in the PBPK-PD model were specific for human metabolic and physiological processes. HHA reviewed the evaluations of the model by US EPA and other scientific groups and agrees with the conclusion that the derived human parameters adequately

predict AChE inhibition in controlled human dosing studies and support the reduction of the default interspecies UF of 10 to 1.Comparison of the human and animal NOELs from the available literature also suggest that humans are not more sensitive than animals with respect to ChE inhibition. Nevertheless, we recognize that model systems are not designed to account for all physiological processes that influence xenobiotic concentrations at the target site.

VI.D.2 Intraspecies UF:
The 2014 US EPA PBPK-PD model is not designed to account for all physiological changes during pregnancy. The model published in 2017 was updated to characterize maternal changes during pregnancy, including increased respiration, cardiac output and blood volume (both plasma and RBC), increased glomerular filtration, potential changes in metabolism, enlarged uterus, breasts, and fetal growth (Poet et al., 2017a). However, concerns exist for the updated model as raised by SciPinion reviewers about the model capabilities to estimate AChE inhibition in the fetus and neonate (Oliver et al., 2017).

The main parameters responsible for inter-individual variation in RBC acetylcholinesterase inhibition are related to metabolic clearance of CPF and CPF-oxon. In the PBPK-PD model, predictions of all human age-dependent variability based on hepatic P450 metabolism of CPF to the oxon and subsequent plasma and hepatic PON1 detoxification of CPF-oxon to TCPy were derived from a small sample size. These included 30 human liver microsomes and plasma samples from 20 individuals ranging in age from 13 days old to 75 years old. Adult samples were selected to match adult population distributions for the primary CPF metabolizing P450s (CYP1A2, 3A4/5, 2B6, 2C19). Nevertheless, the small sample size was compensated in the model by using bootstrapping from the raw data and Monte Carlo simulations that increased the variability by up to 10-fold for the critical parameters (see Table 5 earlier in this document).

The liver enzyme activities incorporated into the PBPK-PD model were described in Smith et al. (2011). The liver microsomes were obtained from human cryopreserved tissues. There is concern that these tissues are not representative of live tissues due to the potential for enzyme degradation before or after death. However, the human livers were collected and flash cryopreserved following procedures for organ transplant. Human microsomal fractions were then prepared from these cryopreserved livers following standardized protocols (https://www.xenotech.com/products/subcellular-fractions/human/liver/ microsomes; Rewerts, C., Maciej Czerwinski, M. and Loewen, G. personal communication). Several studies have indicated that PON1 activity is relatively stable during an extended tissue collection time, with liver enzyme functionality declining by less than 30% after 12 hours at room temperature (Gonzalvo et al., 1998) and remaining stable for many years in frozen samples (Huen *et al.*, 2009); https://www.xenotech.com/products/subcellular-fractions/human/liver/microsomes). Utilization of microsomes derived from human tissues is described and recommended in the Federal Food and Drug Administration specifically for use in PBPK modeling (FDA, 2012). However, there are no measured T_0 activity levels for fresh versus preserved human liver microsomes, so the comparative metabolic processes may not be perfectly concordant.

Based on Poet et al. (2017a), the acute oral PoDs used in this risk assessment appear to be the median values for 10% RBC AChE inhibition in non-pregnant females (ED_{10}). The updated 2017 PBPK-PD model also provided ED_{10} values for two other simulated populations (Poet et al.,

2017a): pregnant females and infants. Compared to the respective median values (i.e., 50th percentile), the calculated ED_{10} values based on 10% RBC AChE inhibition at the 1st percentile are about 3-fold lower for pregnant females and 4-fold lower for infants. Therefore, if ED_{10} values at the 1st percentile were used, the associated risks would be up to 4-fold higher.

VI.D.2.a. The Role of Plasma ChE (BuChE) and Neurodevelopment

CPF has been shown to affect plasma/BuChE during development in numerous studies described earlier. Plasma ChE is involved in embryonic development of both neural and extraneural tissues (Brimijoin and Koenigsberger, 1999; Mack and Robitzki, 2000). Importantly, plasma ChE has been shown to be inhibited in animal studies at doses equal to or less than RBC AChE (Marty and Andrus, 2010). Zheng et al. (2000)demonstrated greater BuChE inhibition than RBC AChE in rat neonates after both acute and repeated dose administration of CPF.

A study with gene-targeted mice deficient in AChE ($AChE^{-/-}$) showed that BuChE and likely other enzymes may have assumed the function of AChE during early development (Li et al., 2000a; Xie et al., 2000). The $AChE^{-/-}$ mice showed no physical defects at birth. Their organs and blood cells showed no morphological abnormalities. Electron microscopic examination of the neuromuscular junctions showed normal morphology. Interestingly, BuChE levels in the tissues were similar to those in the wild-type and AChE heterozygous mice. In addition, in the absence of AChE, plasma /BuChE was apparently essential for vital functions. When $AChE^{-/-}$ mice were treated with bambuterol, a specific plasma/BuChE inhibitor, they died immediately after treatment, while wild-type mice treated with the same dose were not affected. Therefore, the role of plasma/BuChE inhibition in neurodevelopment introduces uncertainty as to the long-term effects occurring at doses lower than those inhibiting RBC AChE.

VI.D.2.b. Uncertainties with the Use of AChE Inhibition as an Endpoint for Protecting against Neurodevelopmental Effects

Selection of RBC AChE inhibition as the critical toxicity endpoint was intended to protect human populations from impacts on other neurological endpoints that are not as easily measured. However, collective results from epidemiology and animal toxicity studies indicate that CPF may cause neurodevelopmental and neurobehavioral effects in the absence AChE inhibition.

VI.D.2.c. ToxCast™ Profiles and Tox21 HTS Profiles

The ToxCast and Tox21 high-throughput screening assays (HTS) were examined for indications of pathway disruptions that could lead to toxic effects. Zebrafish is a promising test model to examine the potential CPF neurobehavioral effects and compare active concentrations to those inhibiting ChE activity. Abnormal behaviors (increased “fish at rest”, decreased swim speed, decrease in fish with a preference for being on the side or on the edge of their swim lane) occur at CPF exposure levels 10-fold lower than those inhibiting AChE. This provides support for the use of an UF of 10 to account for potential neurodevelopmental effects.

ToxCast and Tox21 provide indications of CPF pathway disruptions in cell adhesion, cell cycle, and cell morphology assays. CPF is also a positive hit for molecular targets that regulate 1) induction and inhibition of CYP enzymes, 2) hormone levels in the brain, 3) endocrine receptor

binding, and 4) steroidogenesis inhibition. However, it is unclear if these impacted pathways are potential noncholinergic key molecular events responsible for the observed CPF neurodevelopmental toxicity *in vivo*.

VI.D.2.d. Animal Studies:

CPF affects several neurotransmitters in the CNS that are critical to behaviors related to mood, emotion, learning, and memory including the endocannabinoids, dopamine, and serotonin. CPF has been shown to affect behavior related to anxiety in animals that is associated with dopamine and serotonin levels. While the overall evidence indicates that CPF may cause neurodevelopmental effects, few *in vivo* animal toxicology studies include doses lower than 1 mg/kg/day, the threshold for ChE inhibition (Carr et al., 2014; Carr et al., 2015a; Carr et al., 2015b, Carr et al., 2017; Mohammed et al, 2015; Silva et al 2017, Gomez–Gimenez et al, 2017; Lee et al, 2015). As such, a definitive conclusion whether these effects are more sensitive than ChE inhibition could not be made at this time. Several in vitro studies have observed negative effects of CPF and CPF-oxon on neuronal growth in tissue culture, including decreased axonal length and inhibition of neurite outgrowth (reviewed in Eaton *et al.*, 2008). These in vitro effects occurred at concentrations orders of magnitude less than what would result in AChE inhibition.

VI.D.2.e. Human Studies

Several published reviews have considered the association between prenatal or early pesticide exposure and adverse impacts on human growth and development (Eaton et al., 2008; Prueitt et al., 2011; Goodman et al., 2012; Li et al., 2012; Saunders et al., 2012; Ntzani et al., 2013; Hernández et al., 2016; Furlong et al., 2017). The reviewed studies and those considered in the present assessment may be grouped by type of exposure assessment.

Predicted exposure. Several epidemiology studies used maternal proximity during pregnancy to agricultural pesticide applications to predict exposures or used questionnaires to determine which activities in the participant's past may have led to a potential exposure. Both Harari et al. (2010) and Llop et al. (2013) showed deficits in psychomotor development in children and both evaluated prenatal pesticide use by questionnaire. However, questionnaire responses typically do not provide sufficient information to determine the level of in utero exposure of chlorpyrifos. Berkowitz et al. (2003) found no association between use of pesticides during pregnancy (collected by questionnaire) and the quantitative urinary analysis of OP pesticide biomarkers, underscoring the difficulty of using questionnaires to ascertain exposure. Likewise, the associations reported in studies that relied on pesticide use or application data would have been strengthened by using actual exposure analysis in potential exposed subpopulations.

Measured metabolites. Multiple epidemiology studies utilized urinary metabolites of OP pesticides as biomarkers of exposure. Dialkyl phosphate (DAP) metabolites (DEP, DMP, DETP, DMTP, etc.) are nonspecific metabolites of OP pesticides. Their presence in urine may indicate exposure to an O,O-diethyl pesticide or its degradates, but not a specific active ingredient (Barr and Angerer, 2006). The presence of TCPy in urine also suggests exposure to several different chemicals, including environmental degradates of CPF, CPF-oxon, or CPF-methyl, or TCPy itself. Epidemiological studies have reported associations between total prenatal DAPs, individual DAPs, or TCPy and various decrements in pediatric growth and behavior. However,

when the data were pooled, no consistent dose-effect associations between studies emerged (Engel et al., 2016; Harley et al., 2016). This could have been due to study differences in biomarkers of exposure or effect that limited the ability to cross-compare results. In addition, there is a high degree of within-person variability of urinary biomarkers due to the intermittent nature of exposure, the variety of environmental and dietary sources, individual rates of metabolism and elimination, up-regulation and expression of metabolizing enzymes, the mass balance of the substrates present, as well as substrate binding affinity. Spaan and colleagues (2015) found that when comparing multiple urinary OP metabolites across pregnancy, the within-person variability exceeded the between-person variability. Even while AI-specific information cannot be derived from these metabolites, they can be an indication of the exposure to OPs as a class of pesticides (Barr and Angerer, 2006).

Quantitation of Chlorpyrifos. The only way to unequivocally identify CPF exposure is by measuring the intact pesticide in blood samples. CPF in maternal and cord blood have been associated with various decrements of human growth and development, which are compelling. Blood samples are inherently more difficult to collect then urine. Chlorpyrifos concentrations in blood can be difficult to quantify above the analytical limit of detection (ppt versus ppb levels in urine) (Barr and Angerer, 2006). In addition, the time that the sample was collected (at or within 48 hrs of delivery) is not necessarily indicative of chlorpyrifos exposure during critical windows of in utero development. There currently is no way to precisely categorize CPF exposure throughout pregnancy without highly intrusive and repeated serial sampling of subjects.

Human neurodevelopment is multifactorial. Recent findings indicate a growing association between CPF exposures during gestation and impacts on human growth and development, even though an AOP for chlorpyrifos neurotoxicity has not been elucidated. There may be multiple pathways or covariates independent of AChE inhibition at play, such as PON1-mediated oxidative stress (Harley et al., 2011). In addition, there is evidence that in vitro neuronal growth is impacted by CPF-oxon concentrations below those that inhibit AChE (reviewed in Eaton et al. (2008). There are challenges in incorporating epidemiological results into quantitative risk assessment because of limited exposure data and inconsistencies across studies in dose and effect. However, a lack of a clear mechanism of action does not negate results from numerous observational studies. It is important to consider potential associations documented in epidemiological studies as important mechanistic investigations continue.

VI.D.2.f. The Latest US EPA Methodologies for Deriving PoDs for CPF

US EPA utilized the PBPK portion of the PBPK-PD model from the 2014 US EPA Revised Human Health Risk Assessment to predict CPF blood concentrations in women for comparison with the measured values in the Columbia CCCEH cohort. Subsequently, US EPA revised their risk assessment approach using reverse dosimetry based on a simulated time-weighted average (TWA) concentration of CPF in blood for predicting exposures in adults, infants, and children (US EPA, 2016b). The PoDs were drastically (200-11,000-fold) lower than the PoDs in the US EPA 2014 Revised Human Health Risk Assessment which were based on RBC AChE inhibition. However, for the first approach, SAP did not accept the methodology due to the numerous uncertainties, involved in the design, database uncertainties and missing data. The second approach has not gone through an external scientific review.

As discussed throughout this document, HHA is aware of the uncertainties associated with the use of AChE inhibition as the critical effect for assessing the risk from CPF exposures when potentially more sensitive neurodevelopmental effects have been reported in epidemiology and animal toxicology studies. However, at this time HHA chose not use the PoDs estimated in the Nov 2016 US EPA revised risk assessment. These PoDs were derived using physiologically-based pharmacokinetic modeling to predict time weighted average (TWA) blood concentrations of CPF for the women in the Columbia cohort. HHA carefully reviewed this novel approach and concluded that these PoDs carry substantial uncertainty due to the unknown exposure levels, duration, and critical windows of susceptibility. Because of these uncertainties and the fact that the approach in the 2016 revised risk assessment has not yet undergone external scientific review, HHA has continued to use the 2014 US EPA PoDs based on 10% RBC AChE as the starting point for the present analysis.

VI.D.2.h. Updated Chlorpyrifos PBPK Modeled Steady State (21 Days) Point of Departure (PoD) for Inhalation Exposure for Children 1-2 Years Old

In 2017, Dow AgroSciences LLC (DAS) commented that the steady state (21 day) inhalation PoD of departure for children of 1-2 years old (2.37 mg/m^3) presented in the US EPA 2014 revised chlorpyrifos risk assessment would not achieve a 10% reduction in RBC AChE (Bret *et al.*, 2017). The DAS comment was subsequently confirmed by DPR in communication to US EPA. In a separate analysis requested by DPR, DAS used the DPR default physiological parameters for children 1-2 years old (e.g., 13 kg; Andrews and Patterson, 2000) and estimated an air concentration of 3.0 mg/m^3 that will result in 10% RBC AChE inhibition at 1 hour per day for 21 days (Poet, 2017). Given the fact that HHA adopted all PoD values from the US EPA 2014 risk assessment into the August 2017 DPR draft risk assessment, the updated inhalation PoD value needs to be consistent with the physiological parameters US EPA used for generating other PoD values (e.g., dietary) for children 1-2 years old (e.g., 11 kg rather than 13 kg used previously). Therefore, we estimated a separate 21-day (steady state) PoD value for inhalation using the latest version of the CPF PBPK/PD model (Poet *et al.*, 2017b) and the model input parameters as specified in the US EPA 2014 chlorpyrifos risk assessment. The resulting PoD was 2.85 mg/m^3, which is similar to that generated by DAS but slightly higher than the 2014 US EPA PoD value (Table 62). The simulation result is shown in Figure 13.

Table 62. Comparison of PBPK Modeled 21-Day PoD for Inhalation Exposure of Children (1-2 years old) by US EPA, DAS, and DPR

Inhalation Concentration (mg/m^3)	Exposure Hours per Day for 21 Days	Percent Control RBC AChE Activity	Source
2.37	1	<<10%	US EPA
3.0	1	~10%	DAS
2.85	1	~10%	DPR

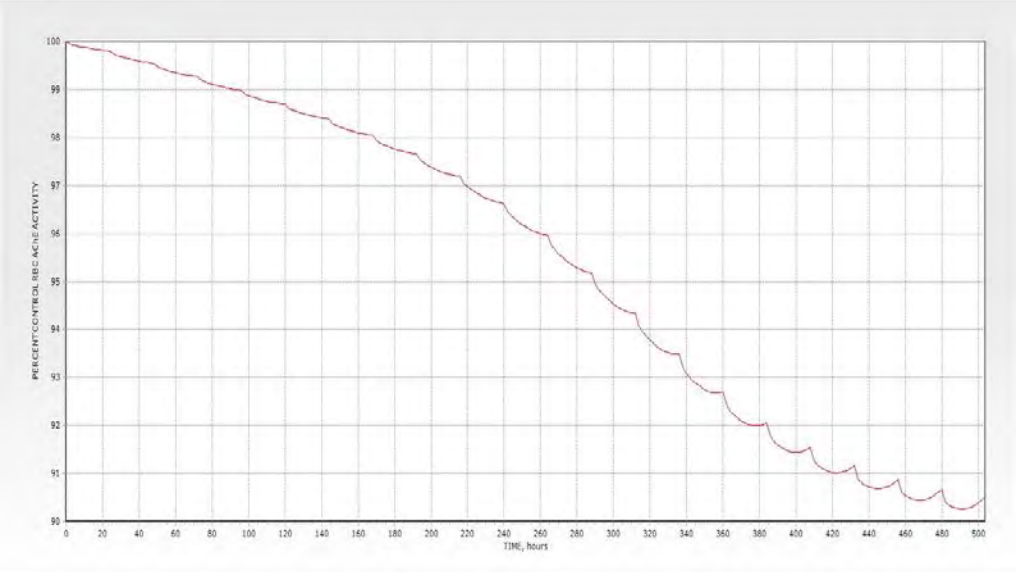

Figure 13. PBPK model simulation result of the percent control RBC AChE activity at an air concentration of 2.85 mg/m3 for one hour per day for 21 days

VI.D.2.h. Risk Assessment Approaches Adopted by Other Regulatory Authorities

Currently, other regulatory authorities employed animal models to derive PoDs for CPF risk assessment. These included European Food Safety Authority (EFSA), the Australian Pesticides and Veterinary Medicines Authority (APVMA), and Health Canada's Pest Management Regulatory Agency (PRMA). Table 63 summarizes the critical endpoints employed by these agencies, all of which are based on 20% ChE inhibition. EFSA and APVMA did not use an additional safety factor for neurodevelopmental effects, whereas Health Canada PMRA applied a UF of 3 for developmental neurotoxicity.

Table 63. Points of Departure, Uncertainty Factors and Reference Doses Generated by Regulatory Agencies

Risk Assessment	**US EPA 2014 Human PBPK-PD** (10% RBC AChEI[a])		**DPR 2015 Human PBPK-PD** (10% RBC AChEI[a])		**EFSA 2014 Rat NOEL** (20% RBC AChEI[b])		**Australia 2017 Human NOEL** (20% RBC or plasma ChE[c])		**Health Canada Rat NOEL** (20% Brain AChEI[d])	
Oral	PoD	RfD	PoD	RfD	PoD	RfD	PoD	RfD	PoD	RfD
Acute	**0.5**	**0.005**	**0.5**	**0.005**	**0.5**	**0.005**	**1**	**0.1**	**0.3**	**0.001**
UF inter **UF intra** **UF FQPA/ neurodev**		1 10 10		1 10 10		10 10 N/A		1 10 N/A		10 10 3
Short term/ chronic	0.08	0.0008	0.08	0.0008	0.1	0.001	0.03	0.003	0.3	0.001
UF inter **UF intra** **UF FQPA/ neurodev**		1 10 10		1 10 10		10 10 N/A		1 10 N/A		10 10 3[d]

a-From US EPA (2014a)
b-European Food Safety Authority (2014) used the adult male rat single dose study (Mendrala and Brzak, 1998) and the comparative cholinesterase study in rat to obtain (Marty and Andrus, 2010) obtain acute and long-term PoDs, respectively.
c-Acute and short-term/chronic PoDs based on a human volunteer study using chlorpyrifos (Coulston et al., 1972)
d=PoDs based on the rat developmental neurotoxicity study (Hoberman, 1998)

CONCLUSION

The focus of the current risk assessment was the rigorous analysis of results from in vivo and in vitro experiments, computational toxicity, epidemiological studies, dietary assessment, pesticide illness reports, and exposure analysis and modeling, to determine the relative risks of exposure to chlorpyrifos to guide risk management decisions.

The database for chlorpyrifos is extensive, covering all aspects of in vitro and in vivo toxicology, metabolism, pharmacokinetics and dynamics. Chlorpyrifos is one of the rare chemicals with a PBPK-PD model which has been extensively peer-reviewed and used in whole or in part by several regulatory bodies. Besides DPR and US EPA, multiple international bodies have conducted human health risk assessments on chlorpyrifos including the European Food Safety Authority (EFSA), the Australian Pesticides and Veterinary Medicines Authority (APVMA), Health Canada's Pest Management Regulatory Agency (PRMA), the Agency for Toxic Substances and Disease Registry (ATSDR), and the Food and Agriculture Organization/ World Health Organization (FAO/WHO). In addition, several epidemiological cohorts, observational studies, and meta analyses have investigated potential associations between adverse human health outcomes and exposure to chlorpyrifos.

The current assessment addresses potential human effects arising from exposure to chlorpyrifos from food, drinking water, air and skin contact, incidental ingestion, as well as aggregate exposures from various combined scenarios. The assessment focused on four at-risk subpopulations: infants (<1 year old), children 1-2 years, children 6-12 years, and women of childbearing age (13-49 years). The critical toxicological points of departure (PoDs) used to characterize the risk from exposure to chlorpyrifos were human equivalent doses estimated by PBPK-PD modeling, adopted from the 2014 US EPA Revised Human Risk Assessment for chlorpyrifos. Risks were calculated as margins of exposure (MOEs), which are equal to the critical PoD divided by the anticipated human exposure level. For this assessment, a MOE of 100 is considered protective of human health for all exposure scenarios. The target of 100 included uncertainty factors (UF) of 1 for interspecies sensitivity, 10 for intraspecies variability, and 10 for potential neurodevelopmental effects. Exposures resulting in MOEs lower than the target of 100 are considered to be of potential health risk to humans. DPR used the PoDs and the target UF of 100 to estimate reference doses or reference concentrations for chlorpyrifos.

No risks were identified from exposures to children and women of childbearing age from dietary sources (food and drinking water) and dermal exposures resulting from spray drift. Potential health risks were identified from hand-to-mouth exposure to children, from inhalation exposure to children and women of childbearing age, and from various aggregate exposures from combined media (dietary (food only), drinking water, and deposition from spray-drift).

The results of the current assessment found that the aggregate MOEs for a number of combined scenarios were below the target of 100. The air component contributed up to 95% to the aggregate risk. Consequently, the aggregate MOEs were significantly reduced when the air exposure was added to the dermal, non-dietary oral, and dietary exposures. In conclusion, the exposure from air near application sites was identified as the main driver when the aggregate MOEs fell below the target value of 100 for children 1-2 years old.

DPR's Human Health Assessment (HHA) Branch has confidence both in the cholinesterase-based PoDs it employed as toxicological endpoints and in the scenarios it chose to characterize exposure of adults and children, which reflect the typical chlorpyrifos use in California.

The most prominent uncertainties in this assessment include:

1. Reduction of the PoDs by a factor of 10 to address variability within the human population with respect to RBC AChE inhibition. HHA recognizes that the 10-fold default uncertainty factor may not account for the entire range of variability within the human population.

2. Selection of 10% RBC AChE inhibition as the critical toxicity endpoint. This was intended to protect human populations from potential impacts on neurological or neurodevelopmental parameters that are not easily measured and may occur at doses lower than those necessary to elicit AChE inhibition. Since neither the exposure levels of CPF causing neurodevelopmental toxicity nor the critical windows of susceptibility are known, the use of PoDs based on 10% RBC AChE inhibition may not be sufficiently health protective. Consequently, HHA further reduced the PoDs by a factor of 10 to account for the possibility of neurodevelopmental effects.

Although the critical endpoint used in this assessment was 10% RBC AChE inhibition, DPR recognizes that there is a potential for other effects occurring at chlorpyrifos concentrations lower than those that inhibit cholinesterase. There could be other modes of action and adverse outcome pathways leading to neurodevelopmental effects, including non-cholinergic systems, the endocannabinoid system, other signaling pathways, and oxidative stress. At this time, the database does not identify linkage between molecular initiating events, cellular responses, and the developmental neurotoxicity of chlorpyrifos. It is important to note, however, that neurotoxic and neurobehavioral alterations have been documented in experimental animal studies. There is also evidence of potential associations between in utero exposure to chlorpyrifos and altered human growth and behavior later in life. There are acknowledged uncertainties in the human evidence, including a lack of dose-effect relationships, inconsistencies in reported outcomes across studies, and no consistent use of quantitative markers of chlorpyrifos exposure. Nevertheless, human and animal neurodevelopmental effects are compelling.

In conclusion, DPR recognizes that the science is evolving and new data will be analyzed as they become available. The department is confident that this assessment captures the current state of the science of chlorpyrifos toxicity and welcomes comments by the scientific community as we develop approaches to quantitatively address additional adverse outcomes.

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APPENDIX 1.

SUMMARY OF TOXICOLOGY FOR CHLORPYRIFOS

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

DEPARTMENT OF PESTICIDE REGULATION

HUMAN HEALTH ASSESSMENT BRANCH

SUMMARY OF TOXICOLOGY DATA

CHLORPYRIFOS

Chemical Code # 00253 Document Processing Number (DPN) # 0342

SB 950 # 221

Summary initiated: 5/8/86

Revisions on 8/11/86, 11/24/86, 6/5/87, 4/25/89, 11/09/89, 3/16/90, 11/8/90, 5/11/92, 6/28/93, 7/19/94, 9/3/97, 11/13/98, 10/13/99, 9/27/01, 6/5/13, 11/19/13, and June 8, 2015

DATA GAP STATUS

Chronic toxicity, rat: No

data gap, possible adverse effect

Chronic toxicity, dog:

No

data gap, no adverse effect

Oncogenicity, rat:

No

data gap, no adverse effect

Oncogenicity, mouse:

No

data gap, no adverse effect

Reproduction, rat:

No

data gap, no adverse effect

Developmental toxicity, rat: No

data gap, no adverse effect

Developmental toxicity, rabbit: No

data gap, no adverse effect

Gene mutation:

No

data gap, no adverse effect

Chromosome effects:

No

data gap, no adverse effect

DNA damage: No data gap, possible adverse effect

Neurotoxicity: No data gap, no adverse effect

Toxicology one-liners are attached.
All record numbers for the above study types through 284915 (Document No. 342-0969) were examined. This includes all relevant studies indexed by DPR as of June 2, 2015.
In the 1-liners below:
indicates an acceptable study.
Bold face indicates a possible adverse effect.
indicates a study on file but not yet reviewed.
File name: t20150605 chlorpyrifos
Current revision by C. Aldous, June 8, 2015
NOTE: The following symbols may be used in the Table of Contents which follows:
** = data adequately address FIFRA requirement
† = study(ies) flagged as "possible adverse effect"
(N/A) = study type not currently required
This record contains summaries of studies. Individual worksheets may be useful for detailed assessment.

METABOLISM AND PHARMACOKINETICS ** (based on collective data)

NOTE: A number of studies in the "Miscellaneous" section near the end of this Summary include metabolism, pharmacokinetics, and cholinesterase inhibition data.

342-0343 071390 Nolan, R. J., M. D. Dryzga, B. D. Landenberger, and P. E. Kastl, "Chlorpyrifos: tissue distribution and metabolism of orally administered ^{14}C-labeled chlorpyrifos in Fischer 344 rats," The Dow Chemical Company, Midland, MI, 12/23/87. Laboratory Study # K-044793-(76). Five rats/sex/group were dosed by gavage in 2 ml/kg corn oil in single labeled doses of 0.5 or 25 mg/kg or 15 consecutive daily doses of unlabeled chlorpyrifos at 0.5 mg/kg/d, followed 1 day after the 15th dose with a single labeled dose of 0.5 mg/kg. Labeled chlorpyrifos (>99% radiopurity) was 12 µCi per gram of corn oil regardless of dose. Only the 3,5,6-trichloro-2-pyridinol group was labeled. Unlabeled chlorpyrifos, used to dilute the high dose group, was 99.9% purity. Investigators evaluated label in urine, feces, and tissues, and identified the three significant urinary metabolites. Urine plus cage wash accounted for 86 to 93% of administered label, regardless of sex or dosing regimen. Six to 11% of label was found in feces. Urinary excretion was rapid: usually over 50% of administered dose was collected in urine within the first 12 hours (T1/2 was 8-9 hours for single or multiple 0.5 mg/kg treatments, and somewhat longer for 25 mg/kg rats). Urinary metabolites were composed chiefly of 3,5,6-trichloro-2-pyridinol, and usually slightly more of its glucuronide, collectively accounting for over 90% of urinary metabolites. About 5% of urinary residues consisted of the sulfate conjugate of 3,5,6-trichloro-2-pyridinol. Parent chlorpyrifos was not found in urine. Most fecal label was obtained

within the first 24 hours. Exhaled CO2 was trapped for radioanalysis from the 25 mg/kg group. This collection accounted for <0.01% of administered dose. Fecal metabolites were not assessed. Tissue residues were assessed at 72 hrs (M) and at 144 hrs (F). Total tissue residues were very small (0.2% of administered dose in 25 mg/kg group) to negligible (<0.01%), and generally only quantifiable in peri-renal fat (M and F). In the 25 mg/kg groups only, tiny but quantifiable residues were also found in liver (M) and ovaries. This is a valid supplementary study. Aldous, June 5, 2015.

GUIDELINE ACUTE STUDIES ON ACTIVE INGREDIENT

Acute oral toxicity, rat **

**342-716; 154442; Stebbins, K. E., "Dursban F Insecticidal Chemical: Acute Oral Toxicity Study in Fischer 344 rats," study type 811; The Toxicology Research Laboratory, Health and Environmental Sciences, The Dow Chemical Company, Midland, MI; Study No. K-044793-102A; 11/27/96; Dursban F Insecticidal Chemical (purity: 97.6%); 5 animals/sex/group; Doses: 50, 100, 500 mg/kg as 3% suspension in 0.5% aqueous solution of Methocel A4M; Mortality: 50 (M/F:0/5), 100 (M/F:0/5), 500 (M/F:5/5), deaths occurring with 3 days after dosing; Clinical Observations: fecal soiling, lacrimation, urine soiling, salivation, decreased activity; Necropsy: no treatment-related lesions noted; LD50 (M/F): 223 mg/kg; Toxicity Category II; Study acceptable. (Moore, 5/29/97)

**342-708; 154314; Nissimov, S. and A. Nyska, "Pyrinex Tech.: Acute Oral Toxicity in the rat," study type 811; Life Science Research Israel Ltd., Ness Ziona 70451, Israel; Study No. MAK/056/PYR; 5/12/84; Pyrinex Tech; 5 animals/sex/group; Doses: 90, 164, 298, 543, 987 mg/kg, in corn oil; Mortality: 90 (M/F:0/5), 164 (M:0/5, F:4/5), 298 (M/F:5/5), 543 (M/F:5/5), 987 (M/F:5/5); Clinical Observations: tremors, hunched posture, salivation, diarrhea, decreased motor activity, ataxia; Necropsy: hemorrhagic and/or ulcerated stomach and intestines; LD50 (95% confidence interval): (M) 221 (181 to 269) mg/kg, (F) 144 (105 to 200) mg/kg; Toxicity Category II; Study acceptable. (Moore, 6/10/97)

Acute dermal toxicity **

**342-716; 154444; Stebbins, K. E., "Dursban F Insecticidal Chemical: Acute Dermal Toxicity Study in New Zealand White Rabbits," study type 812; The Toxicology Research Laboratory, Health and Environmental Sciences, The Dow Chemical Company, Midland, MI; Study No. K-044793-102D; 11/27/96; Dursban F Insecticidal Chemical (purity: 97.6%); 5 animals/sex/group; Doses: 2000, 5000 mg/kg, test material liquefied prior to application, 24 hour exposure; No mortality; Clinical Observations: fecal soiling, dermal irritation at the site of application; Necropsy: no treatment-related lesions; LD50 (M/F) > 5000 mg/kg; Toxicity Category IV; Study acceptable. (Moore, 5/30/97)

**342-709; 154315; Nissimov, S. and A. Nyska, "Pyrinex Tech.: Acute Dermal Toxicity in rabbits," study type 812; Life Science Research Israel Ltd., Ness Ziona 70451, Israel; Study No. MAK/059/PYR; 5/12/84; Pyrinex Tech; 5 animals/sex; Dose: 2000 mg/kg, liquefied prior to application, 24 hour exposure, semi-occlusive wrap; No mortality; Clinical Observations: no

treatment-related signs; Necropsy: congested lungs, skin lesions, multiple petechiae on thymus; LD50 (M/F) > 2000 mg/kg; Toxicity Category III; Study acceptable. (Moore, 6/10/97)

Acute inhalation toxicity, rat **

**342-710; 154316; Buch, S. A., "Pyrinex Tech.: Acute Inhalation Toxicity in rats," study type 813; Life Science Research, Stock, Essex, England; Study No. 80/MAK025/362; 8/27/80; Pyrinex Tech (purity: 95.%); 5 animals/sex/group unless otherwise noted; Exposure Concentrations (gravimetric): 1.69 (F only), 2.23, 2.98, 3.56, 4.07 mg/l, MMAD (GSD): 7.4 (2.2), 7.9 (1.7), 8.2 (1.9), 8.0 (2.0), 8.6 (2.1) µm, respectively, respirable concentration (mass of particles < 10 µm): 1.40, 1.86, 2.61, 3.01, 3.47 mg/l, respectively, 4 hour nose-only exposure (test material was prepared as a 60% (w/v) in xylene) (concentrations based upon non-volatile portion of exposure atmosphere); Mortality: 1.69 (F:1/5), 2.23 (M:0/5, F:2/5), 2.98 (M:0/5, F:3/5), 3.56 (M:0/5, F:2/5), 4.07 (M:0/10, F:4/5); Clinical Observations: decreased motor activity, hunched posture, ataxia, tremor, hypothermia, piloerection, pigmented stain around eye and snout, gasping, bradypnea, muscle fasciculations; Necropsy: lungs pale and/or congested, liver pale with accentuation of lobular pattern, increased relative lung weights among the decedents; LC50 (95% confidence limit): (M) > 4.07 mg/l, (F) 2.89 (2.01 to 4.16) mg/l; Toxicity Category III; Study acceptable. (Moore, 6/11/97)

342-343; 71387; Landry, T. D., D. A. Dittenber, L. G. Lomax, and J. J. Momany-Pfruender, "Chlorpyrifos: an acute vapor inhalation toxicity study with Fischer 344 rats," study type 813; Dow Chemical Company, Mammalian and Environmental Toxicology Research Laboratory, Midland MI; Lab Study No. K-44793-74; 12/3/86; Chlorpyrifos (Reference No. AGR 219646; purity = 100%), used neat; 0 (air) (24M/24F), 3.5 (6M/6F), 6 (12M/12F), 14 (6M/6F) ppm (analytical); vapor inhalation, 6-hour, whole-body and nose-only exposures; Mortality- one male at 6 ppm (attributed to physical trauma); Clinical Observations- reduced plasma cholinesterase activity (13-24% reduction) in 6 ppm group only (attributed to oral ingestion or dermal absorption of the dose); hyperactivity (considered not exposure-related); Necropsy- no treatment-related findings; reported LC50 (M and F) > 14 ppm (0.22 mg/l); Supplemental. (Duncan, 6/21/91)

Primary eye irritation, rabbit **

**342-716; 154445; Stebbins, K. E., "Dursban F Insecticidal Chemical: Primary Eye Irritation Study in New Zealand White Rabbits," study type 814, The Toxicology Research Laboratory, Health and Environmental Sciences, The Dow Chemical Company, Midland, MI; Study No. K-044793-102C; 11/27/96; Dursban F Insecticidal Chemical (purity:97.6%); 6 animals; Dose: 0.1 ml/eye, liquefied prior to application; Observations: no ocular irritation evident at 24 hours; Toxicity Category IV; Study acceptable. (Moore, 5/30/97)

**342-711; 154317; Buch, S. A. and J. R. Gardner, "Pyrinex Tech.: Irritance to rabbit eye," study type 814; Life Science Research, Stock, Essex, England; Study No. 80/MAK023/143; 4/30/80; Pyrinex Tech; 6 animals (eyes not rinsed); Dose: 100 mg/eye; Observations: no corneal opacity nor iritis evident, Conjunctiva (redness)-grades 2 (1/6) and 1 (5/6) at 24 hours, grade 1 (1/6) through 7 days (termination), no chemosis nor discharge evident at 24 hours; Toxicity Category III; Study acceptable. (Moore, 6/11/97)

Primary dermal irritation **

**342-716; 154446; Stebbins, K. E., "Dursban F Insecticidal Chemical: Primary Dermal Irritation Study in New Zealand White Rabbits," study type 815; The Toxicology Research Laboratory, Health and Environmental Sciences, The Dow Chemical Company, Midland, MI; Study No. K-044973-102B; 11/27/96; Dursban F Insecticidal Chemical (purity: 97.6%); 6 animals; Dose: 0.5 ml/site, liquefied prior to application, 4 hour exposure; Observations: erythema-grade 1 (6/6) at 30 minutes post-exposure, grade 1 (4/6) at 24 hours, grade 1 (2/6) at 48 and 72 hours, clear by 7 days; Toxicity Category IV; Study acceptable. (Moore, 5/30/97)

**342-712; 154319; Buch, S. A. and J. R. Gardner, "Pyrinex Tech.: Irritance to rabbit skin," study type 815; Life Science Research, Stock, Essex, England; Study No. 80/MAK024/144; 4/30/80; Pyrinex Tech; 6 animals; Dose: 0.5 gm/site (4 sites, 2 intact, 2 abraded), moistened with 0.2 ml of physiological saline, 23 hour exposure, occlusive wrap; Observations: (intact sites) erythema-grades 2 (3/6) and 1 (3/6) at 24 hours post-dosing, grade 1 (1/6) at 72 hours and on day 8, edema-grade 1 (1/6) at 24 hours post-dosing, clear by 72 hours; Toxicity Category IV; Study acceptable. (Moore, 6/11/97)

Dermal sensitization **

342-0716 154447 Stebbins, K. E., "Dursban F Insecticidal Chemical: Dermal Sensitization Potential in Hartley Albino Guinea Pigs," The Dow Chemical Company, Midland, MI, 11/27/96. Laboratory Study # K-044793-102E. Investigators first determined that the lowest non-irritating dose of Dursban F was 1% in dipropylene glycol monomethyl ether (DPGME). This dose level was used in the primary study. In all sensitization cases, induction was performed weekly for 3 weeks, and challenge followed two weeks after the third induction (with skin site examination 24 and 48 hrs after challenge). On each occasion, 0.4 ml of material was applied to clipped, intact skin for 6 hours. Test materials for positive controls was either DER 331 epoxy resin (neat) and dinitrochlorobenzene (DNCB, 0.5% in DPGME vehicle). Groups of five naïve animals were dosed twice (one week apart) with each of the three treatments as non-induced controls. Under these circumstances, Dursban F induction/challenge group showed erythema in only one animal (the same animal showing "slight" erythema during induction week 1 and again "slight" erythema 48 hrs after challenge). Main study positive controls were uniformly negative for skin irritation during the first two induction treatments, then frequently showed "slight" erythema at the third induction treatment. Both positive controls typically displayed "slight" to "moderate" erythema at challenge. Treatments of naïve animals were uniformly negative, except for one Dursban F animal with "slight" erythema. Thus test system was viable, and **negative for dermal sensitization for Dursban F. Study is **acceptable**, with no adverse effects. Aldous, 4/14/15.

342-0713 154320 Berman, C. L., "Evaluation of Chlorpyrifos (Pyrinex) for dermal sensitization of guinea pig," Arthur D. Little, Inc., Cambridge, MA, 10/21/1987. Test article was chlorpyrifos, 96.8% purity, Technical grade. This study was examined on 7/29/97 by C. Rech of DPR, who noted several deficiencies, and requested a replacement study. This unacceptable study did not indicate sensitization potential. (Aldous, June 3, 2015).

**342-0744 162453 Bassett, J. and M. Watson, "Dermal Sensitization study (closed-patch repeated insult) in guinea pigs with Chlorpyrifos Technical (Pyrinex)," Department of

Toxicology, Ricerca, Inc., Painesville, OH, 3/31/98. Technical chlorpyrifos (97% purity) was administered to 20 Hartley guinea pigs for the induction phase at 50% concentration in peanut oil, 0.4 ml/site, administered to the shaved dorsal and lateral skin 3 times at weekly intervals. Challenge was 2 weeks after the last induction exposure, administered in 50% propylene glycol. Chlorpyrifos did not elicit a challenge response (i.e. is not a sensitizer). Positive control (DCNB) was effective. This study was considered as negative for sensitization and acceptable by DPR reviewers, D. E. Haskell and J. R. Sanborn (review of Dec. 2, 1998).

SUBCHRONIC STUDIES

Subchronic Oral toxicity, rat:

342-354 74494 Szabo, J. R., J. T. Young, and M. Grandjean, "Chlorpyrifos: 13-week dietary toxicity study in Fischer - 344 rats." Lake Jackson Research Center [The Dow Chemical Co.], Freeport, Texas, 12/28/88. This study was submitted by Dow to contest the CDFA decision of a cholinesterase (ChE) NOEL at 0.05 mg/kg/d in the 2-year study, 345:072300. No comprehensive CDFA review of this subchronic study is necessary at this time, since the purpose of the 13-week study was to set dose levels for the cited 2-year study, which has already been accepted by CDFA. This subchronic study found statistically reduced plasma ChE levels ($p < 0.05$, two tailed) at day 44, but not at day 91. Investigators concluded findings at day 44 "not considered to be of toxicologic or biologic significance." CDFA concludes that the findings are probably treatment effects, which however have no apparent toxicological consequence: the plasma ChE NOEL remains 0.05 mg/kg/d, but a practical NOAEL for ChE inhibition is 0.1 mg/kg/d. C. Aldous, 11/9/89.

Subchronic Oral toxicity, non-rodent: (a supplementary 3-mo. dog study has been reviewed. No further non-rodent subchronic data are requested at this time.

342-306 063996 [Author appears to be McCollister, S. B.], "Results of 93-day dietary feeding studies of O,O-diethyl O-3,5,6-trichloro-2-pyridyl phosphorothioate in beagle hounds," 1/15/64. This study pre-dates modern guidelines, and should be considered only for information on major symptoms of toxicity. Dogs were initially administered chlorpyrifos (98% purity) at 0, 200, 600, or 2000 ppm (report designates units of initial exposure as 0, 0.02, 0.06, and 0.2 percent in diet). There were 4 controls/sex, and 2/sex for each of the other groups. None of these treated dose levels were sustainable, due to cholinergic symptoms such as "dilated and watery eyes, loose stools, vomiting, rough coats, labored breathing and tremors of the legs and head." The 2000 ppm dogs were "essentially starving" as of treatment day 5, so that their diet was reduced to 0.006% (60 ppm) for the balance of the study. The dogs administered initially 600 ppm "were developing gross cholinergic symptoms," and had diets reduced to 0.002% (20 ppm) after 16 days. Dogs originally administered 200 ppm were placed on control diet from day 45 onward. An additional group (N = 2/sex) was administered 200 ppm chlorpyrifos for about 45 days prior to sacrifice (designated as "Group B," with estimated mean exposure of 3.4 mg/kg/d). Dogs were evaluated periodically for plasma and RBC cholinesterase (ChE), and brain acetylcholinesterase (AChE) was assessed at termination. Hematology, limited clinical chemistry, and terminal necropsy and histopathology were also recorded. These data were initially reviewed mainly to justify dose levels used in the chronic dog study (Record No. 036338). Small group sizes and altered dosing regimens limited the utility of this study. Group

B 200 ppm dogs lost weight during their 45-day treatment, at a life stage when control dogs were still gaining weight. In particular one of the two Group B females lost 1.4 kg, and the other (which died shortly before scheduled sacrifice) lost 1.65 kg. The two Group B dogs surviving to termination and which had brain tissue assayed for AChE had brain AChE activities of about 50% of controls. The most relevant blood ChE data for these dogs was at 27 days of continuous treatment: at this time, the highly variable plasma ChE averaged about 10% of pre-exposure activity, and similarly variable RBC AChE activity was less than 20% of pre-exposure activity. Group A 200 ppm dogs had progressively diminishing plasma and RBC AChE inhibition over the time frame from 14 to 41 days of continuous exposure. When these dogs came off treatment, plasma ChE activity was visibly improving by 3 days, and was roughly 80% of pre-treatment levels by the 18th day off treatment. RBC AChE activity was slower to recover: with about 50% of pre-dosing activity between recovery days 18 and 32. RBC AChE activity was still below baseline at the last blood assay on recovery day 41. Brain AChE in these Group A 200 ppm dogs appeared to be in the normal range after 48 days of recovery. Dogs administered the medium dose (60 ppm for all but the first 5 study days) finished the study with plasma and RBC AChE activities at about 50% of pre-exposure values. At termination, males had brain AChE activity in the normal range, whereas females had implausibly low brain activities (i.e. lower than those observed in 200 ppm dogs after about 45 days of dosing). Dogs on the lowest sustained dose level (20 ppm) had plasma ChE activities of about 25% of pre-treatment levels, and RBC AChE activities of about 50% of pre-treatment levels. The 20 ppm males had normal brain AChE activity at termination, whereas one female had normal brain AChE activity, and one had about 40% of normal brain activity. In summary, although this study does not meet modern guidelines, had small group sizes and large variability in key responses, responses provide useful information on high dose effects to augment results from the later dog chronic studies. "One-liner" was re-written by Aldous on June 4, 2015 in support of risk assessment efforts in DPR.

Subchronic Inhalation toxicity, rat:

342-0967 284609 Newton, P. E., "A thirteen week nose-only inhalation toxicity study of chlorpyrifos technical (Pyrinex) in the rat," Bio/dynamics Inc., East Millstone, NJ, 11/14/88, Project No. 88-8058. Fifteen F344 rats/sex/group were dosed by nose-only inhalation to chlorpyrifos vapors (Pyrinex Technical, 95% purity) at targeted concentrations of 0, 5, 10, and 20 ppb, respectively [6 hours/day, 5 days/week, for 13 weeks]. There were no treatment effects on clinical signs (in chamber or at detailed weekly examinations), or on body weight, food consumption, hematology, clinical chemistry [other than possible plasma cholinesterase (ChE)]. Ophthalmology, necropsy observations, and histopathology findings were negative. Brain and RBC AChE activities were unaffected. The 20 ppb male plasma ChE activities were lower than any other contemporary groups and also lower than the limited pre-test ChE activities available. This reviewer considers that this represents a plausible treatment effect, with a NOEL of 10 ppb. NOEL for females = 20 ppb (no changes observed). This is a valid supplementary study (not a study design routinely expected under FIFRA requirements). See also the 1986 study: 342-0343 071389 (Corley et al.), which did **not** find any ChE effects at similar dose levels in nose-only vapor subchronic inhalation conditions like the present study. These equivocal, marginal plasma ChE findings are not designated as "possible adverse effects" under these circumstances. Aldous, June 3, 2015.

342-0967 284608. This is a brief report of corrections to 342-0967 284609, above. The cause of death had been erroneously coded for two rats in the original report. Survival was not dose-related in this study, and the corrections had no consequential impact on study interpretation.

Dermal toxicity, 21/28-day or 90-day:

342-0343 071391 Calhoun, L. L. and K. A. Johnson, "4-day dermal probe and 21-day dermal toxicity studies in Fischer 344 rats," The Dow Chemical Company, Midland, MI, Sept. 1, 1988. Laboratory Study Nos. K-044793-085, K-044793-086. Chlorpyrifos, purity 100±0.1%, was applied in corn oil vehicle 6 hours/treatment to intact clipped dorsal skin (under gauze, secured by bandages) as indicated. Four female rats/sex/group were dosed by dermal application in corn oil at 0, 1, 10, 100, or 500 mg/kg/d for 4 consecutive days at 6 hours/treatment in a **probe study**. That study found that plasma cholinesterase was inhibited by 45%, 91%, and 97% at 10, 100, and 500 mg/kg/d, respectively. Also, RBC cholinesterase was inhibited by 16%, 49%, and 75% at respective dose levels. There were no other definitive findings in the probe study (which also assessed application site response, clinical signs, and body weight). The **primary** study was a 21-day dermal regimen, with dosing each weekday for a total of 15 exposures at 0, 0.1, 0.5, 1, or 5 mg/kg/d (N = 5/sex). Necropsy followed 2 consecutive treatment days in the final week. Investigators evaluated the parameters of the pilot study, plus a limited FOB, hematology, clinical chemistry, and histopathology. There were no definitive treatment effects in the primary study, hence the highest dose tested of 5 mg/kg/d is the NOEL for both sexes. This study is supplementary and not upgradeable (mainly because the dose range in the primary study was well below what the probe study showed to be supportable). Aldous, June 5, 2015.

CHRONIC STUDIES

Combined (chronic/oncogenicity), rat ** † ("possible adverse effect" based on non-oncogenicity findings in Record No. 153114, rat oncogenicity study)

342-345 072300 Young, J. T., and M. Grandjean, "Chlorpyrifos: 2-year dietary chronic toxicity-oncogenicity study in Fischer-344 rats". Dow Chemical Co., Freeport TX, 12/23/88. Chlorpyrifos ("AGR 214637"), 98.5%, in diet at 0, 0.05, 0.1, 1, and 10 mg/kg/d. 10/sex/dose designated for 1-year interim sacrifice: 50/sex/dose designated for 2-year duration. Cholinesterase (ChE) inhibition NOEL = 0.05 mg/kg/d (based on slight plasma ChE inhibition at 0.1 mg/kg/d in females). Acetylcholinesterase ChE inhibition NOAEL of 0.1 mg/kg/d is nevertheless supportable, considering the issues discussed in the review for 354:074494. The NOEL for effects other than ChE inhibition was 0.1 mg/kg/d [based on very slight ($\leq$ 3%) but often statistically significant body weight decrease in 1 mg/kg/d males]. Body weights were statistically significantly reduced in 10 mg/kg/d males (7 to 9% throughout study). The "non-ChE effects" NOAEL was 1 mg/kg/d. Findings at 10 mg/kg/d were frequent perineal yellow staining in females, approximately 50% brain ChE inhibition in males and females, a slight increase in the degree of vacuolation of the adrenal zona fasciculata (males only), and a slight increase in diffuse retinal degeneration in 10 mg/kg/d females. None of these findings indicates possible adverse health effects (see review). ACCEPTABLE.** C. Aldous, 4/21/89, 11/9/89 (see 354:074494). NOTE: Another rat study (see Record No. 153114 under AOncogenicity, Rat@ similarly identified retinal atrophy and cataracts at the highest dose tested (100 ppm in the latter case).

342-363 087917 (supplemental information to 342-345:072300). "Macroscopic postmortem examination of the eyes and associated structures in albino rats (Dow Method)". (Refers to technique used at Freeport, TX, facility), method description dated 9/11/89. Methodology was presented in accordance with a CDFA request, which was made in the 4/21/89 CDFA review of the cited study. C. Aldous, 3/16/90.

342-250 and -251 036335-036337 McCollister, S. B., R. J. Kociba, P. J. Gehring, and C. G. Humiston, "Results of Two-Year Dietary Feeding Studies on DOWCO 179 in Rats" Dow Chemical, Midland, Michigan, 9/20/71. Chlorpyrifos, (presumed technical); 0, 0.01, 0.03, 0.1, 1.0, and 3.0 mg/kg/d in diet. NOEL cholinesterase enzyme inhibition = 0.1 mg/kg/d. NOEL for other systemic effects = 3.0 mg/kg/d (HDT). No oncogenicity observed. Incomplete, UNACCEPTABLE, and not upgradeable Too few animals, too much attrition due to disease (largely chronic murine pneumonia) & dose levels not justified and apparently below the MTD. C. Aldous, 1/28/86.

EPA 1-liner: [2-year feeding, rat, Dow Chemical Co, 9/20/71] Systemic NOEL 3.0 mg/kg/d (HDT); ChE NOEL = 0.1 mg/kg/d. Carcinogenic potential negative up to 3.0 mg/kg/d (HDT). Core grade, Supplementary.

342-044 031074 Published summary of 250/251:036335-036337.

342-013/053 031070 Summary of 250/251:036335-036337.

EPA 1-liner: [2-year feeding, rat, Dow Chemical Co, 9/20/71] Systemic NOEL 3.0 mg/kg/d (HDT); ChE NOEL = 0.1 mg/kg/d. Carcinogenic potential negative up to 3.0 mg/kg/d (HDT). Core grade, Supplementary.

342-044 031074 Published summary of 250/251:036335-036337.

342-013/053 031070 Summary of 250/251:036335-036337.

Chronic, dog **

**342-0252 036338-036339 McCollister, S. B., R. J. Kociba, P. J. Gehring, and C. G. Humiston, "Results of Two-Year Dietary Feeding Studies on DOWCO® 179 in Beagle Dogs," Dow Chemical, Midland, MI, 12/10/71. Chlorpyrifos (97.2% purity) was administered in diets at concentrations adjusted to provide 0, 0.01, 0.03, 0.1, 1.0, and 3.0 mg/kg/d. This study had two phases. In Phase A, there were 3/sex/group treated for 1 year, at which time 1/sex was necropsied. The remaining 2/sex were taken off treatment for 3 months prior to necropsy to evaluate recovery. In Phase B, 4/sex were dosed for 2 years at the above levels. Investigators assessed standard parameters of chronic studies. To assess cholinesterase (ChE) effects, plasma and RBC AChE activities were assayed 3 times pre-treatment and at 6 intervals during Phase A treatment. In Phase B, plasma and RBC AChE activities were assayed twice pre-treatment and at 8 intervals during treatment. Brain ChE was assessed at sacrifices of all dogs in both phases. Plasma ChE inhibition NOEL = 0.01 ppm, based on dose-related inhibition at 0.03 ppm and above. RBC AChE NOEL = 0.1 ppm, based on strong inhibition at 1.0 and 3.0 ppm compared to

the same subjects at pre-treatment assessments. (See also Record No. 284915, which is a composite analysis of the RBC data from this study). Brain ChE activity at 3.0 mg/kg/d was reduced by an average of about 18%, with no evident sex difference in magnitude of response. There is a NOEL of 1.0 mg/kg/d for brain ChE. The NOEL for other effects, including behavioral observations, was the highest dose tested of 3.0 mg/kg/d. The study was designated as **acceptable** on 3/16/90, on receipt of details on preparation of treated food. Previous objections of CDFA to this study were (1) concerns that dosage range may not have adequately challenged the dogs, and (2) lack of reporting of ophthalmological examination data in the final report. These were addressed in submissions 306:063996 and 338:070883, respectively. This study was examined by C. Aldous on1/29/86, 4/11/89, 3/16/90 (see also rebuttal response of 6/4/87 and minutes of meeting with Dow Chemical Co. representatives on 6/29/88). A final examination by Aldous on June 3, 2015 updated this summary and noted recent submission of the cited Record No. 284915 data. This study does not indicate an "adverse effect." ChE enzyme responses in this study are well-characterized and consistent with results of other rat dietary studies such as the rat subchronic, developmental toxicity, and reproductive effects studies.

342-363 087918 (Addendum to 342-252:036338, combined dog study). Submission contains mean body weights/sex and average food consumption for a 6-week period. At the end of the 6-week period, it was determined that 100 ppm in diet corresponded closely to 3.0 mg/kg/d in either sex. From that time on, diets were prepared at fixed levels of 100, 33, 3.3, 1.0, and 0.33 ppm by serial dilutions of diets. These data permit an upgrade of the 1971 dog study to ACCEPTABLE status. Aldous, 3/16/90.

342-0969 270309 (Supplementary to Document No. 342-0252, Record Nos. 036338-036339), Authors of the re-analysis are Mattsson, J. L., L. Holden, D. L. Eisenbrandt, and J. E. Gibson. "Reanalysis with optimized power of red blood cell acetylcholinesterase activity from a 1-year dietary treatment of dogs to chlorpyrifos." The date of the re-analysis was 9/22/2000. Study ID: GHC-5127. Chlorpyrifos (97.2% purity) in the dog chronic study was administered in diets at concentrations adjusted to provide 0, 0.01, 0.03, 0.1, 1.0, and 3.0 mg/kg/d. That study had two phases at the above dose levels, which were comparable in design, so that parallel results could properly be considered together. The present analysis was confined to RBC acetylcholinesterase (AChE) inhibition analysis. Four figures show RBC AChE activities by phase and sex consistent with tabular summary data in Record No. 036338. These figures show marked inhibition of RBC AChE activity at 1.0 and 3.0 mg/kg/d, whereas AChE activities of other groups tended to cluster together at any given time point. Individual pre-treatment AChE activities had more influence on subsequent treatment-phase activities than did possible treatment group effects, except at the two highest dose levels. When investigators normalized the baseline for each group pre-treatment mean, combining data for both sexes in both phases at assay intervals during the first year gave N = 14. A depiction of inter-group differences on this basis found no meaningful differences between control and treatment groups through 0.1 mg/kg/d. When all assays during the first year of treatment were considered together for each group, activity of the 1.0 mg/kg/d group was nearly 50% below baseline, and the 3.0 mg/kg/d group activity was 80% below baseline, whereas all other groups remained within about 4% of baseline. Collectively, these amalgamated data support a NOEL of 0.1 mg/kg/d for RBC AChE. Aldous, June 2, 2015.

342-273 056902 (Tab 3) EPA Office of Pesticide Programs, Toxicology Branch review of study 252:036338-036339. The review was submitted on Oct. 10, 1985 as OPP Toxicology Branch Document #004712. The review classified the study as "Core Minimum Data".

EPA 1-liner: [2-year feeding - dog; Dow Chem. Co.; 12/10/71] Systemic NOEL = > 3.0 mg/kg/d (HDT); Plasma ChE NOEL = 0.01 mg/kg/d; Plasma ChE LEL = 0.10 mg/kg; RBC AChE NOEL = 0.10 mg/kg/d; RBC AChE LEL = 1.0 mg/kg; Brain ChE NOEL = 1.0 mg/kg/d; Brain ChE LEL = 3 mg/kg; Core grade, supplementary [note upgrade to "core minimum" status, indicated in 273:042783].

342-338 070881-070882 are dietary analyses and analytical methods descriptions. These data were evaluated with respect to study 252:036338 in the 4/11/89 CDFA review.

342-338 070883 is a supplement to the original 2-year dog feeding study report. Supplement included ophthalmology data. These data had been submitted to EPA in 1985. These data were evaluated with respect to study 252:036338 in the 4/11/89 CDFA review.

342-044 031073 Published summary of 252:036338.

342-013/053 031070 Summaries of 252:036338-36339

Oncogenicity, rat (see "Combined, Rat" above)

****342-692 153114** Crown, S., "Pyrinex technical oncogenicity study in the rat", Life Science Research Israel, Ltd., July 12, 1990. Laboratory Study # MAK/095/PYR. Pyrinex (chlorpyrifos), 96.1% purity, was administered in diet to 60 F344 rats/sex/group at 0.2, 5, and 100 ppm. There were two control groups (with and without corn oil mixing supplement), each composed of 60/sex/group. Treatment was for 2 yr, except that 5/sex/group were sacrificed at wk 50 for brain cholinesterase (ChE) assays. ChE enzyme inhibition NOEL = 0.2 ppm (inhibition of plasma ChE at 5 ppm). NOEL for non-ChE-related changes = 5 ppm. No definitive cholinergic signs were evident at any dose level. Findings at 100 ppm included modest body weight decrements and over 50% brain ChE inhibition in both sexes, and an increase over baseline incidences of diffuse retinal atrophy and cataracts in 100 ppm females. The latter findings are **"possible adverse effects**" in an **acceptable** oncogenicity study. Aldous, 8/28/97.

Oncogenicity, mouse **

**342-693 153115 Gur, E., "Pyrinex technical oncogenicity study in the mouse", Life Science Research Israel, Ltd.,10/15/92. Laboratory Study # MAK/106/PYR. Fifty-nine CD-1 mice/sex/group were dosed for 79 weeks with Pyrinex technical (chlorpyrifos) in diet at 0, 5, 50, or 250 ppm. An additional 5/sex/group were killed at week 42 for cholinesterase (ChE) evaluation. There was no ChE NOEL in the tested dosage range (dose-related inhibition of plasma ChE in both sexes at weeks 42 and 78). Brain ChE was modestly reduced at 50 ppm and greatly reduced at 250 ppm (residual activity about 20% or less in both sexes and both sampling intervals). RBC AChE was reduced at 250 ppm only. There were no definitive cholinergic signs at any dose. NOEL for other effects was 5 ppm (males displayed excessive lacrimation, opaque

eyes, and hair loss around eyes: all plausibly related to contact irritability of test article with resultant scratching). High dose findings, in addition to signs consistent with local irritation, included hepatocyte vacuolation and cystic dilatation of bulbourethral glands (males), and alveolar macrophage accumulation in lungs (females). Male body weights and food consumption were decreased at 250 ppm, and water consumption was sharply reduced in both sexes at that dose level. Survival of high dose males was remarkably higher than other groups. This is an **acceptable** oncogenicity study with no adverse chronic effects. Aldous, 8/22/97.

**342-253 036340 Warner, S. D., C. G. Gerbig, R. J. Strebing, and J. A. Molello, "Results of a two-year toxicity and oncogenic study of Chlorpyrifos administered to CD-1 mice in the diet," Dow Chemical Toxicology Laboratory, Indianapolis, Indiana, 3/4/80. Chlorpyrifos, Ref. No. 1-500-2: 99.6% purity at 0, 0.5, 5.0, and 15.0 ppm in diet. NOEL = 15 ppm (no toxicity). No oncogenicity. ACCEPTABLE, based on re-reading of blood smears by S. D. Warner, D.V.M., PhD (data in CDFA record 315:065762) answering a question by CDFA regarding possible effects on lymphocytes, (see 5/29/87 CDFA review). (Other concerns which CDFA had on this report were addressed in the 5/29/87 CDFA review). C. Aldous, 1/31/86, 5/29/87, 4/12/89.

342-273 042782 (Tab #4) Supplemental to 253:36340. Davies, D. B., J. T. Tollett, and L. G. Lomax, "Chlorpyrifos: A Four -Week Dietary Study in CD-1 Mice," Dow Chemical, Midland, MI. Dietary administration of 0 or 15 ppm chlorpyrifos (95.7% purity) to CD-1 mice. 4 week study with body weights slightly reduced and plasma and serum ChE levels statistically significantly reduced (see especially. Table 13). This study supports dose level selection for the oncogenicity study (such as 253:036340, above). After 4 weeks, treated mice had about 10% of control plasma cholinesterase (ChE) activity, and about 50% of RBC AChE activity. Brain AChE activity was statistically reduced in treated females and statistically elevated in treated males: magnitudes were small in both cases and appear to have been incidental. Examined 11/24/86 and again on 6/4/15 by C. Aldous. No written review was required or performed.

EPA 1-liner: [2-Year oncogenic - mice; Dow Chemical Co.; 3/04/80]: Systemic and oncogenic NOEL > 15 ppm (HDT). Core grade, minimum.

342-290:050623 (Rebuttal/Additional data to 253:36340) "Results of a Two-Year Toxicity and Oncogenic Study of Chlorpyrifos Administered to CD-1 Mice in the Diet". Dow Chemical Toxicology Laboratory, 3/4/80. New information consists of individual data for blood smear exams, clinical observation and animal disposition, and gross and histopathology. Reviewer (Aldous) examined previously submitted chemical analyses of test material used in this and in one other study, and included evaluation in 5/29/87 review. No adverse effects noted. Study not acceptable, but possibly upgradeable. C. Aldous, 5/29/87.

342-013/053 031071 Summary only of 253:036340.

GENOTOXICITY

Bacterial reverse mutation assay ** (see after In vitro mammalian cell assay section for summary statement)

342-255 036348 Simmon, V. F., A. D. Mitchell, and T. A. Jorgenson, "Evaluation of Selected Pesticides As Chemical Mutagens, In Vitro and In Vivo Studies," (brief summary) SRI, 1977; Salmonella and E. coli. UNACCEPTABLE with no adverse effect reported. Salmonella, 4 strains (no TA98), were tested with and without activation at 0, 1, 5, 10, 50, 100, 500 and 1000 µg/plate and with Escherichia coli at the same concentrations. Chlorpyrifos, 98.8%. No evidence of a cytotoxic concentration or rationale for maximum concentration used. No repeat trial, no individual plate counts if more than one was made. Not upgradeable. J. Gee, 2/13/86.

342-273 042784 Bruce, R. J. and J. A. Zempel, "Chlorpyrifos: Evaluation in the Ames' Salmonella/Mammalian-Microsome Mutagenicity Assay," Dow Chemical, Freeport, Texas, 1986; Salmonella. Chlorpyrifos (95.7%) tested in strains TA1535, TA1537, TA98 and TA100 at 0, 1, 3.16, 10, 31.6 and 100 µg/plate; with and without rat liver activation; 30 min preincubation before plating, triplicate plates, one trial, no evidence for increased reversion rate. UNACCEPTABLE. Report states that a precipitate formed at 100 µg/plate. The earlier study did not mention this. J. Gee, 7/30/86.

342-419 116728. Supplement to 042784. Contains individual plate counts and a revised table of contents. No change in the study status. No worksheet. Kellner and Gee, 7/9/93.

Mutagenicity: In vitro mammalian cell assay **

**342-255 036351 Mendrala, A. L., "Evaluation of Chlorpyrifos in the Chinese Hamster Ovary Cell-Hypoxanthine (Guanine) Phosphoribosyl Transferase (CHO/HGPRT) Forward Mutation Assay," Dow Chemical, Midland, MI, Sept. 3, 1985. Chlorpyrifos, 95.7% purity, was tested at 0, 10, 20, 25, 30, 40 or 50 µM with and without activation for 4 hours. Positive control was 3 mM EMS. There were 5 dishes per treatment, in a single trial. A precipitate formed at 30 µM and above. Survival percentages (relative to 0 µM control) at chlorpyrifos levels of 10, 20, 25, 30, 40 or 50 were 92, 31, 23, 16, 9, and 7%, respectively. Testing thus bracketed practical limits based on both solubility and cytotoxicity. There was no increase in mutation frequency reported for chlorpyrifos in any single trial. Positive control mutation frequency was about 100x above background. Initially, results were considered to be negative for chlorpyrifos mutagenicity, however study was designated as unacceptable, based on lack of a confirming trial (see original review by J. Gee, 2/13/86). Current guidelines (OPPTS 870.5300, page 7) do not routinely require a repeat this assay after a negative response. Consistent with contemporary guidelines, study should be re-classified as acceptable, with no adverse effects. Aldous, June 5, 2015.

342-291 [No Record No., second "Mutagenicity" tab in volume]. Rebuttal comments ref 255:036351. CDFA conclusion was study still UNACCEPTABLE: major concern remaining is lack of a confirmatory test for a negative result. (J. Gee, 6/5/87).

342-291 057655 A table entitled "Analytical determination of stability of Chlorpyrifos in DMSO" in support of 255:036351, above. (Submitted as part of rebuttal document of 12/1/86).

***SUMMARY: The 1977 SRI study (#036348), using four strains of Salmonella (but not TA98) at 0 to 1000 µg/plate, was negative for increased reversion. Also, the CHO/HGPRT study on file showed negative results. EPA accepted this CHO study (#036351) although CDFA review found it unacceptable because there was no repeat. Considering all of these studies, with

no one alone being acceptable, and that #042784 is a repeat of #036348 -- the deficiency for which each was rejected separately -- the 842 data gap is considered filled.

Mutagenicity: In vivo cytogenetics **

342-419 116722 "Evaluation of Chlorpyrifos in an In Vitro Chromosomal Aberration Assay Utilizing Rat Lymphocytes", (Linscombe, V., Mensik D. and Clem, B., Dow Chemical Company, Lab Project Study ID: K-044793-092, 1/29/92). Chlorpyrifos, purity of 98.6%, was evaluated for clastogenic potential using rat lymphocytes treated for 4 hours with concentrations of 0 (DMSO), 5, 16.7, 50, 167.7, 500, 1667.0 or 5000 mg/ml (Assay 1) and 0, 5.0, 16.7, 50.0 and 167.0 mg/ml (Assay 2) with and without S-9 metabolic activation. Cultures were harvested 24 hours after treatment in Assay 1 and 24 and 48 hours after treatment in Assay 2. **No Adverse Effects: No increase in chromosomal aberrations at the highest scorable dose levels of 167 mg/ml (without S-9) and 50 mg/ml (with S-9). ACCEPTABLE. (Kishiyama, Kellner and Gee, 7/1/93).

342-739 161321 Exact duplicate of 342-419 116722 (above). This was submitted in a volume which contained primarily product chemistry data. Aldous, 11/12/98.

342-363 087919 McClintock, M. L., and B. B. Gollapudi, "Evaluation of Chlorpyrifos in the Bone Marrow Micronucleus Test." (Dow, TXT: K-044793-067A, 9/22/89). Chlorpyrifos, lot AGR 214637, 97.9%; tested with CD-1 (ICR) BR mice, with sacrifices of 5/sex/group at 24, 48 or 72 hours after a single oral gavage dosing of 0 (corn oil) or 90 mg/kg b. wt. stated to be 80% of the LD_{50}; cyclophosphamide as positive control; no mortalities but decrease in body weights in the treatment groups; no evidence of micronuclei formation and no clear effect on PCE/NCE. UNACCEPTABLE (only one dose level). (Gee, 3/12/90)

342-255 036350 Gollapudi, B. B., V. A. Linscombe, and J. E. Wilkerson, "Evaluation of Chlorpyrifos in the Mouse Bone Marrow Micronucleus Test," Dow Chemical, Freeport, Texas, 1985; Mouse micronucleus test. UNACCEPTABLE with no adverse effect. Chlorpyrifos, 95.7%, was given by oral gavage to 5/sex/group at 0, 7, 22, or 70 mg/kg with sacrifices at 24 and 48 hours. No statistically significant increase in micronuclei in PCE's is reported; % PCE marginally effected in females only at 48 hours being 63 as compared with 76 for the vehicle control. This is suggestive that a higher dose and/or a longer sampling time should have been included even at the risk of losing some of the animals. In the Appendix, data show that survival at 100 mg/kg would be adequate for the assay. Also, no clinical signs were observed. The high dose reportedly was based on 60% of the LD50 of approximately 111 mg/kg. Guidelines and the meaningfulness of the test call for some signs than a toxic dose was reached, either the MTD for the animal or cytotoxicity to the bone marrow. The only death was in female vehicle control. No data on micronucleated normochromatic erythrocytes are included. Because positive effects have been reported in gene conversion and DNA repair, an adequate test in this test area is needed. Not upgradeable. J. Gee, 2/13/86.

NOTE: EPA considers this study as acceptable, according to the EPA response to CDFA data gap status issues on chlorpyrifos, dated 1/17/89. Aldous, 12/4/89.

342-291 [No Record number, first "Mutagenicity" tab in volume]. Rebuttal comments ref 255:036350. CDFA conclusion was study still UNACCEPTABLE: major concerns remaining are inadequate justification of treatment levels, and lack of a 72 hr sacrifice time. J. Gee, 6/5/87.

Mutagenicity: DNA Damage (not a normally required test category) ** †

342-255 036349 Simmon, V. F., A. D. Mitchell, and T. A. Jorgenson, "Evaluation of Selected Pesticides As Chemical Mutagens, In Vitro and In Vivo Studies," [Segment on mammalian *in vitro* unscheduled DNA synthesis assays] SRI, 1977; UDS in WI-38. UNACCEPTABLE but upgradeable with no adverse effect reported. Chlorpyrifos, 98.8%. WI-38, human embryonic lung fibroblasts, were exposed with and without activation (rat liver) to 0, 10^{-7}, 10^{-6}, 10^{-5}, 10^{-4}, and 10^{-3} with six cultures -S9 and 3 +S9. DPM/µg DNA is reported with no change in the DPM with increasing concentrations. DNA was extracted from the cells by a standard method and an aliquot used to determine the amount of DNA and another portion used to determine the incorporation of tritiated thymidine by liquid scintillation counting as a measure of DNA repair in response to damage by the test article. Missing information on how the CPM were converted to DPM, the quantity of DNA recovered per culture, the passage number of the WI-38, and the rationale for the selection of the concentrations used - whether solubility or cytotoxicity. CDFA review 2-13-86 J. Gee.

342-255 036347 Simmon, V. F., A. D. Mitchell, and T. A. Jorgenson, "Evaluation of Selected Pesticides As Chemical Mutagens, In Vitro and In Vivo Studies --Microbiological Assays" (summary report), SRI, 1977; Saccharomyces cerevisiae D_3. UNACCEPTABLE with a positive effect reported. Mitotic recombination-gene conversion in yeast exposed to a 5% concentration for 4 hours, with and without metabolic activation. The test was repeated. No individual data. Because of the lack of data, the significance of the effect cannot be evaluated but the possible genotoxic effect must be noted. Upgradeable. J. Gee, 2/13/86.

342-255 042609 Simmon, V. F., A. D. Mitchell, and T. A. Jorgenson, "Evaluation of Selected Pesticides As Chemical Mutagens, In Vitro and In Vivo Studies -Microbiological Assays" (summary), SRI, 1977; Escherichia coli and Bacillus subtilis [found under Tab 12, pg. 20]. UNACCEPTABLE with a positive adverse effect reported. Chlorpyrifos, 98.8% purity, at 2.5 µg/disc, was tested with E. coli W3110 and p3478 and with B. subtilis H17 and M45. No activation was included and the test reportedly was repeated 3 times. The comparable zones of inhibition between the strains indicated a larger zone for the repair defective strains. Only one value for each strain is reported. If the full report were submitted, it is possible that the effect could be evaluated for significance. Since no activation was included, the study is not upgradeable. J. Gee, 2/13/86.

**342-273 042785 Mendrala, A. L. and M. D. Dryzga, "Evaluation of Chlorpyrifos in the Rat Hepatocyte Unscheduled DNA Synthesis (UDS) Assay," Dow Chemical, Midland, MI, 1986; Chlorpyrifos (95.7%); primary rat hepatocytes tested for unscheduled DNA synthesis at 10^{-6}, 3.13×10^{-6}, $\times 10^{-5}$, 3.16×10^{-5} and 1×10^{-4} M; triplicate cultures in a single trial; no evidence of UDS; toxicity at the highest concentration. Acceptable. J. Gee, 7/30/86.

SUMMARY: The positive findings in the two microbial studies are somewhat related. The B. subtilis test compares the response of rec^- (recombination defective) with wild type organisms.

The rec⁻ strain is not as competent to repair damage and hence shows a greater inhibition of growth from lethality due to DNA damage. The test in Saccharomyces also measures recombination-type events in competent organisms and the increase in these events confirms the DNA damage. The complete versions of these two reports are needed to assess their significance. The two tests in mammalian cells measure a different repair event (excision repair) with repair replication occurring to fill the DNA gap following removal of damaged bases by excision using different enzymes. The positive findings in the microbial tests cannot be dismissed without more information about the bacterial studies.

REPRODUCTIVE TOXICITY, RAT **

**342-399 097570 "Chlorpyrifos: Two-generation dietary reproduction study in Sprague-Dawley rats", (W. J. Breslin, A. B. Liberacki, D. A. Dittenber, K. A. Brzak, and J. F. Quast). The Toxicology Research Laboratory, Health and Environmental Sciences, The Dow Chemical Company, Midland, MI., Study ID: K-044793-088, 6/5/91). Chlorpyrifos, (technical grade Dursban F insecticide, AGR 273801), 98.5% purity, was fed in the diet to 30 Sprague-Dawley rats/sex/group through 2 generations with 1 litter per generation. Concentrations were adjusted as needed to achieve exposures of 0, 0.1, 1.0, and 5.0 mg/kg/d. Treatment began approximately 10 and 12 weeks prior to breeding for the F0 and F1 adults, respectively. Cholinesterase (ChE) inhibition NOEL = 0.1 mg/kg/d (Plasma and RBC AChE inhibition at 1.0 and 5.0 mg/kg/d). Parental NOEL = 1.0 mg/kg/d (increased degree of vacuolation in zona fasciculata, especially in males; altered tinctorial properties in this tissue in females). Reproductive NOEL = 1.0 mg/kg/d (slightly reduced pup weights and slightly reduced pup survival at 5.0 mg/kg/d). There were no clinical signs specifically indicating ChE inhibition. The reproductive findings at 5 mg/kg/d do not warrant a "possible adverse effects" designation, since brain ChE levels were very markedly depressed at that dose level, and all observed reproductive effects appeared to be due to failure of dams to nurture pups which were otherwise normal. ACCEPTABLE. (Green and Aldous, 5/11/92).

342-685 152365 Exact duplicate of 342-399 097570.

342-374 090493 Interim report for Record No. 097570, above.

342-686 152368 Breslin, W. J., A. B. Liberacki, D. A. Dittenber, and J. F. Quast. "Evaluation of the developmental and reproductive toxicity of chlorpyrifos in the rat". *Fundam. Appl. Toxicol*. **29**:119-130 (1996). This is a published summary of major findings of two accepted studies: the reproduction study above (342-399 097570) and the rat teratology study (342-254 036344). Since the abstract was consistent with DPR 1-liner conclusions for the two studies, this publication was not independently reviewed. Aldous, 7/31/97.

342-254 036341 "Three Generation Reproduction and Teratology Study in the Rat Following Prolonged Dietary Exposure to Dursban, O,O-Diethyl O-3,5,6-Trichloro-2-Pyridyl Phosphorothioate," Dow Chemical, Zionsville, Indiana, 8/20/71. Chlorpyrifos, purity and grade not specified. Doses for the main portion of the reproduction study were 0, 0.1, 0.3, and 1.0 mg/kg/d in diet. ChE inhibition NOEL= 0.3 mg/kg/d. General adult toxicity NOEL = 1.0 mg/kg/d (HDT). Reproductive NOEL = 0.3 mg/kg/d (slightly increased pup mortality in first 5

days post-partum) UNACCEPTABLE, incomplete, not upgradeable (more definitive follow-up study is 254:036343). C. Aldous, 1/31/86.

(An additional copy of 036341 is found in Document No. 342-685, Tab 49 (no record #).

EPA 1-liner: [3-Generation reproduction/teratology - rat; Dow Chem. Co.; 8/20/71] Reproduction NOEL>1.0 mg/kg/d (HDT); Teratogenic NOEL = inconclusive. ChE NOEL=0.1 mg/kg Core grade, minimum

342-254 036343 Dietz, F. K., D. C. Mensik, C. A. Hinze, B. L., Rachunek, and H. W. Taylor, "Dursban Insecticide: Assessment of Neonatal Survival In A Two-Generation Reproduction Study In Rats," Dow Chemical, Freeport, Texas, 7/83. Chlorpyrifos, technical; 0, 0.5, 0.8, and 1.2 mg/kg/d (dietary). Parental toxicity NOEL = reproductive toxicity NOEL = highest dose tested = 1.2 mg/kg/d. UNACCEPTABLE, incomplete, upgradeability unlikely (highest dose level not demonstrably toxic, and no justification offered for dosage selection). C. Aldous 2/7/86.

EPA 1-liner: [Two generation repro - rat; Dow Chem.: 7/83] Reproductive NOEL > 1.2 mg/kg/d (HDT); Systemic NOEL = 0.8 mg/kg; Systemic LEL= 1.2 mg/kg (decreased weight gain); Core grade, supplementary.

342-681 152366 Exact duplicate of 254 036343, above.

342-291: [No Record #, Tab = "Reproduction"] Rebuttal comments ref. rat reproduction studies 254:036341 and 254:036343. Registrant noted that CDFA should consider both reproduction studies together, considering additionally rat chronic data. Registrant suggested that plasma and RBC AChE inhibition data support adequacy of dose. CDFA response: Doses are not justified in terms of parental toxicity, notwithstanding enzyme inhibition effects. Chronic studies are imperfect surrogate studies for evaluation of microscopic changes due to test article, since in chronic studies there is no evaluation of effects which carry over the generations. No change in status of studies. C. Aldous, 6/2/87.

342-686 152367 James, P., A. Stubbs, C. A. Parker, J. M. Offer, A. Anderson, "The effect of Pyrinex (chlorpyrifos) on reproductive function of two generations in the rat", Huntingdon Research Centre, Ltd., 4/22/88. HRC Report # MBS 29/881452. Crl:CD®(SD)BR rats received diets containing 0, 2, 10, or 50 ppm chlorpyrifos (95% purity) in diets over 2 generations (1 litter per generation). Parental rats numbered 28/sex/group in the F0 generation, and 24/sex/group in the F1 generation. Protocol was that of a standard reproduction study, with a few pre-weaning developmental evaluations added (surface righting, air righting, and startle responses; and pupil reflex). There were **no definitive treatment-related effects** (report attributes 3 high dose deaths to treatment, however there were deaths in other groups and no evident unique symptoms in high dose decedents). Study is **not acceptable** as presented (report evidently contains 401 pages, but only pp. 1-228 are present, "confidentiality" stamps cover much of the text, more definitive high dose justification would be needed, and histopathology of parental rats is needed if this study is to be upgraded). Aldous, 8/22/97.

DEVELOPMENTAL TOXICITY

Rat Developmental Toxicity **

**342-254 036344 Ouellette, J. H., D. A. Dittenber, P. M. Kloes, and J. A. John, "Chlorpyrifos: Oral Teratology Study in Fischer 344 Rats," Toxicology Research Lab., Dow Chemical USA, Midland, MI, 7/5/83. Chlorpyrifos, 96.6%. 0, 0.1, 3.0, and 15 mg/kg/d (gavage). Maternal NOEL (excluding cholinesterase (ChE) inhibition) = 3.0 mg/kg/d (cholinergic effects). Maternal ChE inhibition NOEL = 0.1 mg/kg/d (inhibition of plasma and RBC AChE). Developmental toxicity NOEL = 15 mg/kg/d (HDT). ACCEPTABLE due to submission of supplementary information. See CDFA Rebuttal comments, C. Aldous, 6/1/87. (Study had been classified unacceptable in previous review by C. Aldous 2-10-86). C. Aldous, 6/1/87.

EPA 1-liner: [Teratology - rat; Toxicology. Research Lab; 7/5/83] Teratogenic and fetotoxic NOEL> 15 mg/kg/d (HDT); Maternal NOEL= 0.1 mg/kg; Maternal LEL= 3.0 (ChE inhibition) Core grade, minimum.

342-683 152360 (exact duplicate of 342-254 036344, above).

342-291 050624 (Rebuttal by Ouellette *et al*. to primary study 254:036344). Considered in 6/1/87 review of primary study, 254:036344, above.

342-291 050625 (Pilot study to primary study 254:036344). Ouellette, J. H., D. A. Dittenber, R. J. Kociba, and J. A. John, "Chlorpyrifos: Oral teratology probe study in rats". Toxicology Research Lab, Dow, 1/4/83.

Chlorpyrifos, 96.6%. 0, 3, 10, and 30 mg/kg/d by gavage in cottonseed oil. Study demonstrates that 30 mg/kg/d is severely toxic to dams: maternal deaths, typical cholinergic signs, high number of resorptions. Slightly matted haircoat and slight enlargement of adrenals were observed at 15 mg/kg/d. This pilot study clearly substantiates the adequacy of the dosage range selected for the primary study, 254:036344. C. Aldous, 6/1/87.

342-695 153117 Rubin, Y., N. Gal, T. Waner, and A. Nyska, "Pyrinex teratogenicity study in the rat", Makhteshim-Agan of North America Inc., 7/15/87. Laboratory Study #MAK/101/PYR. At least 21 pregnant CD rats/group were dosed with Pyrinex Technical (chlorpyrifos), purity 96.1% by gavage in corn oil on days 6-15 p.c. at 0, 0.5, 2.5, or 15 mg/kg/d. No maternal ChE NOEL was identified (dose-related plasma ChE inhibition at all dose levels at day 15 p.c., with restoration of normal ChE activity in all but high dose dams by p.c. day 20. Maternal functional NOEL = 2.5 mg/kg/d (tremors in 3/21 dams, transient food consumption reduction, modest but consistent body weight decrement). Developmental NOEL = 2.5 mg/kg/d (slight increase in early resorptions). **No adverse reproductive effect at dose levels sufficient to elicit cholinergic responses. Acceptable. Aldous; May 1, 1997.

342-683 152361 Exact duplicate of 342-695 153117, above.

342-681 152354 Muto, M. A., F. Lobelle, J. H. Bidanset, and J. N. D. Wurpel, "Embryotoxicity and neurotoxicity in rats associated with prenatal exposure to Dursban", *Veterinary and Human Toxicology* 34, 498-501 (1992). Investigators from the Department of Pharmaceutical Sciences, St. John's University, Jamaica, NY. Test article was a formulation of 1% chlorpyrifos, 6%

xylene, and 93% water. Suspensions were diluted to an unspecified dosing volume with saline. Dosing was ip, either on days 0-7 or on days 7-21 at dose levels of 0, 0.03, 0.1, or 0.3 mg/kg/d of chlorpyrifos. In most cases, there were 8 pregnant rats (strain unspecified) per dose for each treatment time period. Dams were allowed to litter, then pups were evaluated for "general viability, body weight and physical characteristics". Selected pups were evaluated for "neurotoxicity" on a rotorod on day 16. The same day, pups were evaluated for motor behavior (subjective open field observation) and for righting behavior on an inclined screen. An additional study evaluated the neurotoxicity and behavioral tests following exposures of 0.1 or 0.3 mg (presumably ip) as single doses on day 3, 10, or 12 postpartum, or as multiple doses on days 6-10 postpartum. Investigators claimed that treatment caused increased embryolethality following dosing on gestation days 0-7 and gestation days 7-21. Since the highest embryolethality was in the lowest dose group treated on gestation days 0-7 (77% lethality), these data are of questionable value. Incidences of "physical abnormalities" were reportedly highest in 0.1 and 0.3 mg/kg/d groups (66 and 55%, respectively), among litters treated on gestation days 0-7. No corresponding control data were presented. Rotorod performance was reported to be impaired in pups dosed at 0.3 mg/kg on days 3, 10, and 12, and in offspring of dams dosed with 0.3 mg/kg on days 7-21, and in offspring of dams dosed with 0.03, 0.1, or 0.3 mg/kg on days 0-7. These data are suspect because differences between mean values at any treatment time dwarfed differences between dose groups at individual treatment times, even though all pups were evaluated at day 16. The study is unacceptable (in addition to deficiencies noted above, test article does not represent either the AI or any end use product; the route (ip) is not a plausible route of human exposure; the conclusions are speculative, evidenced by discussion of possible delayed distal neuropathy, while ignoring a valid 1986 subchronic hen neurotoxicity study, which would have been available through "freedom of information" provisions long before the time of this publication; and the presentation of the article shows that it could not have gone through a meaningful review, indicated by the above deficiencies, and by misspellings (the term "access" when "assess" was meant) and by failures to provide control data in figures or to provide numerical counts for types of purported treatment-caused malformations. No more information is requested of this paper. Aldous, 9/3/97.

342-681 152355 Nimphius, M. J. (M.S. dissertation under direction of graduate advisor J. H. Bidanset at St. John's University College of Pharmacy and Allied Health Professions, New York). "The effects of chlorpyrifos and xylene on embryonal and fetal development in the rat" (approval date: 9/13/95). Sprague-Dawley rats were dosed subcutaneously with 0, 0.3, 3, or 10 mg/kg/d chlorpyrifos (analytical grade, 99% purity) on days 1-7 of gestation (typically 8/dose/group), then sacrificed on gestation day 19 or 20. Other rats received xylene or chlorpyrifos/xylene s.c. on the same schedule. Parameters examined were resorptions, weights and lengths of fetuses, and external malformations. None of these showed biologically meaningful changes. This study is unacceptable (it does not conform to any FIFRA study design: route is not relevant to plausible human exposure, timing of dosing is not useful for evaluation of malformations, fetal examinations were only for grossly evident changes, group sizes were too small, and sacrifices were not done on a fixed gestation day). The study does not make a significant contribution to chlorpyrifos hazard assessment. Aldous, 9/3/97.

[Rat Developmental Toxicity Studies: Chlorpyrifos Metabolites]

342-684 152362 Hanley, T. R., G. J. Zielke, and L. G. Lomax, "3,5,6-Trichloro-2-pyridinol: oral teratology study in Fischer 344 rats", The Dow Chemical Co., Midland, MI, 7/23/87. Laboratory Study #: K-038278-011. Groups of 32-34 mated Fischer 344 rats were dosed with 0, 50, 100, or 150 mg/kg/d 3,5,6-trichloro-2-pyridinol (TCPy, 99.7% purity) by gavage in 4 ml/kg Methocel on days 6-15 of gestation in a standard teratology study. Maternal NOEL = 50 mg/kg/d (minor body weight gain decrements). Developmental NOEL = 150 mg/kg/d (HDT). An acceptable study of a major metabolite of chlorpyrifos, with no adverse effect indicated. Aldous, 7/31/97.

Rabbit Developmental Toxicity ** (No adverse effects for technical chlorpyrifos, however high doses of a metabolite caused developmental toxicity)

342-694 153116 Rubin, Y., A. Nyska, and T. Waner, "Pyrinex teratogenicity study in the rabbit", Life Science Research Israel Ltd., 7/15/87. Laboratory Study # MAK/103/PYR. At least 14 HY/CR (a NZW variety) rabbits per group were dosed by gavage in corn oil with chlorpyrifos (Pyrinex Technical, purity 96.1%) on days 7-19 p.c. at 0, 1, 9, 81, or 140 mg/kg/d. Maternal NOEL = 81 mg/kg/d (body weight gain decrement during treatment period). Developmental NOEL = 81 mg/kg/d [reduced crown/rump length, reduced fetal weight, ossification delays (indicated by non-ossification of fifth sternebra and/or xiphisternum)]. No adverse effects are indicated. For comparison, the pilot study had found 100% lethality in does at 270 mg/kg/d. **Acceptable. Aldous, 4/29/97.

342-685 152364 Exact duplicate of 342-694 153116, above.

[Rabbit Developmental Toxicity Studies: Chlorpyrifos Metabolites]

342-684 152363 Hanley, T. R., G. J. Zielke, and L. G. Lomax, "3,5,6-Trichloro-2-pyridinol: oral teratology study in New Zealand White rabbits", The Dow Chemical Co., Midland, MI, 7/23/87. Laboratory Study #: K-038278-015. Sixteen does/group were dosed with 0, 25, 100, or 250 mg/kg/d 3,5,6-trichloro-2-pyridinol (TCP, purity 99.7%) by gavage in aqueous 0.5% Methocel on gestation days 7-19 in a teratology study. Maternal NOEL = 100 mg/kg/d (minor maternal body weight decrement during treatment). Developmental NOEL = 25 mg/kg/d (hydrocephaly and dilated cerebral ventricles). The latter observations were not statistically significantly increased in either of the two higher dose groups compared to concurrent controls, however historical background incidences were very low (compare hydrocephaly litter incidences of 2/13 and 3/13 at 100 and 250 mg/kg/d, respectively, to a historical incidence of 1/839 litters). These findings indicate a **possible adverse effect**. For perspective, 100 mg/kg/d of TCP is the molar equivalent to 66% of a chlorpyrifos dose which caused 100% mortality in LSRI Report MAK/102/PYR (cited in the accepted chlorpyrifos rabbit teratology study under DPR Record No. 153166). **Acceptable** metabolite study. Aldous, 7/31/97.

Mouse Developmental Toxicity **

**342-254 036345 Deacon, M. M., J. S. Murray, M. K. Pilny, D. A. Dittenber, T. R. Hanley, Jr., and J. A. John, "The Effects of Orally Administered Chlorpyrifos on Embryonal and Fetal Development in Mice," Dow Chemical, Toxicology Research Lab., Midland, MI, 7/24/79; Chlorpyrifos, presumed technical; 0, 0.1, 1, 10, and 25 mg/kg/d by gavage; NOEL for maternal

functional toxicity = 1 mg/kg/d [cholinesterase (ChE) effects as salivation, tremors, etc.]. ChE enzyme NOEL = 0.1 mg/kg/d (significant inhibition of maternal plasma ChE at 1 mg/kg/d). Developmental toxicity NOEL = 10 mg/kg/d (decreased fetal length and weight, delayed ossification in skull, sternebrae). ACCEPTABLE, in consideration of additional information in 291:050626 (See one-liner below). Report was previously not accepted (CDFA review 2/13/86, C. Aldous). C. Aldous, 6/1/87.

342-291 050626 (Addendum to 254:036345, primary mouse teratology study). Dow Chemical, Midland, MI, 7/24/79. New information provides grade of test article, dates of preparation of dose solutions, individual necropsy sheets for dams dying prior to term, and rationale for selection of mouse as test animal. C. Aldous, 6/1/87.

EPA 1-liner: Teratology - mice; Toxicology. Research Lab.; 7/24/74 [sic: presumed this is the 7/24/79 study]; Teratogenic NOEL > 25 mg/kg/d (HDT); fetotoxic NOEL = 10 mg/kg fetotoxic LEL = 25 mg/kg (decreased fetal length, increased skeletal variants); Plasma and RBC AChE NOEL = 0.1 mg/kg/d.

342-013/053 031072 Summary of 254:036345 (see above).

342-682 152359 (Tab 43). Deacon, M. M., J. S. Murray, M. K. Pilny, K. S. Rao, D. A. Dittenber, T. R. Hanley, Jr., and J. A. John, "Embryotoxicity and Fetotoxicity of Orally Administered Chlorpyrifos in Mice", *Toxicol. Appl. Pharmacol.* 54:31-40 (1980). This is the published report corresponding to 342-254 036345, above.

Developmental Toxicity: Allegations of Effects on Humans

The following critical review by Dr. J. E. Gibson and associated support documents were submitted in response to allegations that chlorpyrifos elicited human malformations

342-680 152356 Gibson, J. E., "Critical review of allegations associating Dursban with human teratogenicity", 12/23/96 (analysis was given DowElanco Study ID JEG122396). Dr. Gibson was responding to allegations by Dr. J. Sherman that chlorpyrifos was the causative agent for several human birth defects. The most detailed version of Dr. Sherman's report was in Int. J. Occup. Med. Toxicol., 4:417-431 (1995). Dr. Gibson's primary objections to the article were (1) Dr. Sherman does not have the training and experience to properly perform such an analysis, (2) the four cases described do not present a coherent pattern of effects, (3) the possibilities of genetic causation were ignored, even though in most cases one or more physicians experienced in evaluation of birth defects attributed findings to genetic defects (4) none of the cases offered measures of exposure, (5) statistical analysis in the article was unsound, (6) outcomes of cited animal studies were misunderstood or misrepresented, and (7) the article did not state the author's role as paid consultant in lawsuits filed by the three affected families, which disclosure is an ethical responsibility of authorship. All lawsuits involving the four children have been dismissed. Neither the Sherman report (DPR Record No. 152349) nor Dr. Gibson's review are primary sources of new data, hence do not have independent worksheets. **Supporting data, including some complete studies, follow in Document Nos. 342-681 to 342-686. "One-liners" describing these submissions are found in this worksheet.** Aldous, 8/22/97.

Records submitted in support of 342-680 152356 above, included: Document No. 342-681: Record Nos. 152349, 152350, 152351, 152352, 152353 152354,152355; and Document No. 342-682: Record Nos. 152357, 152358, 152359.

NEUROTOXICITY

Acute neurotoxicity, rat **

342-448 126408 Wilmer, J., et. al. "Chlorpyrifos: Acute Neurotoxicity Study in Fischer 344 Rats", (Dow Chemical Company, Study ID: K-044793-093B, 9/11/92). Chlorpyrifos (purity 98.1%, lot #MM-890115-616) was administered in a single oral gavage to 10 Fischer 344 rats/sex/group at levels of 0, 10, 50 or 100 mg/kg. Body weights of mid- and high-dose rats were significantly reduced on day 2 but not on day 8 or 15. Clinical signs (increased perineal soiling) in mid- and high-dose rats and FOB observations (incoordination, decreased muscle tone, tremor, increased lacrimation and salivation) in high-dose females were seen soon after dosing (day 1). Motor activity was reduced in mid- and high dose rats on day 1; some reductions persisted to day 8 in high-dose females. NOEL (Body wt., Clinical signs, FOB and motor activity) = 10 mg/kg. No histopathologic changes. NOEL (histopathology) = 100 mg/kg. **No Adverse Effects. Original DPR review had requested additional purity, stability and homogeneity data on the dosing material, justification for dose level selection, and clarification of the statistical methods used, as criteria for "acceptable" status. These data were provided (see review for Record No. 132457, below) and report is now **acceptable**. This study type is classified as "supplemental" for SB 950 at this time. Kellner and Gee, 7/5/94; Aldous, 4/9/97.

342-492 132457 [Cover letter referencing supplementary data was by Blewett, T. C. The acute range-finding study in this record supporting dose selection for the acute neurotoxicity study was by Wilmer, J. W. *et al.* (Study ID K-044793-093A)]. Addendum to Document # 342-448, Record # 126408 (rat acute neurotoxicity). Cover letter date: 10/4/94. The three primary acceptability concerns expressed in the original DPR review have been adequately addressed: characterization of technical and treated diets for content, stability, and homogeneity; range finding study clinical signs data as evidence that selected dose levels were appropriate; and evaluation of statistical significance for major parameters of this study. In the range-finding study, two F344 rats/sex/group were dosed once by corn oil gavage at 50, 100, 150, and 200 mg/kg. Clinical signs consistent with ChE inhibition peaked at about 6 hr after dosing. Major signs were decreased activity, incoordination, lacrimation, muscle twitches, perineal soiling, salivation, and tremors. These signs were well established at 100 mg/kg and above, especially in females. Range finding study data are sufficient to justify dose levels used in the neurotoxicity study. Additional statistical data are consistent with interpretations in the original DPR review. The study is re-classified as **acceptable**, with **no adverse effects** other than expected ChE inhibition-associated changes. Aldous, 4/9/97.

90-day neurotoxicity, rat **

**342-445 126304, "Chlorpyrifos: 13-Week Neurotoxicity Study in Fischer Rats", (Shankar, M., Bond, D. and Crissman, J., Dow Chemical Company, Laboratory Project K-044793-094, 9/16/93). Chlorpyrifos, purity 98.1%, was administered in the feed at concentrations of 0, 0.1, 1, 5 or 15 mg/kg to 10 Fischer 344 rats/sex/group for 13 weeks. High-dose males and females had

reduced motor activity at week 4. Perineal soiling (low incidence) was observed for 5 and 15 mg/kg/d groups; NOEL (for clinical signs, FOB, motor activity) = 1 mg/kg/d. No histopathologic findings. Neuropathological NOEL = 15 mg/kg/d. **No Adverse Effects.** Report was originally classified as unacceptable, but upgradeable. Data provided in Record No. 132458 (see below) allowed an upgrade to **acceptable** status. This study type is considered "supplemental" under SB 950 at this time. Kishiyama, Kellner and Gee, 7/6/94; Aldous, 4/8/97.

342-493 132458 (Addendum to Document # 342-445, Record # 126304). Cover letter dated 10/4/94. The three primary acceptability concerns expressed in the original DPR review have been adequately addressed: characterization of technical and treated diets for content, stability, and homogeneity; ChE inhibition data as evidence that selected dose levels were appropriate; and evaluation of statistical significance for major parameters of this study. Data obtained from a 1988 subchronic feeding study found ChE enzyme inhibition NOEL = 0.1 mg/kg/d (inhibition of plasma ChE in both sexes and of RBC AChE in females at 1 mg/kg/d). ChE-related clinical effects NOEL = 1 mg/kg/d (perineal staining in occasional females at 5 and 15 mg/kg/d). Motor activity reduction, at 15 mg/kg/d during the week 4 evaluation only, was confirmed statistically. NOEL for findings other than probable acute ChE effects = 15 mg/kg/d (HDT). The study is re-classified as **acceptable**, with **no adverse effects** other than expected ChE inhibition and associated changes. Aldous, 4/8/97.

342-448 126409 Spencer, P. *et. al*. "Positive Control Exercises: Motor Activity, Functional Observational Battery and Neuropathology". Dow Chemical Co. submitted this report in support of -445:126304 and -448:126408; it contains validation studies of motor activity tests, functional observational battery (FOB) assays and neuropathological examinations using rats that were administered compounds with well-documented neurotoxic potential. This document was found to be ACCEPTABLE to satisfy the FIFRA guidelines for positive controls. An evaluation of these studies is included in the background sections of the acute and 13-week rat neurotoxicity studies mentioned above. No Worksheet. Kellner and Gee, 7/18/94.

4-week rat oral gavage cognitive study **

**342-747 162522 Maurissen, J. P., M. R. Shankar, and J. L. Mattsson, "Chlorpyrifos: cognitive study in adult Long-Evans rats", The Dow Chemical Co., Midland, MI, 4/29/96, Laboratory Project ID: K-044793-096. Female Long-Evans rats were dosed by gavage in corn oil with 0, 1, 3, or 10 mg/kg/d chlorpyrifos (98.1% purity) for 4 weeks. The cognitive study was a "delayed matching to position task" design. Cognitive testing was done during each of the treatment weeks and for 4 weeks thereafter, by methods described below. Rats were placed on modest food restriction to provide incentive to seek the "food reward" in the study. Rats were trained and selected for the study, based on positional memory performance. In a given test, a rat was presented with one of two retractable levers. The rat was to press the lever offered, cross the cage and interrupt a beam at the food cup within 10 seconds, and then return to the side of the cage with the levers. At this time, both levers would be presented. The rat was expected to select and press the correct lever (i.e., the one just presented a few seconds earlier) within 10 seconds after leaving the food cup station. A correct choice made a food reward available at the food cup. In addition to the above test, the task was made more difficult by involving progressively longer delays (up to 15 seconds) between the first lever press and the time in which a nose-poke in the food cup would extend the levers (called the delayed matching-to-position or

"DMPT" paradigm). These rats were also examined twice daily on treatment days during the 4-wk dosing period: observations were about 3 hr and 21 hr after the most recent treatment. Satellite groups of 6/dose/interval were used for ChE assays and brain NTE assays on the day following the last treatment, and 1 month after the last treatment. The 1998 DPR review placed the NOEL for memory retention at 3 mg/kg/d (considering a small apparent memory retention change at 10 mg/kg/d to be a "possible adverse effect"). **This determination was subsequently changed** (see review for Document No. 342-789, immediately below). NOEL for clinical observations is 1 mg/kg/d (miosis). There is no NOEL for ChE inhibition (marked inhibition of plasma and RBC AChE and modest (8%) inhibition of brain ChE at 1 mg/kg/d). Some high dose observations associated with the DMPT tests were appropriately considered by investigators to have been attributable to motor slowing and/or decreased motivation (increased "actual total delay", increased "void trials", and decreased numbers of nose-pokes per trial). None of these were noted after the end of the treatment period. Report was originally classified as not acceptable (requiring dosing solution analysis). Such data were subsequently provided (see immediately below). Study is **acceptable**. Aldous, 11/6/98, 10/12/99.

342-789 168961, 168962, and 168963. **Supplemental information to the above cognitive study (Record 342-747 162522)**. Additional data and explanatory text were provided. Essential responses summarized below are detailed in review "W162522 s01.wpd". New data supplied dosing solution analyses, and additional tables showing mean correct responses for individual animals and for treatment groups, including methodology used to obtain memory retention slope values. **These data allow an upgrade of Record No. 162522 to acceptable status.** In addition, investigators provided a statistical analysis of slopes of the memory retention curves for the various treatment groups. Data show that there were no statistically significant responses, hence data **do not demonstrate a possible adverse effect** (a change from the previous review). The variability of the data is sufficiently large that only a very substantial decrease of memory retention would have been detectable, thus the present study conditions **did not provide a sensitive test**. Aldous, 10/12/99.

Developmental neurotoxicity, rat **

**342-746 162521, Hoberman, A. M., "Developmental neurotoxicity study of chlorpyrifos administered orally via gavage to Crl:CD®(SD)BR VAF/Plus® presumed pregnant rats", Argus Research Laboratories, Inc., 5/1/98. Sponsor Protocol No. K-044793-109; Argus Study ID 304-001. Crl:CD®(SD)BR VAF/Plus® presumed pregnant rats were gavaged on gestation day 6 through lactation day 11 with chlorpyrifos (99.8%) in corn oil at 0, 0.3, 1, and 5 mg/kg/d. Initially there were 25 dams/group on treatment. On lactation day 5, twenty litters/treatment were continued on study. Four subsets of 20 pups/sex/group were selected on lactation day 5, each consisting of 1/sex/litter. Primary investigations for the subsets were: (Subset 1): morphometric evaluations and histopathology of brains after postpartum day 12 sacrifice, (Subset 2): spatial delayed alternation studies at postpartum days 23-25 and 62-91, (Subset 3): motor activity testing on postpartum days 14, 18, 22, and 61: auditory startle on postpartum days 23 and 62, (Subset 4): evaluation of developmental landmarks (pinna unfolding, eye opening, preputial separation or vaginal opening); brain weight evaluation in 10/sex/group sacrificed during lactation days 66-71, and neurohistopathology following *in situ* perfusion of 6/sex/litter. Maternal NOEL = 0.3 mg/kg/d (brain ChE inhibition). Clinical signs of ChE inhibition were observed in 5 mg/kg/d dams. Developmental NOEL = 1 mg/kg/d (decreased neonatal survival;

decreased pup growth, with 11% reduction in body weight at 66 days postpartum in males; maturational delays of pinna unfolding, preputial separation in males, and vaginal patency in females; reduced morphometric dimensions of cerebellum and hippocampal gyrus at day 12 postpartum compared to concurrent and historical controls, reduced morphometric dimensions of parietal cortex and hippocampal gyrus at day 66 postpartum compared to concurrent and historical controls in high dose females, reduced motor activity at day 14 postpartum, reduced auditory startle habituation peak response and increased latency to response at day 23 postpartum). This study was classified as "not acceptable but upgradeable" in the initial review, with the primary concern being appropriateness of the validation studies for evaluation of spatial delayed alternation. The response in Record No. 168955 (below) addressed the advantages of the using memory retention as a function of time for validation of technique, as compared with memory reduction due to exogenous chemicals. The investigators' response gave examples of many confounding effects of exogenous chemicals on parameters other than on memory. Study findings are not of sufficient magnitude or persistence to be considered as "adverse". Report is now **acceptable**. Aldous, 11/13/98 and 9/17/99.

342-769 164347 Submission of morphometry and histopathology data on F1 rats sacrificed after day 66 in Record No. 162521, above. Data were incorporated into the review for the main study under that Record Number. Aldous, 11/12/98.

342-789 168955, 168959, and 168960. Supplemental information to developmental neurotoxicity study 342-746 162521. Final report date of update: 5/7/99. Additional data and explanatory text were provided, **allowing an upgrade of Record No. 162521 to acceptable status**. Essential responses summarized below are detailed in review "s162521 s01.wpd". The validation studies for evaluation of spatial delayed alternation, which were based on temporal patterns of memory performance over sufficient duration to show a consistent linear change over time, were shown to be satisfactory. Representative micrographs prepared by the pathologist were presented, demonstrating several of the commonly encountered lesions following insult to the several areas of the CNS, dorsal root ganglia, and peripheral nerves. Additional brain morphometric data requested by US EPA were provided, plus selected published articles. One article showed that poor nutrition reduces pup brain weight increases, although to a much lesser extent than the decrement of body weight gain. Another article determined that the reductions of dimensions in brain regions appear to affect all brain morphometric measurements proportionately. A third article showed that poor nutrition leads to locomotion delays which are quite remarkable during lactation days 14-16, whereas some components of coordinated movement and altered posture remain affected for a longer time. Aldous, 9/17/99.

342-832 (suppl. to 342-746) 182481 (suppl. to 162521) Hoberman, A. M., Report Supplement 3 to: "Developmental neurotoxicity study of chlorpyrifos administered orally via gavage to Crl:CD®(SD)BR VAF/Plus® presumed pregnant rats, "Argus Research Laboratories, Inc., dated 5/1/98 (of original study), this supplement dated Oct. 9, 2000. Protocol No. of this supplement: 304-001. Brain morphometric data from the original report were re-tabulated alongside historical control data from 4 or 5 studies per parameter. Only one measurement having a high dose value statistically significantly different from concurrent controls was outside the range of the historical controls: the cerebellar anterior/posterior dimension in 5 mg/kg/d male 12-day pups was significantly below concurrent control dimension, and also outside the range of the available historical controls. Females did not suggest such a relationship at 12 days, and neither sex

showed altered cerebellar anterior/posterior distance after 66 days. In the context of the demonstrated high maternal and neonatal toxicity of this dose, the supplemental data reinforce the lack of demonstrated special toxicity of the test article toward the developing nervous system. Supplemental to a previously acceptable study with no adverse effects. Aldous, 9/26/01.

342-824 178362 [Same report as 342-746 162521, above].

Delayed neurotoxicity, hen **

**342-291 051119 Barna-Lloyd, T., J. R. Szabo, and J. T. Young, "Chlorpyrifos: Subchronic Organophosphate-Induced Delayed-Neurotoxicity (OPIDN) Study In Laying Chicken Hens," (Report No. TXT:K-044793-064), Health & Environmental Sciences, Dow Chemical, Freeport, Texas, 4/86. Chlorpyrifos, tech. (approx. 96% purity). 0, 1, 5, and 10 mg/kg/d. No evidence of delayed distal neuropathy. 10 mg/kg/d chlorpyrifos caused weight loss, diminished egg laying capacity, and transient abnormal gait (fully reversible between dosing periods, and not persistent throughout study). Study fills neurotoxicity data requirement. C. Aldous, 6/3/87.

342-255 036346 Rowe, L. D., S. D. Warner, and R. V. Johnston, "Acute Delayed Neurotoxicologic Evaluation of Chlorpyrifos in White Leghorn Hens," Dow Chemical, Lake Jackson, Texas, 5/22/78; Chlorpyrifos, tech; 0, 50, and 100 mg/kg (gelatin capsule); NOEL = 100 mg/kg for behavioral or microscopically evident delayed neuropathy (Highest dose tested) NOT ACCEPTABLE, not complete, not upgradeable (no repeat dosage at day 21 when no effects were observed, not all currently required tissues examined.) C. Aldous, 2/13/86.

EPA 1-liner: [Acute delayed neurotoxicity - hen; Dow; 5/22/78] LD50 in hens= 50 mg/kg Negative @ 50 & 100 mg/kg. Core grade, minimum.

342-496 132855 Abou-Donia, M. B., and K. R. Wilmarth, "DowElanco chlorpyrifos joint neurotoxic action of chlorpyrifos and safrotin in hens (Duke Univ. Medical Center Dept. of Physiology and Pharmacology, Durham, NC). Assigned to Worker Health and Safety Branch for review. (Aldous, 8/8/97).

342-745 162520 (No Author) "Preliminary Report: Assessment of neurotoxicity associated with co-exposure to the organophosphorus insecticides chlorpyrifos and diazinon". White leghorn hens were dosed with maximal levels of chlorpyrifos and/or diazinon and kept alive with atropine and 2-PAM for 96 hours prior to sacrifice and assays of ChE (plasma and brain), and brain NTE. There were apparently cumulative effects for brain and plasma ChE. Although diazinon by itself did not affect NTE activity, diazinon potentiated the NTE inhibition of chlorpyrifos from 35% to 65% of normal. There is insufficient information in this preliminary report to warrant a Medical Toxicology Branch worksheet. Aldous, 11/09/98.

IMMUNOTOXICITY **

** 342-0907; 258212; AChlorpyrifos: Assessment of Immunotoxic Potential Using the Sheep Red Blood Cell Assay after 28-Day Dietary Exposure to Rats@; (D.R. Boverhof, J.A. Murray, R. Sura; Toxicology & Environmental Research and Consulting, The Dow Chemical Company,

Midland, MI; Study ID No. 101023; 6/28/10); Ten female Sprague-Dawley rats/group received 0, 0.4, 2.0 and 10.0 mg/kg/d of Chlorpyrifos technical (lot no. KC28161419; purity: 99.8%) in the diet for 28 days. Another 10 females were dosed by intraperitioneal injection with 20 mg/kg/d of cyclophosphamid from day 24 through day 28 as the positive control group. No deaths occurred during the treatment period. There was no treatment-related effect upon the mean body weights or food consumption. The hematology parameters were not affected by the treatment. Red blood cell cholinesterase (ChE) activity was reduced in a dose-related manner for all treatment groups. Brain ChE activity was significantly less than that of the controls at the 2 and 10 mg/kg treatment levels. The mean absolute and relative weights of the spleen and thymus were not affected by the treatment. The anti-SRBC IgM serum titers were less for the 2 and 10 mg/kg treatment groups. However, the effect was not manifested in a dose-related manner (i.e., the titers for 2 and 10 mg/kg groups were 36 and 59% of the control group, respectively). These results were judged to be equivocal based on the range of variability demonstrated in the control group values and the lack of a clear dose-response. Other parameters (spleen and thymus weights, white blood cell differential counts) did not indicate any suppression of immunopotency. The positive control was functional. **Study acceptable.** (Moore, 5/3/11)

ENDOCRINE DISRUPTOR STUDIES SUPPLEMENTAL STUDIES

Human Epidemiological Studies Related to Neurotoxicity

(This is not an exhaustive list, since primary responsibility to evaluate these studies belongs to Worker Health and Safety Branch

342-543 138174 Nolan, R. J. (Study Director) "Critical analysis of the allegations of neuropathy due to chlorpyrifos submitted to the United States Environmental Protection Agency on November 7, 1994". DowElanco had identified 31 individuals for whom physicians had made at least tentative diagnoses of neuropathy having possible association with chlorpyrifos. Although several cases of massive chlorpyrifos exposure had previously been documented, only one appeared to have caused organophosphate-type delayed neuropathy (OPIDN): this was an attempted suicide in which heroic treatments were required to address severe cholinergic symptoms (investigators citing Lotti *et al.*, 1986). The primary focus of the present investigation was on OPIDN symptoms, however other neurological findings were noted where found. None of the exposures (or worst plausible estimates of exposures) were judged to have been "biologically significant" [i.e., exposures were likely to have been too low to have measurably depressed plasma ChE, or (for inhalation route) were less than the NAS guideline of 10 $\mu g/m^3$]. Studies to date have indicated that it is critical to achieve at least 50% inhibition of neurotoxic esterase in order obtain OPIDN symptoms: this is unlikely to happen except at dose sufficient to elicit major cholinergic crises. Onsets of acute symptoms in this study were compared with plausible response times for acute ChE inhibitory signs (usually within 4 hr, in any case within 24 hr). The majority of cases presented no cholinergic signs, and none presented signs which were unambiguously due to ChE inhibition. Only three persons had documented neuropathy which became evident within one month of alleged exposure (a plausible time frame for OPIDN), without a demonstrated alternate cause. Of these, no two of them had consistent symptoms. DowElanco therefore determined that the alleged neuropathologies could not reasonably be attributed to chlorpyrifos. No SB-950 worksheet is appropriate, since this is not a relevant study type, and data do not support a treatment effect. Aldous, 8/11/97.

342-707 154147 "Critical assessment of reported entitled 'Review of chlorpyrifos poisoning data'". This report was directed to Worker Health and Safety Branch for review, since the commonly expected poisoning incidents would be acute cholinergic events. No Medical Toxicology Branch review has been requested. Aldous, 8/11/97.

NON-GUIDELINE STUDIES RELATING TO CHOLINESTERASE AND METABOLISM

Human acute oral, evaluating clinical signs, metabolism, and/or cholinesterase

342-788; 168932; "A Rising Dose Toxicology Study to Determine the No-Observable-Effect-Levels (NOEL) for erythrocyte Acetylcholinesterase (AChE) Inhibition and Cholinergic Signs and Symptoms of Chlorpyrifos at Three Dose Levels"; (Kisicki, J.C. *et. al.*; MDS Harris, Lincoln, Nebraska; Study ID. DR K-044793-284; 4/19/99); Six male and six female human volunteers/treatment group were fasted overnight prior to being dosed orally once with 0 (placebo: lactose monohydrate), 0.5 or 1.0 mg/kg of chlorpyrifos powder (purity: 99.8%) in capsules (phase 1) or 0 or 2.0 mg/kg (phase 2) in a double blind, randomized study. The health status of each subject was monitored for up to 7 days. Vital signs (blood pressure, pulse rate, respiration rate, and body temperature) were recorded prior to dosing and at 1, 2, 4, 8, 12, 24, 48 and 168 hours after dosing. Blood samples for erythrocyte acetylcholinesterase (AChE) analysis were drawn 10 hours prior to dosing, at the time of dosing and at 2, 4, 8, 12, 24, 36, 48, 72, 96, 120, 144 and 168 hours post-dose for erythrocyte AChE activity and chlorpyrifos and metabolite analyses. A blood sample was drawn prior to dosing for paraoxonase activity determination. Urine samples were collected at 12 hour intervals starting 48 hours prior to dosing and at 0 to 6 and 6 to 12 hours post-dose and 12 hour intervals thereafter up to 168 hours after dosing. Although clinical symptoms such as anorexia, diarrhea, nausea, vomiting, dizziness, dyspnea, and headache were reported, none of these signs occurred in a dose-related manner. There was no apparent treatment-related effect upon any of the vital signs. Mean erythrocyte AChE activities were not significantly affected in a dose-related manner. One subject in the 2.0 mg/kg treatment group demonstrated a maximal 30% inhibition between AChE activity reported at 0 time and at 12 hours post-dose. Otherwise, no other subject in the high dose group had a reduction in erythrocyte AChE activity greater than 12% based on the higher of the two baseline values. The blood and urine levels of chlorpyrifos and its metabolites and the paraoxonase activity analysis for individual subjects were not included in this initial report and thus could not be evaluated. **No adverse effects indicated. NOEL:** 1.0 mg/kg (based upon the 30% inhibition of erythrocyte AChE demonstrated by one of the subjects in the 2.0 mg/kg treatment group). **Supplemental Study.** (Moore, 5/18/99).

342-823 178361 This is a copy of study 342-788; 168932, above.

342-822 178360; Brzak, K. A., "A Rising Dose Toxicology Study to Determine the No-Observable-Effect- Levels (NOEL) for erythrocyte Acetylcholinesterase (AChE) Inhibition and Cholinergic Signs and Symptoms of Chlorpyrifos at Three Dose Levels – Part B" Acetylcholinesterase (AChE) Inhibition Study; Human; The Dow Chemical Company, Midland, MI; Laboratory I.D. No. 981176; 6/5/00; Chlorpyrifos; Human volunteers (6/sex/dose) received a single oral dose of 0.0, 0.5, 1.0 or 2.0 mg/kg (capsule form) in a double-blind clinical trial; blood and urine specimens were collected and analyzed for chlorpyrifos and its metabolites

(chlorpyrifos oxon and 3,5,6-trichloro-2-pyridinol (TCP)) using GC-MS; pretreatment Chlorpyrifos Oxonase (CPOase), paraoxonase and diazoxonase were determined spectrophotometrically; blood and urine specimens were generally below the limit of quantitation (LOQ) for chlorpyrifos; average AUC for TCP in blood (by increasing dose) was 14.0, 25.2 and 51.2 µg/g, respectively and amount TCP excreted in the urine was 4.1, 8.7 and 15.9 mg, respectively during the first 168 hr following ingestion; blood and urinary TCP levels increased rapidly, remained constant over first 48 hr post-treatment, and then declined with an average half-life of 29 to 36 hr; administration by capsule probably reduced absorption (average of 34.7%, 30.8% and 29.5% absorbed in 0.5, 1.0 or 2.0 mg/kg dose group, respectively); serum CPOase activity was within the range of activity reported in previous studies and there were no extreme values; RBC AChE depression was seen in only one individual, a 2.0 mg/kg female that showed unusually high absorption of chlorpyrifos (87.9% versus 29.5%). Supplementary Data. Kellner, 2/23/01. [NOTE by C. Aldous: This study is "Part B" of 342-788; 168932, above].

342-834 183264 This is a copy of 342-822 178360, above.

Human repeat dosing, oral, evaluating clinical signs, metabolism, and/or cholinesterase

342-0343 071392 Coulston, F., T. Griffin, and L. Golberg, "Safety evaluation of Dowco 179 in human volunteers," Institute of Experimental Pathology and Toxicology, Albany Medical College, Albany, NY, March 1972. Four male volunteers/group were dosed by tablet with Dowco 179 (chlorpyrifos) at 0 mg/kg/d (placebo) for 48 days, 0.014 mg/kg/d for 27 days, 0.03 mg/kg/d for 20 days, or 0.10 mg/kg/d for 9 days. Investigators assessed hematology and clinical chemistry weekly, and plasma cholinesterase (ChE) and RBC AChE twice weekly. These assessments continued as needed post-treatment to determine recovery. No treatments affected hematology or clinical chemistry or RBC AChE. Plasma ChE inhibition was marked and progressive over time at 0.10 mg/kg/d, with inhibition of 10% on days 1 to 3, 46% inhibition on day 6, and 66% inhibition on day 9, when dosing of that group was stopped. Recovery of this group progressed after cessation of dosing, with plasma ChE reaching twice the treatment day 9 activity at recovery day 11, and complete recovery to pre-treatment activity at recovery day 25. Plasma ChE activity in the 0.03 mg/kg/d group was reduced by about 30% during days 16-20. Complete recovery from this lesser effect was complete by 20 days off treatment. Study gives useful supplementary information. Aldous, June 5, 2015.

342-0607 145821 is an exact copy of 342-0343 071392, above.

Human dermal (or dermal/oral comparison), evaluating clinical signs, metabolism, and/or cholinesterase

342-122 948115 Nolan, R. J., D. L. Rick, N. L. Freshour, and J. H. Saunders, "Chlorpyrifos: pharmacokinetics in human volunteers following single oral and dermal doses," Dow Chemical, Midland, MI, Aug. 1982. Healthy male volunteers were dosed with chlorpyrifos (analytical grade, 99.8% purity) to assess kinetics of chlorpyrifos and of its major metabolite (3,5,6-trichloro-2-pyridinol), and to follow changes in plasma and RBC cholinesterase (ChE) over time. N = 5 for major parameters. Exposures were a 0.5 mg/kg single oral dose, followed 4 weeks

later (ample time for clearance from the oral exposure) by a single 5 mg/kg dermal dose. None of these doses elicited clinical signs. Following 0.5 mg/kg oral dosing, plasma ChE was inhibited to about 15% of baseline, with greatest inhibition at 0.5 to 2 hrs after dosing. By 8 hours, plasma ChE levels were 3-4 fold higher than the lowest activity. By 27 to 30 hours, plasma ChE activity was essentially back to baseline. Dermal dosing with 5 mg/kg chlorpyrifos had no definitive effect on plasma ChE at any time post-dose. RBC AChE activity was inherently more variable than plasma ChE. RBC AChE activity was not measurably affected by these oral or dermal exposure levels. Blood chlorpyrifos levels following 0.5 mg/kg oral dosing was either non-detectable, or was in the range of 5-30 ng/ml blood. The highest blood chlorpyrifos levels did not appear at consistent times post-dosing, and clearly would not represent a reliable measure of exposure. Blood concentrations of chlorpyrifos following 5 mg/kg dermal exposure were either non-detectable or did not exceed 10 ng/ml. Blood levels of 3,5,6-trichloro-2-pyridinol following 0.5 mg/kg oral dosing showed quite variable kinetics between subjects, but tended to peak at 2-8 hours at about 1 µg/ml blood, with levels at 24 hours being no less than 50% of peak concentrations. This confirms that this metabolite would be a good indicator of exposure. Dermal exposure of 5 mg/kg yielded 3,5,6-trichloro-2-pyridinol blood levels which occasionally exceeded 0.1 µg/ml. There was about a 4-fold range of peak 3,5,6-trichloro-2-pyridinol blood between dermal exposure subjects. Investigators estimated the half-life of 3,5,6-trichloro-2-pyridinol to be about 27 hours by either route. Urinary peak excretion rates of 3,5,6-trichloro-2-pyridinol were at about 9 hours for oral route, and about 42 hours for the dermal route. Time to decrease to about 50% of maximum urinary 3,5,6-trichloro-2-pyridinol levels were roughly 30 hours for oral exposure and 84 hours for dermal route. Thus this study shows that chlorpyrifos is only moderately absorbed through the skin, that plasma ChE is a good marker of systemic load for several hours after exposure, whereas urinary 3,5,6-trichloro-2-pyridinol assays would be useful for qualitative exposure assessment for 2-3 days for oral route, and slightly longer for dermal exposure. Useful supplementary data. Aldous, 4/16/15.

342-0197 001367, also 342-0627 149353 These are exact copies of 342-122 948115, above.

342-0343 071383 Nolan, R. J., D. L. Rick, N. L. Freshour, and J. H. Saunders, "Chlorpyrifos: pharmacokinetics in human volunteers," *Toxicol Appl Pharmacol* **73**, 8-15 (1984). This is a published version of Record No. 948115.

342-763 165484 Griffin, P., H. Mason, K. Heywood, and J. Crocker, "Oral and dermal absorption of chlorpyrifos: A human volunteer study", cover letter dated 11/23/98. (This was a manuscript accepted for publication in Occupational & Environmental Medicine). Data were reviewed by T. Thongsinthusak of DPR Worker Health and Safety Branch: that review is bound with the volume. Dermal applications led to 1% absorption (evidenced as dialkylphosphate urinary metabolites), and 53% unaltered chlorpyrifos was recovered by washing the application site. Investigators did not account for the balance for the remainder of residues. Aldous, 10/13/99.

Rat acute oral, evaluating clinical signs, metabolism, and/or cholinesterase

342-763 164102 Mendrala, A. L. and K. A. Brzak, "Chlorpyrifos: Part A - Concentration - time course of chlorpyrifos and chlorpyrifos-oxon in blood", The Dow Chemical Co., Midland,

8/31/98, Laboratory Project Study ID 971187A. Chlorpyrifos was administered by gavage in corn oil to male F344 rats at dose levels of 0.5 to 100 mg/kg. [Segment 1]: Four rats/group were killed at intervals of 10 min to 12 hr to determine time course of (a) concentrations of chlorpyrifos and chlorpyrifos-oxon, and (b) plasma and brain cholinesterase (ChE) activities. Chlorpyrifos concentrations peaked at 3 hr, with levels dropping substantially at 6 to 12 hr. Chlorpyrifos-oxon was only about 1% as abundant as chlorpyrifos, and was typically detectable at 1 hr and 3 hr intervals only. Plasma ChE inhibition was evident at all dose levels (15% inhibition at 0.5 mg/kg). Brain ChE inhibition was marginally evident at 5 mg/kg (NOEL = 1 mg/kg). [Segment 2]: Four rats/group were dosed by gavage in corn oil with nominal 5 or 100 mg/kg (achieved levels of 3 and 63 mg/kg) of ring-labeled ^{14}C-chlorpyrifos 3 hr prior to sacrifice. Blood was collected for measurements of circulating chlorpyrifos, chlorpyrifos-oxon, and the trichloropyridinol (TCP) hydrolysis product. TCP was by far the most abundant labeled species found in blood (about 98% of label at either dose level), with most of the remaining label as chlorpyrifos. Useful supplemental data, no DPR worksheet. Aldous, 10/13/99.

Rat chlorpyrifos acute vapor inhalation, evaluating clinical signs, metabolism, and/or cholinesterase

NOTE: The two rat acute vapor inhalation studies below assess acute responses to parent chlorpyrifos and to chlorpyrifos oxon, respectively.

342-0937; 271252; Hotchkiss, J. A., S. M. Krieger, K. M. Mahoney, K. A. Brzak, N. A. Malowinski, and D. L. Rick, "Nose-Only Inhalation of Chlorpyrifos Vapor: Limited Toxicokinetics and Determination of Time-Dependent Effects on Plasma, Red Blood Cell, Brain and Lung Cholinesterase Activity in Female CD(SD): Crl Rats"; (Toxicology & Environmental Research and Consulting, The Dow Chemical Company, Midland, MI; Study ID No. 131040; 5/2/13); Forty female Crl:CD(SD) rats/group were exposed nose-only to either 0 (filtered air) or 17.7 ppb (0.254 µg/l) of a saturated vapor of chlorpyrifos technical (lot no. 7299412; purity: 97.6%) for 6 hours. Eight animals/group/time point were euthanized at 0, 2, 4, 6 and 12 hours post-exposure. Blood, brain and lung tissue were procured from each animal. Cholinesterase activity was assayed in the plasma, blood, brain and lungs. Blood levels of chlorpyrifos and its primary metabolite, trichloropyridinol were determined as well. The animals demonstrated no signs of toxicity during the exposure or for the 12-hour post-exposure period. The peak level of chlorpyrifos in the blood was immediately after the completion of the exposure, diminishing to a non-detectable level by 6 hours post-exposure. The trichloropyridinol peak levels were noted up to 2 hours post-exposure and gradually diminished over the 12-hour post-exposure observation period. Chlorpyrifos-oxon was not detectable in any of the samples. None of the tissues which were assayed from the exposed group demonstrated a significant reduction in cholinesterase activity in comparison to the control activity levels. Activity in the blood and plasma of the exposed animals was 93 and 86%, respectively, of the control values at 4 hours post-exposure, the maximal reduction. The ChE activity in the lungs of the exposed animals was 89% of the control group at that time point. There was no apparent effect upon ChE activity in the brain. **No adverse effect indicated. Study supplemental.** (Moore, 6/4/13)

342-0950 274123; "Nose-Only Inhalation of Chlorpyrifos-Oxon Vapor: Limited Toxicokinetics and Determination of Time-Dependent Effects on Plasma, Red Blood Cell, Brain and Lung Cholinesterase Activity in Female CD(SD):Crl Rats"; (J.A. Hotchkiss, S.M. Krieger,

K.M. Mahoney, K.A. Brzak, N.A. Malowinski, D.L. Rick; Toxicology & Environmental Research and Consulting, The Dow Chemical Company, Midland, MI; Study ID. 131067; 8/30/13); In Phase 1, the highest attainable saturated vapor concentration of chlorpyrifos-oxon (oxon) under standard laboratory conditions typical of an acute nose-only inhalation exposure study was determined and selected for Phase 2 of this study. In Phase 2, eight female CD(SD):Crl rats/group/sacrifice time were exposed for 6 consecutive hours to filtered air (control) or a time weighted average concentration of 35.3 µg/m^3 (2.58 ppb) oxon vapors using a flow-past nose-only inhalation exposure system. Rats were sacrificed immediately (0 hr) and at 1, 2, 4, 8 and 24 hours after the end of exposure. Blood and tissues were isolated and processed to determine cholinesterase (ChE) activity in red blood cells (RBC), plasma, and lung and brain tissues. Whole blood samples from n=4 rats in each group/sacrifice time were analyzed to determine the concentrations of oxon and 3,5,6-trichloro-2-pyridinol (TCP). No clinical signs of toxicity were noted in oxon-exposed rats at any time during or after exposure. No oxon was detected in the blood at any time after exposure (lower limit of quantification (LLQ), 0.118 ng/g blood), however, blood TCP levels > LLQ (2.44 ng/g blood) were detected in all assayed blood samples collected at 0 through 4 hours after exposure and in 1/4 assayed blood specimens collected 8 hours post-exposure. By contrast, blood TCP levels were below LLQ in 3/4 and 4/4 animals sacrificed at 8 and 24 hours after exposure, respectively. No oxon-induced inhibition of ChE activity was detected in RBC, plasma, lung or brain at any time after exposure. The presence of TCP in the blood of oxon-exposed rats confirms that oxon vapor is absorbed through the respiratory tract, however, the inhaled oxon is rapidly metabolized and not systemically bioavailable, given that all the assayed blood levels were below LLQ (0.118 ng/g or 3.53×10^{-4} nmol/g blood). Based on the absence of cholinesterase inhibition in RBC, plasma, brain or lung (the portal-of-entry tissue), the 6-hour No Observed Effect Concentration (NOEC) for inhaled oxon vapor is > 35 µg oxon/m^3 air. The results of this study suggest that there is no biologically relevant hazard from inhalation of a saturated vapor concentration (35.3 µg/m^3) of chlorpyrifos oxon. **Study Supplemental**. (Guo, 11/13/13)

Rat chlorpyrifos repeat-dose vapor inhalation, evaluating clinical signs, metabolism, and/or cholinesterase

342-0343 071388 Landry, T. D., D. A. Dittenber, L. L. Calhoun, L. G. Lomax, and P. Morabito, "Chlorpyrifos: 2-week nose-only vapor inhalation exposure study in Fischer 344 rats," The Dow Chemical Company, Midland, MI, 6/10/86. This study exposed female rats (N = 6) to 0 or 12 ppb chlorpyrifos vapor (99.7% purity) 6 hours/day, 5 days/week, with sacrifice one day after the last exposure (with 3 consecutive days of exposure before the day of sacrifice). Investigators evaluated cholinesterase (plasma, RBC, and brain), clinical signs, body weights, hematology, and gross pathology. There were no treatment responses. The tested concentration was noted to be about 50% of the maximum theoretical maximum vapor level for chlorpyrifos. Although individual data were provided, there is no DPR worksheet for this report, since it does not address a data requirement, and because it was negative. Aldous, 5/15/15.

342-0343 071389 Corley, R. A., T. D. Landry, L. L. Calhoun, D. A. Dittenber, and L. G. Lomax, "Chlorpyrifos: 13-week nose-only vapor inhalation exposure study in Fischer 344 rats," The Dow Chemical Company, Midland, MI, 11/13/86. This study exposed both sexes (N = 10) to 0, 5.2, 10.3, or 20.6 ppb chlorpyrifos vapor (100% purity, reporting mean assayed chamber concentrations) 6 hours/day, 5 days/week, with sacrifice one day after the last exposure (with at

least 4 consecutive days of exposure before the day of sacrifice, following overnight fasting). Investigators evaluated cholinesterase (plasma, RBC, and brain), clinical signs (shortly after each exposure period), body weights, organ weights, hematology, clinical chemistry, urinalysis, and gross pathology. Protocol tissues of both sexes were subject to histopathology examination in control and high dose groups. There were no treatment responses. The maximum vapor level for chlorpyrifos was noted to be about 25 ppb. This is a valid supplementary study. Although individual data were provided, there is no DPR worksheet for this report, since it does not address a standard data requirement, and because responses were negative. Aldous, 5/15/15.

Rat chlorpyrifos acute aerosol inhalation, evaluating clinical signs, metabolism, and/or cholinesterase

342-0908; 258214; AAcute Inhalation Exposure of Adult Crl:CD(SD) Rats to Particulate Chlorpyrifos Aerosols: Kinetics of Concentration-Dependent Cholinesterase (ChE) Inhibition in Red Blood Cells, Plasma, Brain and Lung@; (J.A. Hotchkiss, S.M. Krieger, K.A. Brzak, D.L. Rick; Toxicology & Environmental Research and Consulting, The Dow Chemical Company, Midland, MI; Study ID. 091133; 6/29/10); In Phase I, six Sprague-Dawley rats/sex/group were exposed nose-only to 0, 13.3 or 66.7 mg/m^3 (analytical) of Chlorpyrifos technical (lot no. KC28161419; purity: 99.8%) for six hours. Blood was drawn from an indwelling jugular catheter at 2, 4, 6 hours of exposure and at 0.5, 1, 2, 4, 6, 12, and 24 hours post-exposure. Red blood cell and plasma cholinesterase (ChE) activities were assayed for each time point. In Phase II, 54 female rats/group were exposed nose-only to 0, 3.7, 12.9, 22.1 or 53.5 mg/m^3 of the test material for up to 6 hours. Six animals/group/time point were euthanized at 2, 4, and 6 hours of exposure and at 2, 6, 12, 24, 48 and 72 hours post-exposure. Cholinesterase activities in the red blood cells, plasma, lungs and brain were assayed and the blood concentrations of chlorpyrifos (CPF), chlorpyrifos-oxon (CPF-oxon) and trichloropyridinol (TCP) were measured. Urine was collected from 6 animals/group at 0 to 12, 12 to 24, 24 to 48 and 48 to 72 hours and trichloropyridinol concentrations were determined. In Phase I, significant inhibition of red blood cell and plasma ChE activities was evident at 13.3 mg/m^3 For RCE ChE activity, maximal inhibition of 65% for males and 80% for the females was noted at 2 hours post-exposure. For plasma ChE activity, maximal inhibition of 66% for males and 87% for females was evident from 6 hours of exposure to 1 hour post-exposure. Based on these results, females were deemed to be more sensitive to the effects of CPF on ChE activity and thus were selected for testing in Phase II. ChE inhibition in the plasma achieved a maximal level of 48% at 6 hours of exposure in the 3.7 mg/m^3 group. In the lungs, a maximal level of ChE inhibition was noted at 47% in the 3.7 mg/m^3 at 6 hours of exposure. ChE activity in the brain was significantly reduced for the 12.9, 22.1 and 53.5 mg/m^3 groups with maximal inhibitions of 19, 21 and 22%, respectively, which were noted at 6, 6 and 2 hours post-exposure, respectively. For RBC AChE activity, the results were inconsistent at the 3.7 mg/m^3 exposure level possibly due to the variability of the control values. Maximal reduction in activity was not evident until 24 to 48 hours post-exposure. The blood levels of CPF were highest at 4 to 6 hours of exposure for all of the exposure levels with a peak value of 65 ng/g noted for the 53.5 mg/m^3 group. CPF-oxon was recovered in the blood at peak levels of 0.22 ng/g during the exposure at the 53.5 mg/m^3 exposure level. Peak levels of 2400 ng/g of TCP for the highest exposure group were noted at 12 hours post-exposure. The plasma half-life of CPF ranged from 0.463 to 3.34 hours over the exposure concentration range. The ratio of the areas under the curve for TCP/CPF ranged from

545 to 1057. The inhaled dose of the test material was calculated to be 1.04, 3.62, 6.21 and 15.0 mg/kg. Excretion of TCP in the urine demonstrated a half-life ranging from 10.6 to 11.6 hours. Using these excretion data the percentage of inhaled CPF which was absorbed was calculated and ranged from 36 to 79%. **Study supplemental.** (Moore, 5/2/11)

Rat chlorpyrifos life stage comparisons (as neonate vs. young adult), evaluating clinical signs, metabolism, and/or cholinesterase

342-0906; 257044; AComparison of Cholinesterase (ChE) Inhibition in Young Adult and Pre-weanling CD Rats after Acute and Repeated Chlorpyrifos or Chlorpyrifos-Oxon Exposures@; (M.S. Marty, A.K. Andrus; Toxicology & Environmental Research and Consulting, The Dow Chemical Company, Midland, MI; Study ID. 091107; 6/29/10); Pre-weanling (11 days post-natal) and young adult female Sprague-Dawley rats were dosed orally by gavage, using vehicles of corn oil or rat=s milk or in the diet (adult rats only) with concentrations of Chlorpyrifos technical (CPF) (lot no. KC28161419, purity 99.8%) ranging from 0.05 to 10 mg/kg, in a single dose regimen or at concentrations ranging from 0.05 to 3.5 mg/kg/d of CPF in corn oil in a 10-day multiple dosing regimen (pre-weanling: days 11 to 21 post-natal, young adult: 70 to 80 days old). Other groups of pre-weanling and young adult female rats were dosed orally by gavage in a single dose regimen with Chlorpyrifos-oxon (CPF-oxon) in corn oil (lot no. 199902031-66, purity: 94.9%) at concentrations ranging from 0.005 to 1.0 mg/kg. In a 10-day multiple dosing regimen, both pre-weanling and young adult females were dosed orally by gavage with 0.01 and 0.5 mg/kg/d of CPF-oxon in the same manner as the CPF-treated animals. Eight animals/sex were included in the pre-weanling groups and 8 females/group were dosed in the young adult cohort. Preliminary studies were performed in order to establish the time-to-peak inhibition profile for plasma, red blood cell and brain cholinesterase (ChE) inhibition. In the dose-response studies, animals were euthanized at the time-to-peak ChE inhibition. The concentrations of CPF, CPF-oxon and trichloropyridinol (TCP) in the blood of some of the study animals were determined. A functional observational battery was performed on the study animals in the multiple-dosing regimen after 9 days of dosing. The times-to-peak effect were as follows: PND 11 pups: 1. CPF in corn oil (6 hours), 2. CP0 in corn oil (4 hours), 3. CPF in rat=s milk (8 hours); young adult females: 1. CPF in corn oil (8 hours), 2. CPF-oxon in corn oil (4 hours), 3. CPF in diet (after conclusion of the 12-hour exposure period) (8 hours). Based upon the results of the dose response studies, no effect levels were established for plasma, red blood cell and brain ChE inhibition under the different dosing scenarios. In the **single dose regimen**, NOELs for the plasma and red blood cell ChE inhibition were 0.5 mg/kg for both sexes of the pre-weanlings after treatment with CPF, using either corn oil or rat=s milk as the vehicle, and for the young adult females treated by gavage, using a corn oil vehicle, or in the diet. The NOEL values for the brain ChE inhibition were 2 mg/kg for the male pre-weanlings treated with CPF, using either corn oil or rat=s milk as the vehicle, for the female pre-weanlings, using corn oil as the vehicle and for the adult females treated by gavage or in the diet. For the pre-weanling females dosed with CPF in rat=s milk, the brain ChE inhibition NOEL was 0.5 mg/kg. The NOELs for treatment with a single dose regimen of CPF-oxon were as follows: for both male and female pre-weanlings, the NOELs for plasma ChE inhibition: 0.05 mg/kg, for red blood cell ChE inhibition: 0.1 mg/kg and for brain ChE inhibition: 0.5 mg/kg. For the young adult females, the NOEL for plasma, red blood cell and brain ChE inhibition were 0.1, 0.1 and 0.5 mg/kg, respectively. In the **multiple dose regimen** in which the pre-weanlings and young adults were

treated with CPF in corn oil by gavage, the NOEL values for ChE inhibition were as follows: male and female pre-weanlings, plasma and RBC: 0.1 mg/kg, brain: 0.5 mg/kg; young adult females, plasma: 0.1 mg/kg/d, red blood cell: 0.5 mg/kg/d, brain: 0.5 mg/kg/d. The NOELs for ChE inhibition after multiple treatments with CPF-oxon in corn oil were as follows: male and female pre-weanlings and young adult females, plasma and red blood cell: 0.01 mg/kg/d, brain: 0.5 mg/kg/d. The NOEL values were reduced from 0.5 mg/kg to 0.1 mg/kg/d for plasma and red blood cell ChE inhibition in the pre-weanlings after multiple treatments with CPF in corn oil. The brain ChE inhibition for these animals was lowered from 2 mg/kg to 0.5 mg/kg/d. In the young adult females, the NOELs for plasma and brain ChE inhibition were lowered from 0.5 mg/kg to 0.1 mg/kg/d and from 2 mg/kg to 0.5 mg/kg/d, respectively. The concentrations of CPF and TCP in the blood at the NOEL and/or LOEL treatment levels for the various treatment scenarios were examined. Treatment with CPF in corn oil or rat=s milk to pre-weanling rats in either a single dose or multiple dose regimen resulted in TCP/CPF concentration ratios (based on ng/g of blood) ranging from 70 to 209. For the young female rats, in certain instances, the CPF concentration was below the limits of detection and the ratio could not be calculated. Otherwise, the ratios were 935 and 449 (0.5 and 2.0 mg/kg, by gavage, respectively), 7243 (2.0 mg/kg in the diet) in the single dose regimen and 2450 (0.5 mg/kg/d) and 651 (1.0 mg/kg/d) after multiple doses by gavage. These data indicate a possible difference in the metabolic disposition of CPF between the pre-weanling pups and the young adult animals. No treatment-related effects were identified in the FOB. **Supplemental Study.** (Moore, 2/23/11)

342-0897 253051 This is an interim report of 342-0906; 257044, above.

342-764 164103 Mattsson, J. L., J. P. Maurissen, P. J. Spencer, K. A. Brzak, and C. L. Zablotny, “Effects of chlorpyrifos administered via gavage to CD rats during gestation and lactation on plasma, erythrocyte, heart and brain cholinesterase, and analytical determination of chlorpyrifos and metabolites”, The Dow Chemical Co., Midland, 08/98. This study was not reviewed under SB-950, but has been examined extensively by R. Cochran for the chlorpyrifos risk assessment. Aldous 10/13/99.

Dog chlorpyrifos subchronic or subacute, dietary, evaluating clinical signs, metabolism, and/or cholinesterase †

342-836; 183362; “Chlorpyrifos Technical: 6-Week Dietary Study of Acetylcholinesterase Inhibition in Beagle Dogs”; (B.R. Marable, P.C. Baker, K.E. Stebbins and J.P. Maurissen; Toxicology & Environmental Research and Consulting, The Dow Chemical Company, Midland, MI; Study ID: 011036; 7/27/01); Four beagle dogs/sex/group received 0, 0.5, 1.0 or 2.0 mg/kg/d of Dursban FM (Chlorpyrifos Technical) (lot no. 7299412, TSN100759, purity: 97.6%) in the diet for 6 weeks. The animals were fed twice per day and the content of the AI in the diet was adjusted in a manner such that the daily intake per body weight was maintained. No deaths resulted from the treatment. There was no apparent dose-related effect upon the mean body weights. No clinical signs were noted during the treatment period. The mean red blood cell cholinesterase (ChE) activity was reduced in a dose-related manner with maximal levels of inhibition achieved after 6 weeks (% of baseline, males, 0.5: 44.5%, 1.0: 27.6%, 2.0: 14.4%; females, 0.5: 56.9%, 1.0: 32.8%, 2.0: 18.9%). There was no dose-related effect upon the brain, diaphragm, muscle or nodose ganglion acetylcholinesterase (AChE) activity for either sex after 6 weeks of treatment. The AChE activity in the left atrium of the heart of the males was reduced

in a dose-related manner (% of control, 0.5: 99.3, 1.0: 84.5%, 2.0: 74.5%). This effect was not noted for the females. **Possible adverse effect**: significant inhibition of AChE in the heart. **NOEL:** (M/F) < 0.5 mg/kg/d (based upon the reduced red blood cell ChE activity for both the males and females in the 0.5 mg/kg treatment group); **Supplemental Study** (non-guideline study) (Moore, 11/4/02)

342-833 182482 Baker, P. C. *et al.*, "Communication: Preliminary evaluation of acetylcholinesterase (AChE) in brain, peripheral tissues, and RBC in beagle dogs," The Dow Chemical Company, Midland, MI, 5/11/01. Report ID CPF0501. [Report begins on p. 38 of this volume]. Three males/group were dosed in diet with 0, 0.3, 0.6, or 1.2 mg/kg/d chlorpyrifos for 28 days. Parameters evaluated at termination focused on acetylcholinesterase measurements in RBC's, brain, nodose ganglion, left atrium, left ventricle, diaphragm muscle, and thigh muscle. In-life RBC acetylcholinesterase activity was measured weekly. All dogs survived the treatment, and there were no characteristic clinical signs. Body weight was unaffected by treatment. RBC acetylcholinesterase activity was reduced in dose-related fashion. Despite high variability in control activities, reductions in the higher two dose levels were clearly treatment-related (about 50% reduction at 1.2 mg/kg/d). These changes appeared to be progressive over time. No other tissues showed statistically significant reductions in AChE activity. Some of the assayed AChE activity values were so variable that the small numbers of dogs available could only have indicated major treatment responses. This is a useful pilot study, but data are unsuitable for quantitative analysis. Aldous, 9/27/01.

Dog chlorpyrifos subchronic or subacute, pet collar exposure, evaluating clinical signs, metabolism, and/or cholinesterase

342-244; 34080; Boyd, J. P., Cholinesterase Inhibition Study; 855; Dog; P.A.C.E. International, Dallas, TX; Project No. 20-208-1184; 5/14/85; pet collar, 8.0% AI; 6 treated animals, 4 untreated control animals; 1 collar/animal, 91 day treatment period; No mortality; Observations: no treatment-related effects, no irritation evident at the collar site; Cholinesterase (ChE) Inhibition: significant inhibition of plasma ChE from day 3 to end of study (maximal inhibition-83.7%, day 69), no apparent treatment effect on RBC AChE activity; no adverse effect; NOEL cannot be determined (significant inhibition of plasma ChE activity exhibited by treated animals); Study supplemental. (Moore, 5/12/93)

In vitro tissue studies of cholinesterase inhibition and metabolism

342-0951 274124; "*In vitro* Sensitivity of Cholinesterase to Inhibition by Chlorpyrifos-oxon in Several Tissues of the Rat"; (J.E. Chambers, E.C. Meek, H.W. Chambers; Center for Environmental Health Sciences, College of Veterinary Medicine, Mississippi State University, Mississippi State, MS; Study ID. NS000128; 9/16/13); to compare the inherent sensitivity of cholinesterase in several tissues to inhibition by chlorpyrifos-oxon (CPFO) through determination of inhibitory concentrations (IC_{50} values), young adult male rats were euthanized; brain, blood, lung, heart, diaphragm, esophagus, stomach (flushed) and duodenum were removed from the animals and flash frozen in liquid nitrogen. In some animals, the heart and lungs were perfused with saline through the aorta to remove residual blood and the contents of the esophagus and duodenum were flushed out of the tissues, followed by flash freeze. Red blood cells (RBCs) collected were used intact, and also lysed and centrifuged to prepare a RBC ghost.

All tissues were homogenized (except plasma and RBC ghosts) in 0.05 M Tris-HCl buffer, pH 7.4 at 37 °C, with a motorized glass-Teflon homogenizer, and plasma was diluted and RBCs and RBC ghosts were re-suspended in this buffer. A modified Ellman (spectrophotometric) method for measurement of cholinesterase activity was used with acetylthiocholine or butyrylthiocholine (only for some of the plasma duodenum samples) as substrate and 5,5'-dithiobis-(2-nitrobenzoic acid) (DTNB) as the chromogen. Tissue preparations were diluted in the above buffer to yield an activity level that produced about 1.2-2.0 Absorbance Units (AU) following the substrate incubation period (15 min. at 37 °C for all tissues except RBCs which was 1 hr at 37 °C) in the control samples. Five concentrations of CPFO in ethanol were used to provide an inhibition range of 20-80%; protein was quantified by the Lowry method. IC_{50} values were calculated for each of 3 replications (3 separate rats) by log-legit regression, and 95% confidence intervals were calculated for the IC_{50} means. The mean IC_{50} values (for assays conducted with acetylthiocholine as substrate, AChE) were: brain, 3.77 nM; duodenum – flushed, 3.72 nM vs. not flushed, 4.17 nM; esophagus – flushed, 3.13 nM vs. not flushed, 3.28 nM; stomach-flushed, 4.08 nM; lung – perfused, 7.21 nM vs. not perfused, 8.57 nM; heart – perfused, 3.06 nM vs. not perfused, 3.91 nM; diaphragm, 6.64 nM; RBCs, 4.19 nM vs. RBC ghosts, 5.08 nM; plasma, 55.36 nM. The assays conducted with butyrylthiocholine showed IC_{50} values very similar to those by AChE: duodenum – flushed, 3.72 nM vs. not flushed, 5.05 nM; plasma, 50.05 nM. There is no difference in the inherent sensitivity of the acetylcholinesterase in the several solid tissues studied (brain, esophagus, stomach, duodenum, heart, diaphragm, lung and red blood cells) to inhibition by chlorpyrifos-oxon, as indicated by IC_{50} values all within the same order of magnitude. The higher IC_{50} values in plasma logically result from the presence within plasma of other proteins that can be readily inhibited by CPFO (e.g., carboxylesterases) or that can absorb CPFO (e.g., albumin), thus reducing the levels of CPFO that were available to inhibit plasma cholinesterase; lower CPFO bioavailability resulted in a higher IC_{50} value, but it does not necessarily indicate lower inherent sensitivity of plasma cholinesterase. **Study Supplemental**. (Guo, 1/02/14)

342-774 165918 "Standard operating protocol for analysis of the effects of chlorpyrifos, diazinon, and sulfotep on neurite length in differentiating neuroblastoma cells in vitro." This volume is currently in evaluation by another division of DPR, and appears unlikely to be pivotal to Medical Toxicology Branch, based on its title. There are, however, studies in the public literature relating to chlorpyrifos effects on differentiating cells in culture, hence this protocol may be supportive of such a study. C. Aldous, 10/13/99.

Registrant rebuttal responses or commentaries on cholinesterase effects and inter-species extrapolations

342-790 168952 Chen, W. L., R. J. Nolan, and J. L. Mattsson, "Dow AgroSciences' response to the report of the Hazard Identification Assessment Review Committee (HIARC) entitled 'Chlorpyrifos - Hazard Identification Based on Animal Studies'". This record was an evaluation of existing data, and not a report of new data, except for an abstract of a recent human study by Kisicki *et al.* (reviewed as DPR Record No. 168932, see 1-liner below). "Laboratory Study ID" # GH-C 4904. This record was provided to call to question key US EPA conclusions regarding hazard evaluation of chlorpyrifos. **Human clinical sign evaluation:** The cited abstract concluded that the NOEL for RBC AChE was 1 mg/kg, based on 1/12 volunteers having over a 17% decrease in this enzyme at 2 mg/kg. None of the 12 volunteers at the highest dose of 2

mg/kg experienced clinical symptoms. This result suggest that a single subject presenting signs of "blurred vision, feeling of faintness, and runny nose" in an earlier study at 0.1 mg/kg/d was unlikely to have been responding to chlorpyrifos treatment. **Relevance of RBC AChE vs. BuChE:** Registrants observed that the latter has no known physiological function and no apparent relevance to human hazard assessment. In contrast, RBC AChE is evidently identical to the AChE associated with neuromuscular transmission, hence relevant in human hazard assessment. **Comparative inhibition of AChE from different sources:** Rat studies over the dose range of 10 to 100 mg/kg indicated that RBC AChE had a 12-fold lower ED_{50} than whole brain, hence regulation on blood AChE would protect against cholinergic toxicity. AChE in other tissues was less sensitive to inhibition (i.e. had a higher ED_{50}) than whole brain (p. 22). **Primary conclusions of investigators:** Investigators determined (1) that human data are valid and preferable to animal data in assessing human hazard, (2) that human RBC AChE rather than BuChE should be used to set RfD's, (3) and that the laboratory animal data base (if agencies are determined to use such for human safety assessment) is sufficiently complete that (a) there is no justification for an additional ten-fold safety factor for uncertainties regarding possible special toxicity to infants and children and (b) the comparative blood ChE responses of humans and laboratory animals (for RBC AChE and BuChE) are sufficiently well-characterized that a 10-fold interspecies uncertainty factor is not appropriate. Supportive published articles were included: (1) Chen *et al.* "Human red blood cell acetylcholinesterase inhibition as the appropriate and conservative surrogate endpoint for establishing chlorpyrifos reference dose", **Regulatory Toxicology and Pharmacology 29**, 15-22 (1999), (2) Schardein and Scialli, "The legislation of toxicologic safety factors: The Food Quality Protection Act with chlorpyrifos as a test case", **Reproductive Toxicology 13**, 1-14, 1999, and (3) Gibson, J. E. *et al.*, "How to determine if an additional 10x safety factor is needed for chemicals: A test case with chlorpyrifos", **Toxicol Sci 48**, 117-122 (1999). No worksheet (no reviewable data). Aldous, 9/14/99.

342-756 162540 Albers, J. W. *et al.*, "Determination of the reference dose for chlorpyrifos: Expert panel report." No date was given for report: cover letter date for volume was 6/19/98. Dow AgroSciences convened a panel of experts, who determined in this 85-page record that

(1) multiple studies support an RfD for repeated oral dose exposure of 0.01 mg/kg/d, and

(2) the RfD for single oral exposure was determined to be 0.05 mg/kg. There are no new studies, hence no DPR worksheet. Aldous, 10/13/99.

Mechanistic Studies on Serine Hydrolases that Degrade Endocannabinoids

The following studies by R. L. Carr *et al*. explored effects of chlorpyrifos on two serine hydrolase enzymes involved in degradation of endocannabinoid degradation: [monoacylglycerol lipase (MAGL), and fatty acid amide hydrolase (FAAH)]. The associated endocannabinoids were 2-arachidonoylglycerol (2-AG) and anandamide (AEA). The latter are essential in neurodevelopment, but their levels in CNS are controlled by the above enzymes to keep ligand concentrations at optimal levels. Test animals were male and female Sprague-Dawley rat pups, dosed with chlorpyrifos daily by gavage from PND 10 through 16 at up to 5 mg/kg/d. Tissues tested included forebrain, and sometimes midbrain and plasma. Generally cholinesterase (ChE) was assayed in parallel.

(No DPR Record or Document Number) Carr, R. L., A. L. Adams, D. R. Kepler, A. B. Ward, and M. K. Ross, "Induction of endocannabinoid levels in juvenile rat brain following developmental chlorpyrifos exposure," *Toxicol Sci* **135**(1), 193-201, 2013. Ten-day old Sprague-Dawley rat pups were dosed with chlorpyrifos (99% purity) daily by gavage in corn oil from PND 10 through 16 at 0, 1, 2.5, or 5 mg/kg/d, with groups of 6-8 (blocked by sex and litter) sacrificed at 4, 12, 24, or 48 hours after the last dose. Forebrain ChE, MAGL, and FAAH activities were assayed at these intervals, in addition to forebrain levels of the two endocannabinoids which are primarily degraded respectively by MAGL and FAAH: (2-AG and AEA). Forebrain ChE response was strongest at 12 hours after the last dose, with inhibition of 24%, 55%, and 68% at respective dose levels. ChE inhibition at 48 hours was 9%, 36%, and 46% respectively. MAGL response was strongest at 4 hours, with inhibition of 14%, 24%, and 41% at respective dose levels. MAGL inhibition at 48 hours was 7%, 16%, and 33% respectively. FAAH was more strongly inhibited: inhibition was greatest at 4 to 12 hours after the last dose. Inhibition at 12 hours was 52%, 90%, and 93% at respective dose levels. FAAH inhibition at 48 hours was 16%, 38%, and 48% respectively. Levels of 2-AG were most notably increased at 12 hours, at which time respective treated groups had elevations of 30%, 52%, and 63% over controls (all statistically significant). By 48 hours, there were no significant differences from control, however the 5 mg/kg/d group mean was 19% over control. Levels of AEA were also most notably increased at 12 hours, at which time respective treated groups had elevations of 65%, 128%, and 190% over controls (all statistically significant). By 48 hours, the only significant difference from control was at 5 mg/kg/d group (81% over control). Investigators indicated in their discussion that FAAH is the dominant degradation enzyme for AEA, evidenced by other studies showing nearly complete mitigation of AEA effects when a specific FAAH inhibitor is employed. Investigators noted further that other studies had found that 2-AG is subject to appreciable degradation by enzymes not included in the present study. Investigators concluded that particularly alteration of FAAH activity due to chlorpyrifos may alter neuronal system development at critical stages of growth. There is no DPR worksheet, as only summary data were provided. This is a valid supplementary study. Aldous, 5/13/15.

(No DPR Record or Document Number) Carr, R. L., C. A. Graves, L. C. Mangum, C. A. Nail, and M. K. Ross, "Low level chlorpyrifos exposure increases anandamide accumulation in juvenile rat brain in the absence of brain cholinesterase inhibition," *Neurotoxicology* **43**:82-89 (2014). This work is basically an extension of that described in *Toxicol Sci* **135**(1), above, assessing the lower dose of 0.5 mg/kg/d from PND 10-16, with sacrifice at 4 and 12 hours. Serum carboxylesterase was inhibited by 94% and 74% at 4 and 12 hours after the last dose, respectively. Serum cholinesterase was inhibited by 36% and 25% at 4 and 12 hours after the last dose, respectively. Forebrain cholinesterase and forebrain MAGL activities were not altered at this dose. Forebrain FAAH was reduced by 14% at 4 hours (not significant) and by 25% at 12 hours (significant, $p < 0.05$). There was no significant difference in 2-AG in forebrain at 0.5 mg/kg/d, but forebrain AEA levels were increased by 18% at 4 hours and by 37% (significant, $p < 0.05$) at 12 hours. There is no DPR worksheet, as only summary data were provided. This is a valid supplementary study. Aldous, 5/13/15.

(No Document or Record Numbers) Carr, R. L., A. Borazjani, and M. K. Ross, "Effect of developmental chlorpyrifos exposure, on endocannabinoid metabolizing enzymes, in the brain of juvenile rats," Toxicol Sci 122(1): 112-120 (2011). Male and female Sprague-Dawley rats were

exposed to 0, 1, 2.5, or 5 mg/kg/d chlorpyrifos. Most tests were performed in pups dosed on PND 10-16, with sacrifice 4 hours after the PND 16 treatment. Body weight gains were reduced (dose-related) in 2.5 to 5 mg/kg/d pups. ChE activity (as percent of control) was reduced in respective dose groups of pups by tissue as follows: forebrain (18, 41, and 52%), medulla-pons (18, 38, and 55%), and serum (32, 50, and 55%). Pup forebrain MAGL activity was reduced by 14, 22, and 37% in respective groups. Pup forebrain FAAH activity was reduced by 40, 93, and 96% in respective groups. Investigators used a fluororphosphonate-biotin (FP-biotin) probe to mark serine hydrolase enzymes in PND 16 pups and performed an SDS-PAGE separation, ultimately visualizing the marked enzymes with a chemiluminescent reagent and capturing images on x-ray film. FP-biotin probe analyses found a strong reduction of marked FAAH at 1 mg/kg/d, with no visible presence remaining at higher dose levels. MAGL staining was quite faint, even in controls, but suggested a treatment-related reduction in female pups. Another serine hydrolase enzyme, KIAA 1363, described elsewhere as highly responsive to chlorpyrifos oxon, showed a marked dose-related reduction in this treatment range. Possible importance of the latter was outside of the scope of this article, however other abstracts by Cassidy et al. indicate that spontaneous recovery of KIAA 1363 may be rapid enough to not warrant major concern. MAGL was detectible in membrane fractions but not in cytosolic fractions, when evaluated in pup brain extracts. A specific MAGL inhibitor, JZL184, reduced 2-AG hydrolysis activity to about 55% of control activity at 10 μM, with no additional inhibition at higher dose levels. This suggests that chlorpyrifos effects on MAGL are less likely to elicit profound effects on its substrate levels than effects on FAAH. Investigators concluded that chlorpyrifos inhibition of AEA hydrolysis may be the principal concern for juvenile development, with reduced FAAH enzyme activity as the most plausible cause. There is no DPR worksheet, as data are limited to summary tables and figures. Aldous, 5/14/15.

ADDITIONAL STUDIES NOT PRESENTLY ASSIGNED TO HAZARD ASSESSMENT GROUP FOR REVIEW

Record Number 275321 Epidemiology studies pertaining to chlorpyrifos exposures: considerations of reliability and utility

DPR Received Date: 12/13/2013

Study Date:

Document Number: 342-0952

Record Number 279907 Development of chemical specific adjustment factors for chlorpyrifos and chlorpyrifos oxon

DPR Received Date: 09/04/2014

Source: The Dow Chemical Company Midland, Michigan

Study Date: 10/31/2013

Document Number: 342-0960

Record Number 282730 In vitro age-dependent enzymatic metabolism of chlorpyrifos and chlorpyrifos-oxon in human hepatic microsomes and chlorpyrifos-oxon in plasma (journal article)

DPR Received Date: 01/20/2015

Document Number: 342-0965

Record Number 281309 Chlorpyrifos reevaluation in California toxicology research in support of chlorpyrifos (pt.1-2)

DPR Received Date: 11/18/2014

Source: Dow AgroSciences Indianapolis, IN

Study Date: 11/17/2014

Document Number: 342-0964

Record Number 282735 In vitro rat hepatic and intestinal metabolism of the organophosphate pesticides chlorpyrifos and diazinon (journal article)

DPR Received Date: 01/20/2015

Document Number: 342-0965

Record Number 282734 Age-dependent pharmacokinetic and pharmacodynamic response in preventing rats following oral exposure to the organophosphorus insecticide chlorpyrifos (journal article)

DPR Received Date: 01/20/2015

Document Number: 342-0965

Record Number 282731 The effects of plasma lipids on the pharmacokinetics of chlorpyrifos and the impact on interpretation of blood biomonitoring data (journal article)

DPR Received Date: 01/20/2015

Study Date: 02/17/2009

Document Number: 342-0965

Record Number 282729 A human life-stage physiologically based pharmacokinetic and pharmacodynamic modeling for chlorpyrifos: development and validation (journal article)

DPR Received Date: 01/20/2015

Document Number: 342-0965

Record Number 282486 Using PBPK/PD modeling for assessing the toxicity of chlorpyrifos and the risks from current and historical exposures

DPR Received Date: 01/20/2015

Study Date: 12/08/2014

Document Number: 342-0965

Record Number 282559 Chlorpyrifos PBPK/PD modeling for multiple routes of exposure

DPR Received Date: 01/20/2015

Source: Summit Toxicology, L.L.P. Allenspark, CO

Study Date: 11/08/2013

Document Number: 342-0965

Record Number 282740 Serum albumin is as efficient as paraoxonase in the detoxication of paraoxon at toxicologically relevant concentrations (journal article)

DPR Received Date: 01/20/2015

Document Number: 342-0965

Record Number 282741 Cytochrome P450-specific human PBPK/PD models for the organophosphorus pesticides: chlorpyrifos and parathion (journal article)

DPR Received Date: 01/20/2015

Document Number: 342-0965

Record Number 282653 Application of a source-to-outcome model for the assessment of health impacts from dietary exposures to insecticide residues (journal article)

DPR Received Date: 01/20/2015

Document Number: 342-0965

Record Number 282557 Physiologically based pharmacokinetic/pharmacodynamic (PBPK/PD) modeling of dermal exposure to chlorpyrifos: validation and application to mixed oral and dermal exposures

DPR Received Date: 01/20/2015

Source: Battelle Pacific Northwest Laboratories Richland, WA

Study Date: 03/05/2013

Document Number: 342-0965

Record Number 279905 A human life-stage physiologically based pharmacokinetic and pharmacodynamic model for chlorpyrifos: development and validation (journal article)

DPR Received Date: 09/04/2014

Document Number: 342-0960

Record Number 282736 A physiologically based pharmacokinetic and pharmacodynamic (PBPK/PD) model for the organophosphate insecticide chlorpyrifos in rats and humans (journal article)

DPR Received Date: 01/20/2015

Document Number: 342-0965

Record Number 282558 Physiologically based pharmacokinetic/pharmacodynamic (PBPK/PD) modeling of oral exposure to chlorpyrifos: impact on toxicity adjustment factors

DPR Received Date: 01/20/2015

Source: Battelle Pacific Northwest Laboratories Richland, WA

Study Date: 01/25/2013

Document Number: 342-0965

Record Number 282737 Physiologically based pharmacokinetic and pharmacodynamic model for the inhibition of acetylcholinesterase by diisopropylfluorophosphate (journal article)

DPR Received Date: 01/20/2015

Document Number: 342-0965

Record Number 282728 Chlorpyrifos PBPK/PD model for multiple routes of exposure (journal article)

DPR Received Date: 01/20/2015

Document Number: 342-0965

Record Number 282727 Development of a source-to-outcome model for dietary exposures to insecticide residues: an example using chlorpyrifos (journal article)

DPR Received Date: 01/20/2015

Document Number: 342-0965

Record Number 274124 In vitro sensitivity of cholinesterase to inhibition by chlorpyrifos-oxon in several tissues of the rat

DPR Received Date: 10/03/2013

Document Number: 342-0951

Record Number 279906 Chlorpyrifos PBPK/PD model for multiple routes of exposure (journal article)

DPR Received Date: 09/04/2014

Document Number: 342-0960

Record Number 282738 Reduced birth weight in relation to pesticide mixtures detected in cord blood of full-term infants (journal article)

DPR Received Date: 01/20/2015

Document Number: 342-0965

Record Number 282739 Human paraoxonase 1 hydrolysis of nanomolar chlorpyrifos-oxon concentrations is unaffected by phenotype or q192r genotype (journal article)

DPR Received Date: 01/20/2015

Document Number: 342-0965

Record Number 948107) Clinical toxicity of Dursban in dog after multiple applications of aerosol formulation (18P.)

DPR Received Date:

Source: Dow Chemical U.S.A. Midland, MI

Study Date: 12/01/1968

Document Number: 342-0119

Record Number 91999) Final report on safety evaluation and metabolic studies on Dowco 179 (IN 151) (75P.) DowElanco Dowco 179

DPR Received Date: 01/08/1991

Source: Albany Medical College Experimental Pathology & Toxicology Albany, NY

Study Date: 03/01/1971

Document Number: 342-0384

Record Number 948135) Comparison of cholinesterase depression in humans and rabbits following exposure to Chlorpyrifos (22 pp.)

DPR Received Date:

Source: Dow Chemical U.S.A. Midland, MI

Study Date: 08/01/1971

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APPENDIX 2.

SPRAY DRIFT ESTIMATES

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M E M O R A N D U M

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DATE: August 15, 2017

SUBJECT: Revised: Estimation of Chlorpyrifos Horizontal Deposition and Air Concentrations for California Use Scenarios

Background

This memorandum describes modeling procedures used to estimate off-site horizontal deposition and air concentrations associated with California chlorpyrifos use scenarios. The estimates produced with theses modeling procedures are suitable for use in conducting pesticide spray drift human exposure assessments. Horizontal deposition and air concentration estimates associated with primary spray drift from orchard airblast, ground boom, and aerial applications are provided.

Modeling Methods

Two computer simulation models were used in this analysis: AgDRIFT (Teske et al., 2002) and AGDISP (Teske and Curbishley, 2013). The United States Environmental Protection Agency (US EPA) Office of Pesticide Programs (OPP) uses AgDRIFT for all agricultural deposition analysis and uses AGDISP for mosquito adulticide application scenarios (US EPA, 2014 and 2013a). For the analysis presented in this document, the AgDRIFT 2.0.05 model was used to produce the ground boom and orchard airblast deposition estimates only and AGDISP 8.28 was used to produce all aerial application deposition and air concentration estimates.

For this analysis, the AgDRIFT model was chosen for orchard airblast and ground boom because it is the only accepted model available for these two application scenarios. The AGDISP 8.28 model includes a ground boom algorithm, but that algorithm is still under development.

AgDRIFT estimates horizontal deposition for orchard airblast and ground boom applications using empirical models. The data on which the AgDRIFT empirical models are based were produced by the Spray Drift Task Force (SDTF) and were reviewed in a formal peer review (https://archive.epa.gov/scipoly/sap/meetings/web/html/121097_mtg.html). That peer review led to the current grouping of orchard types and ground boom scenarios. AgDRIFT version 2.0.05 executable file dated 8/2002 was used for all orchard airblast and ground boom simulations in this memorandum. AgDRIFT 2.0.05 is an older version of the model but produces ground boom and orchard airblast deposition results identical to the current regulatory version AgDRIFT 2.1.1. In addition, the 90th percentile ground boom results obtained from AgDRIFT 2.0.05 were identical to deposition results shown in the USEPA guidance on spray drift (White et al., 2013) that USEPA produced using the regulatory version of AgDRIFT 2.1.1. The regulatory version of AgDRIFT 2.1.1 was not available when the analysis presented in this memorandum was conducted.

The AGDISP 8.28 model was used for aerial application deposition and air concentration estimates reported in this memorandum. AGDISP is a well vetted model developed through the work of NASA, USDA Forest Service, and the US Army (Bird, et al., 2002). It is a Lagrangian first principles model that is in the public domain and has a Gaussian handoff module to estimate spray drift beyond 2605 ft. The AGDISP model has ongoing support from partnerships between various government agencies and private sector entities and is under continual improvement to bring the model behavior more accurately into line with field measured data. The AgDRIFT model contains an older version of the AGDISP aerial algorithms incorporated to estimate aerial application spray drift. However, the AgDRIFT model is limited to 2605 ft. In addition, AgDRIFT is a proprietary model developed by the SDTF in cooperation with USEPA Office of Research and Development (ORD) under a Cooperative Research Agreement (CRADA). AgDRIFT 2.1.1 does not include a time step improvement incorporated into AGDISP 8.28 (M. Teske, pers. comm., 2014). The lack of that time step improvement in AgDRIFT 2.1.1 results in higher off-site deposition relative to AGDISP 8.28. Analysis later in this memorandum shows that the regulatory version of AgDRIFT 2.1.1 does produce deposition results greater than AGDISP 8.28.

Development of Exposure Scenarios

The deposition and air concentration estimates presented in this document were developed to reflect off-site movement expected under California chlorpyrifos use patterns. Key California use scenario patterns were selected for this analysis (Table 1). A range of application sizes were produced for each of the use scenarios was chosen based upon US EPA default (US EPA, 2013a) and/or analysis of the Pesticide Use Report (PUR) (Tuli, 2013). For orchard airblast the largest application is 40 acres, for ground boom the largest application is 300 acres, for aerial the largest acreage for tree fruit and nuts is 350 acres and for high acreage field crops the highest acreage is

900 acres. A preliminary screening deposition of 0.35% of the application rate was used for initial drift model scenario scoping (S. Beauvais, pers. comm., 2014). This preliminary screening deposition was used only to rank aircraft according to the distance downwind to the deposition fraction of 0.35%. The fixed wing and rotary aircraft showing the longest distance to 0.35% were then chosen to estimate exposures due to horizontal deposition and air concentrations. This process is described in more detail below.

Table 1. Application type scenarios for chlorpyrifos deposition estimates (all application methods) and chlorpyrifos air concentration estimates (aerial application methods only).

Application type	Sub-Type
Orchard Airblast	Sparse/Young
	Dormant Apple
	Vineyard
Ground Boom Medium/Coarse	Low Boom (20 in above the canopy)
	High Boom (50 in above the canopy)
Aerial	Fixed Wing
	Helicopter

The SDTF orchard airblast data is categorized into 5 composite orchard types. The sparse/young orchard airblast is the average of small grapefruit and dormant apple orchards field data. Small grapefruit trees are young, short trees. Dormant apple consists of field data only for apple orchards without leaves. The dormant apple orchard type is based only on the field data for dormant apples. The orchard airblast and ground boom scenarios models are empirical fits to the SDTF field trial data. There are no input variables beyond the orchard type for orchard airblast or spray quality (droplet spectra) and boom height for ground boom. For example, weather conditions cannot be changed. The empirical model outputs reflect the weather conditions at the time of the field trials. For orchard airblast, the only orchard type affected by wind speed was dormant apples where the wind speeds for the field trials varied between 4 mph and 12 mph (SDTF, 1997a). The ground boom field trials were conducted near Plainview, Texas. The weather during the field trials covered a wide range of conditions. The ground boom medium/coarse field trials showed environmental conditions spanning 5 mph to 20 mph wind speeds, 44º F to 91º F air temperatures, and 8% to 82% relative humidity (SDTF, 1997b).

The aerial application model algorithm in both AgDRIFT and AGDISP is a Lagrangian model that tracks droplets released from the nozzles during the simulated application. This type of

model is called a first principles model because the deposition and air concentration estimates are obtained using the laws of physics rather than through statistical fit to observed data. Thus, the aerial model allows input of a wide range of important aspects of an aerial application. Choice of aircraft, how that aircraft is configured, and the specifications of how an aerial application is conducted can make a significant difference in the degree of off-site movement. It is important that the aerial application scenarios simulated are representative of the expected use patterns and that the inputs are clearly stated. For this analysis aerial application information obtained by the Enforcement Branch was used to select candidate aircraft and meteorological conditions (R. Sarracino, pers. comm., 2014). The AGDISP model has a large aircraft library that can be accessed to insure that each aircraft is correctly specified in the model runs. The aircraft list obtained from the Enforcement Branch was examined to match with aircraft that were in the AGDISP aircraft library. All aircraft on the Enforcement Branch aircraft list that were in the AGDISP aircraft library were used for the exploratory analysis and are shown in Table 2. For the exploratory analysis, the meteorological inputs were chosen to reflect an early summer morning application in the San Joaquin Valley. The specific meteorological inputs were the mean wind speed, temperature, and humidity for the time of 0600 hrs over 5 years of weather data (2009-2013) for the dates June 1 to August 31 from the Fresno State CIMIS weather station (station #80). Table 2 shows, for each of the candidate aircraft, the distance to 0.35% horizontal deposition of application rate. Based upon the greatest distance to the preliminary screening deposition level of 0.35% of application rate (S. Beauvais, personal communication, January 29, 2014) the AT802A fixed wing and the Bell 205 helicopter were chosen for further refinement in the final modeling scenarios.

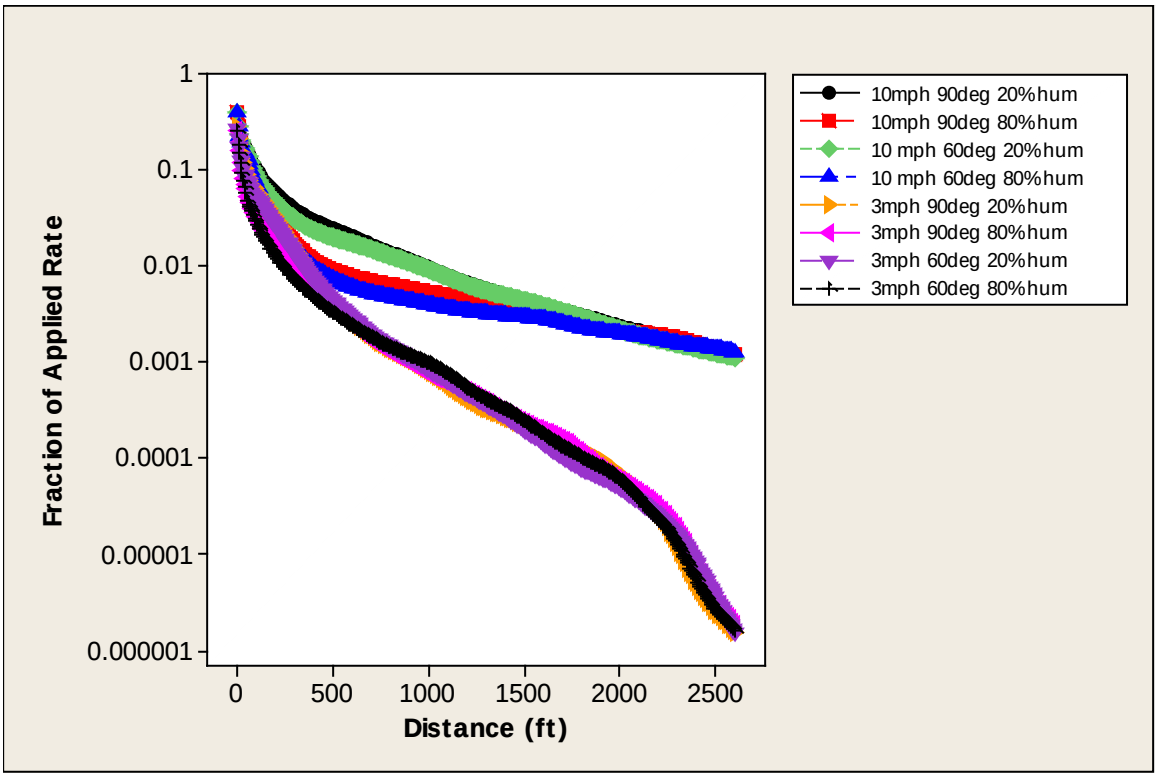
Table 2. Candidate aircraft. All simulations were conducted with a boom length of 76.3% of semi-span or rotor diameter, swath width of 60ft for fixed wing or 1.2x rotor diameter for helicopter, a swath-displacement of 37%, no half-boom effect or swath offset, 2 gal/ac volume, non-volatile active ingredient application rate of 2 lb/ac, 10 mph wind, air temperature 65 deg F, and humidity of 50%. Number of nozzles for each aircraft is the default in the AGDISP library.

Aircraft	Distance to 0.35% of application rate (ft)	Air Speed (mph)	Aircraft Weight (lbs)	Semi-span or Rotor Radius (ft)	Number of Nozzles
Fixed Wing					
AT802A	1174	145	11160	29	39
AT401	1122	120	6000	24.5	42
Trush	1102	140	7665	23.75	32
AT502	1096	155	6660	25	34
AT301	1037	120	5600	22.6	30
AgCat*	1437	150	5022	21.25	29
Helicopter					
Bell 205	1122	92	7697	24	32
Bell 47G-3B-2	1056	58	2422	18.6	25
Hiller UH-12E3	1056	58	2430	17.7	24
Hiller UH-12E3T	1056	58	2370	17.7	24
Aerodyne Wasp	1050	62	2090	17.4	24
Bell 206 Jet Ranger II	1037	69	2053	16.7	23
Bell 206 Jet Ranger III	1037	69	2398	16.7	23
Robinson R-44 Raven	1037	130	1829	16.5	22

*Biplane

Once the AT802A and the Bell 205 aircraft were chosen, the weather conditions were refined for potential worst case conditions. The information gathered by the Enforcement Branch indicated that late afternoon summer applications were expected (R. Sarracino, pers. comm., 2014). Thus, range of weather conditions were chosen to span the possible conditions from sunrise to late afternoon. AGDISP model runs were conducted using all combinations of weather conditions as follows: winds speed 3 mph and 10 mph, temperature 60 deg F and 90 deg F, humidity 20% and 80%. A total of 8 combinations of the chosen wind speed, temperature, and humidity values were simulated for the AT802A aircraft to determine the reasonable worst case weather scenario. The reasonable worst case weather scenario was then used to produce both the deposition and air concentration estimates for the AT802A and the Bell 205 aircrafts. Figure 1 shows the deposition results from those 8 model runs. The 10 mph/20% humidity model runs show the overall highest deposition. The 10 mph/20%humidity/90 deg F scenario shows generally the higher deposition than the 10mph/20% humidity/60 deg F scenario. Thus, the 10 mph/20%humidity/90 deg F meteorology combination was used to produce the deposition and the accompanying air concentrations for the AT802A and the Bell 205 application method scenarios.

Figure 1. AGDISP estimated deposition for the AT802A aircraft under 8 combinations of wind speed, temperature, and humidity.



Uncertainty

No uncertainty factors were added to the modeled deposition or the air concentration estimates. Reasoning for the three application methods of aerial, orchard airblast and ground will be considered separately.

Orchard Airblast. The AgDRIFT orchard airblast empirical model outputs the value of the empirical function. In the case of the least squares fit empirical function this value is the 50th percentile deposition estimate for three orchard types: normal, dense, and sparse. Sparse orchard type was used for this analysis to generally represent California orchards during the dormant spray season, which is reasonable worst case for near field deposition. A refined estimate for specific orchard types is also available. The dormant apples orchard type was simulated as a California specific scenario. The AgDRIFT user manual does not state why a 90th percentile is not estimated for the orchard airblast empirical equations. At the 1999 SAP OPP staff did present tolerance bounds for orchard airblast (U.S. EPA, 1999) but these bounds were not implemented.

Ground Boom. The AgDRIFT ground boom empirical model outputs the value of the empirical function. In the case of the least squares fit empirical function this value is the 50th percentile deposition estimate. In addition, the AgDRIFT ground boom empirical model has the choice to output 90th percentile. However, the derivation of the 90th percentile is not clear. This estimated deposition value does not appear to be large enough, compared to the mean at each distance, to be a tolerance interval capturing the 90th percentile at each distance with a 90% or 95% confidence. More likely what is labeled as the 90th percentile is actually the 90% prediction interval on the empirical function. There is no information provided in the AgDRIFT user manual about exactly how 90th percentile was derived. In the absence of the details of this estimate, and to maintain uniformity in approach between orchard airblast and ground boom, it is preferable to use the 50th percentile estimate (the value on the deposition curve).

Aerial. The AGDISP model produces an ensemble average deposition at a particular distance. For aerial applications all input variables were reasonable worst case. Thus, with all inputs selected for reasonable worst case, the results can be argued to represent a reasonable upper bound on the mean deposition. The AGDISP model algorithm has been compared to numerous field studies and found to produce estimates that are within a factor of two to six of field measured deposition (Bird et al., 2002; Teske and Thistle, 2003; Teske et al., 2003). The AGDISP model algorithm has been found to over-predict deposition in the far field (Bird, et al., 2002). The AGDISP air concentrations estimates have not been compared to field data. However, as mentioned earlier, AGDISP is a first principles model. In addition, mass balance is a feature of the model (Teske and Curbishley, 2013). The air concentration estimated at a particular location includes all the mass in the vertical plane at that location that is present after deposition. Thus, it is likely that the air concentrations will not be sustainably underestimated.

Deposition Estimate Development

Number of swaths. The AgDRIFT and AGDISP models have a maximum number of swaths for each application type. Application sizes are not specified. Instead, the downwind deposition reflects the number of upwind swaths. For these simulations it is assumed that the wind direction is perpendicular to the swath direction and that the deposition estimated is the deposition expected directly downwind from the middle of the swath. Thus, application size was modeled based upon the width in feet of a particular number of swaths. It was further assumed that the field to which the application was made is square. So, the width of the field and the length of the field are assumed to be equal (for aerial applications swath displacement is not considered). The acreage is calculated as the length times the width. For all three application types (orchard airblast, ground boom, and aerial), the width of the desired maximum acreage exceeded the width of the maximum number of swaths the model can simulate. For orchard airblast and

ground boom a maximum of 20 swaths can be simulated. For aerial applications a maximum of 50 swaths can be simulated. Table 3 shows a summary of swath width, maximum number of swaths and the resulting maximum acreage the model will directly produce for each application type.

Table 3. Swath parameter and limits in the AgDRIFT and AGDISP models.

Application Type	Swath Width	Max Number of Swaths	Width of Max Number of Swaths	Equivalent Square Acreage
Orchard Airblast	16 ft	20	320 ft	2.35 ac
Ground Boom	45 ft	20	900 ft	18.6 ac
Aerial Fixed-wing AT802A	60 ft	50	3000 ft	206.6 ac
Aerial Helicopter Bell 205	57.6 ft	50	2880 ft	190.4 ac

The PUR analysis indicates that use patterns in California for orchard airblast and ground boom are commonly much larger than the maximum 20 swath simulations available out of the AgDRIFT model. In order to obtain deposition estimates for applications larger than the maximum single model run limit of 20 swaths the deposition curves from one or more single 20 swath applications were overlaid after being offset upwind by the appropriate distance. Table 4 and Figure 1 show the process for orchard airblast. For orchard airblast, the AgDRIFT model estimates deposition to a maximum downwind distance of 997.4 ft (the prediction domain of the model). A model run of the maximum number of 20 swaths, assuming that rows of the orchard are 16 ft apart (16 ft wide), represents an orchard that is 320 ft wide (20 swaths × 16 ft). With the assumption of a square orchard (320 ft × 320 ft) this results in an orchard that is 2.35 ac. If a second set of 20 swaths is added to the upwind side of this initial orchard then the resulting orchard is 40 swaths, or 640 ft, wide. A square 640 ft by 640 ft orchard is 9.4 ac. Although assuming the next size up orchard is twice as wide and twice as long may seem arbitrary, for the purposes of estimating drift that assumption is not critical because only the width in the upwind direction is most important in determining the downwind deposition. The square orchard is a simplifying assumption. The grape vineyard scenario did not require extension beyond one set of 20 swaths (Table 5). The same extension procedure is used to increase the ground boom application size. Details of the ground boom process are shown in Table 6.

Table 4. Orchard airblast swath extension details. Each set of 20 swaths is 320 ft wide. Downwind deposition curves are offset by the appropriate number of feet and then overlaid. When overlaying, upwind deposition curves are allowed to drop to zero at the model domain limit of 997.4 ft.

Swath Set	Swath Width (ft)	Number of Swaths	Total Application Area Width (Sum of Set Widths)	Upwind Offset (ft)	Total Number of Swaths	Resulting Application Size (acres)	Deposition Curve Distance at Set 1 Downwind Edge (ft)	Section of Deposition Curve added to Set 1 Deposition Curve (ft)
1	16 ft	20	320 ft	0 ft	20	2.35 ac	0 ft	0 ft to 997.4 ft
2	16 ft	20	640 ft	320 ft	40	9.4 ac	320 ft	320 ft to 997.4 ft
3	16 ft	20	960 ft	640 ft	60	21.2 ac	640 ft	640 ft to 997.4 ft
4*	16 ft	20	1280 ft	960 ft	80	37.6 ac	960 ft	960 ft to 997.4 ft

*Set 4 is too far up wind to reliably estimate residue contributions to the downwind deposition curve.

Table 5. Grape Vineyard. Conventional and wrap-around sprayers. Each set of 20 swaths is 240 ft wide. Downwind deposition curves for these scenarios are not overlaid with additional upwind blocks because the deposition is so low that overlays are not necessary.

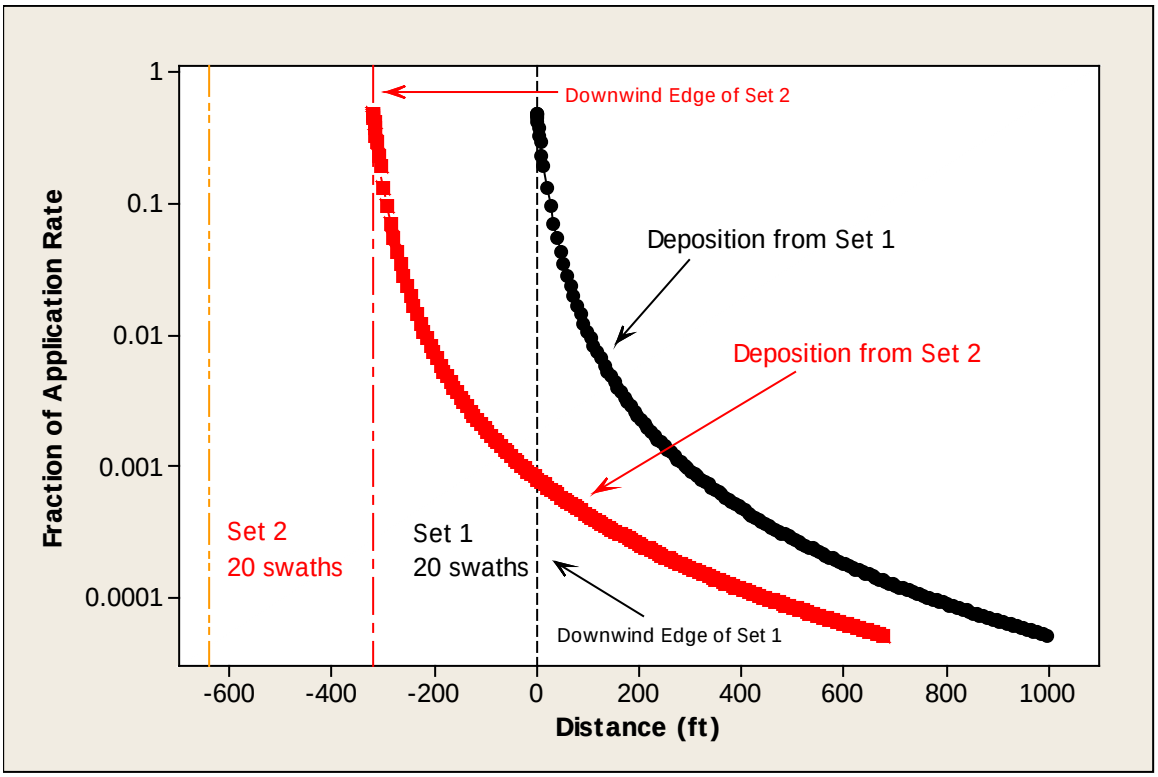
Set	Swath Width (ft)	Number of Swaths	Total Application Area Width (Sum of Set Widths)	Upwind Offset (ft)	Total Number of Swaths	Resulting Application Size (acres)	Deposition Curve Distance at Set 1 Downwind Edge (ft)	Section of Deposition Curve added to Set 1 Deposition Curve (ft)
1	12 ft	20	240 ft	0 ft	20	1.32 ac	0 ft	0 ft to 997.4 ft

Table 6. Ground boom. Each set of 20 swaths is 900 ft wide. Downwind deposition curves are offset by the appropriate number of feet and then overlaid. When overlaying, upwind deposition curves are allowed to drop to zero at the model domain limit of 997.4 ft.

Set	Swath Width (ft)	Number of Swaths	Total Application Area Width (Sum of Set Widths)	Upwind Offset (ft)	Total Number of Swaths	Resulting Application Size (acres)	Deposition Curve Distance at Set 1 Downwind Edge (ft)	Section of Deposition Curve added to Set 1 Deposition Curve (ft)
1	45 ft	20	900 ft	0 ft	20	18.6 ac	0 ft	0 ft to 997.4 ft
2	45 ft	20	1800 ft	900 ft	40	74.4 ac	900 ft	900 ft to 997.4 ft

As an example, the deposition curves from two sets of 20 swaths (Set 1 and Set 2) are overlaid to estimate the composite deposition from the 40 swaths (the total deposition resulting from joining two sets of 20 swaths). The deposition curve from Set 2 is constrained to be used only to 997.4 ft relative to the downwind edge of set 2 (Figure 2). Thus, residues from the Set 2 set of 20 swaths contribute to the downwind deposition from the orchard (Set 1 + Set 2) as a whole only between 0 ft and 677.4 ft on the deposition curve of the Set 1 set of 20 swaths. This process can be repeated for multiple sets of 20 swaths until the upwind setback is so large that the farthest upwind deposition curve extending beyond the downwind edge of the initial set of 20 swaths has a portion too small to sufficiently estimate the residues from the upwind set of swaths. For example, Set 4 in the orchard airblast scenario is too far up wind to reliably estimate residues from Set 4 that might be deposited downwind of Set 1.

Figure 2. Illustration of the deposition curve overlay process to obtain a composite deposition curve for a 40 swath orchard. Two separate 20 swath deposition curves are overlaid as shown below. The Set 2 (red deposition curve) residues only contribute to the total downwind deposition beyond the downwind edge of Set 1. The Set 2 deposition curve is not extended beyond 997.4 ft relative to the downwind edge of Set 2. So, the portion of the composite deposition curve between 667.4 ft and 997.4 ft the Set 1 downwind edge does not receive any deposition from Set 2. This is illustrated by the end of the red deposition curve.



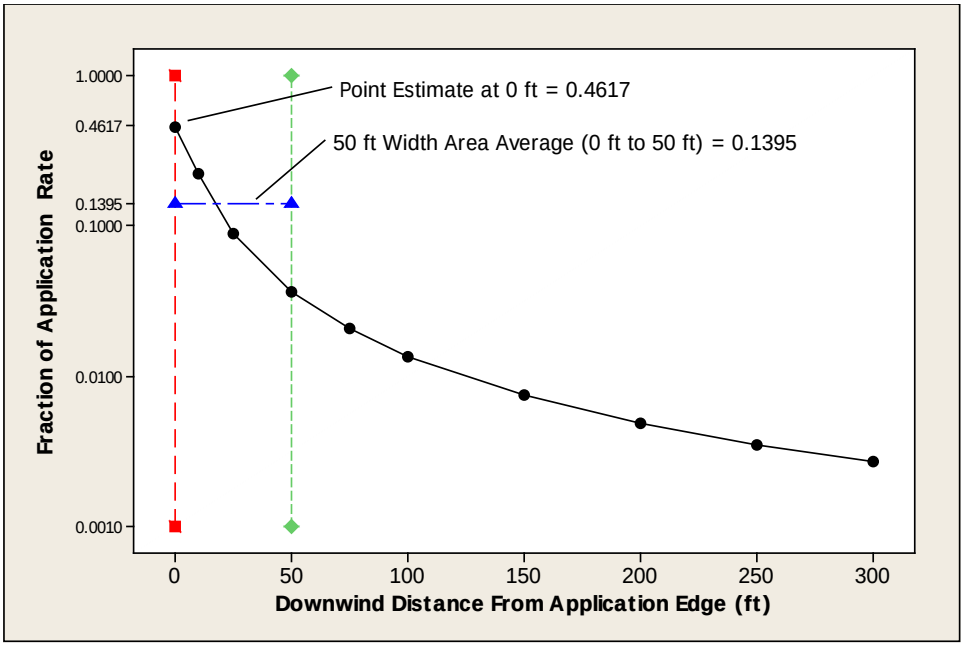
As stated above, this procedure was only implemented if the resulting deposition from the offset upwind swaths was within the prediction domain of the model. The aerial algorithm estimates deposition up to 2605 ft directly downwind of the application (the far field Gaussian handoff was not used in this analysis). The width of the first 50 swaths is 3000 ft for the fixed-wing and 2880 ft for the helicopter. So, the deposition curve from a second set of 50 swaths would fully land on the area of the application comprised by the first 50 swaths. Essentially, all of the deposition from the second set of 50 swaths lands on target. Thus, no new residue would be added to the downwind deposition curve of the first 50 swaths. For this reason the deposition curve overlay procedure was not used for aerial applications. The aerial results were obtained directly out of the AGDISP model.

Once the appropriate composite deposition curves were assembled for 40 swaths and 60 swaths, the point estimates and 50 ft width average deposition at desired distances were produced by fitting an empirical function using TableCurve 2D (AISN, 2000). The purpose of this curve fit was strictly to faithfully reproduce the modelled deposition curve, not as an explanatory analysis. This provided a convenient way to find the deposition at any desired downwind distance. All composite deposition curves were fit in TableCurve2D. Deposition estimates for orchard airblast and ground boom start at 25 ft from the downwind application edge. The SDTF field studies on which the empirical models are based did not include any sampling closer than 25 ft. Thus, the AgDRIFT empirical equations between the field edge and 25 feet are an estimation based on the assumed empirical functions for each of the application methods. These assumed empirical functions may be correct, however, with the data currently available it is impossible to verify that they reflect the actual pattern of deposition very close to the field edge. The deposition fraction likely changes rapidly close to the field. Thus, without measurements it is difficult to place confidence in the empirical estimates between 0 ft and 25 ft. For the ground boom model, the AgDRIFT manual (Teske et al., 2002) shows that a segmented approach is used to produce deposition estimates with two separate functions for 0ft to 25 ft and greater than 25 ft. The orchard airblast does not include a segmented function but the same concerns apply. Reliability of the empirical fit in the downwind direction is also a concern but the empirical functions in the far field decrease slowly and more likely over estimate deposition rather than underestimate. The AgDRIFT manual includes a detailed discussion of far field deposition distances (Teske, et al., 2002). The aerial algorithm is a first principles physics based model so estimates closer than 25 ft are provided.

Two types of estimates were provided, point estimate and an average estimate over a 50 ft width. The 50 ft width is the USEPA standard lawn scenario (USEPA, 2013b). Figure 3 compares the point estimates to the 50ft width area average. This is a generic example not related to chlorpyrifos specifically. The Average Area Deposition is calculated by integrating the area under the deposition curve between a starting downwind distance and a desired width and then dividing by the width. For example, as shown in Figure 3, integrating between 0 ft and 50 ft and

then dividing by 50 ft. In essence this spreads the area under the curve evenly between 0 ft and 50 ft. The difference between the point estimate and the area average is greatest near the application edge because the deposition curve is steep near the application edge (the slope of the curve is steeply negative).

Figure 3. Illustration of the 50 ft Width Average Deposition calculation. The 50 ft width is a moving 50 ft wide segment that depends on the starting downwind distance. In this illustration the starting downwind distance is 0 ft (the application edge) and the segment extends to 50 ft downwind. However, the process is the same regardless of the start and end point of the interval or the width of the interval. See the text for calculation details.



Deposition Estimates

Deposition estimates at selected distances for each scenario are shown in this section. The 20 swath estimates are output directly from either the AgDRIFT or AGDISP model. As described above, all 40 swath and 60 swath estimates are obtained by fitting a function to closely replicate the overlaid deposition curves ($R^2 > 99.9\%$). The 40 swath and 60 swath point and 50ft width average deposition at the selected distances was then evaluated in TableCurve 2D.

Orchard Airblast. Sparse orchard (Tables 7 to 9), dormant apples (Tables 10 to 12), and grapevines (Tables 13 and 14) were simulated. The AgDrift sparse orchard scenario combines

the deposition results from young grapefruit and dormant apples. Dormant apples show higher deposition than sparse orchards near field but lower deposition in the far field (Figure 4).

Table 7. Sparse orchard 20 swath 50th percentile deposition estimates. The development procedure for these deposition estimates is described in the text.

Point Estimates				50 ft Wide Lawn Estimates			
				Location of 50 ft wide Lawn		50 ft Width Average Deposition	
Dist (ft)	Fraction of App	2 lb/ac µg/cm^2		Start	End	Fraction of App	2 lb/ac µg/cm^2
25	0.10070	2.2574		25	75	0.04430	0.9931
50	0.03730	0.8362		50	100	0.02000	0.4483
75	0.01810	0.4057		75	125	0.01100	0.2466
100	0.01030	0.2309		100	150	0.00680	0.1524
150	0.00440	0.0986		150	200	0.00320	0.0717
200	0.00230	0.0516		200	250	0.00180	0.0404
250	0.00140	0.0314		250	300	0.00110	0.0247
300	0.00090	0.0202		300	350	0.00080	0.0179

Table 8. Sparse orchard 40 swath 50th percentile deposition estimates. The development procedure for these deposition estimates is described in the text.

Point Estimates				50 ft Wide Lawn Estimates			
				Location of 50 ft wide Lawn		50 ft Width Average Deposition	
Dist (ft)	Fraction of Rate	2 lb/ac µg/cm^2		Start	End	Fraction of Rate	2 lb/ac µg/cm^2
25	0.10138	2.2726		25	75	0.04472	1.0025
50	0.03783	0.8480		50	100	0.02033	0.4558
75	0.01850	0.4147		75	125	0.01142	0.2560
100	0.01078	0.2418		100	150	0.00729	0.1635
150	0.00492	0.1103		150	200	0.00371	0.0831
200	0.00279	0.0626		200	250	0.00224	0.0502
250	0.00180	0.0403		250	300	0.00150	0.0336
300	0.00125	0.0280		300	350	0.00107	0.0240

Table 9. Sparse orchard 60 swath 50th percentile deposition estimates. The development procedure for these deposition estimates is described in the text.

Point Estimates				50 ft Wide Lawn Estimates			
				Location of 50 ft wide Lawn		50 ft Width Average Deposition	
Dist (ft)	Fraction of Rate	2 lb/ac µg/cm^2		Start	End	Fraction of Rate	2 lb/ac µg/cm^2
25	0.10151	2.2756		25	75	0.04488	1.0060
50	0.03799	0.8517		50	100	0.02044	0.4581
75	0.01860	0.4169		75	125	0.01148	0.2574
100	0.01085	0.2431		100	150	0.00733	0.1644
150	0.00495	0.1110		150	200	0.00373	0.0836
200	0.00281	0.0630		200	250	0.00225	0.0505
250	0.00181	0.0405		250	300	0.00151	0.0338
300	0.00126	0.0282		300	350	0.00108	0.0242

Table 10. Dormant apples 20 swath 50th percentile deposition estimates. The development procedure for these deposition estimates is described in the text.

Point Estimates				50 ft Wide Lawn Estimates			
				Location of 50 ft wide Lawn		50 ft Width Average Deposition	
Dist (ft)	Fraction of Rate	2 lb/ac µg/cm^2		Start	End	Fraction of Rate	2 lb/ac µg/cm^2
25	0.14380	3.2236		25	75	0.05520	1.2374
50	0.04350	0.9751		50	100	0.02090	0.4685
75	0.01820	0.4080		75	125	0.01010	0.2264
100	0.00930	0.2085		100	150	0.00560	0.1255
150	0.00330	0.0740		150	200	0.00230	0.0516
200	0.00160	0.0359		200	250	0.00120	0.0269
250	0.00090	0.0202		250	300	0.00070	0.0157
300	0.00050	0.0112		300	350	0.00040	0.0090

Table 11. Dormant apples 40 swath 50th percentile deposition estimates. The development procedure for these deposition estimates is described in the text.

Point Estimates				50 ft Wide Lawn Estimates			
				Location of 50 ft wide Lawn		50 ft Width Average Deposition	
Dist (ft)	Fraction of Rate	2 lb/ac µg/cm^2		Start	End	Fraction of Rate	2 lb/ac µg/cm^2
25	0.14416	3.2317		25	75	0.05530	1.2397
50	0.04380	0.9818		50	100	0.02101	0.4711
75	0.01846	0.4139		75	125	0.01028	0.2305
100	0.00948	0.2125		100	150	0.00583	0.1306
150	0.00350	0.0784		150	200	0.00244	0.0548
200	0.00169	0.0379		200	250	0.00128	0.0288
250	0.00097	0.0217		250	300	0.00077	0.0173
300	0.00061	0.0136		300	350	0.00049	0.0111

Table 12. Dormant apples 60 swath 50th percentile deposition estimates. The development procedure for these deposition estimates is described in the text.

Point Estimates				50 ft Wide Lawn Estimates			
				Location of 50 ft wide Lawn		50 ft Width Average Deposition	
Dist (ft)	Fraction of Rate	2 lb/ac µg/cm^2		Start	End	Fraction of Rate	2 lb/ac µg/cm^2
25	0.14422	3.2330		25	75	0.05535	1.2409
50	0.04385	0.9830		50	100	0.02106	0.4721
75	0.01851	0.4150		75	125	0.01033	0.2315
100	0.00952	0.2135		100	150	0.00587	0.1315
150	0.00353	0.0792		150	200	0.00248	0.0555
200	0.00172	0.0386		200	250	0.00131	0.0294
250	0.00099	0.0223		250	300	0.00079	0.0178
300	0.00063	0.0141		300	350	0.00051	0.0115

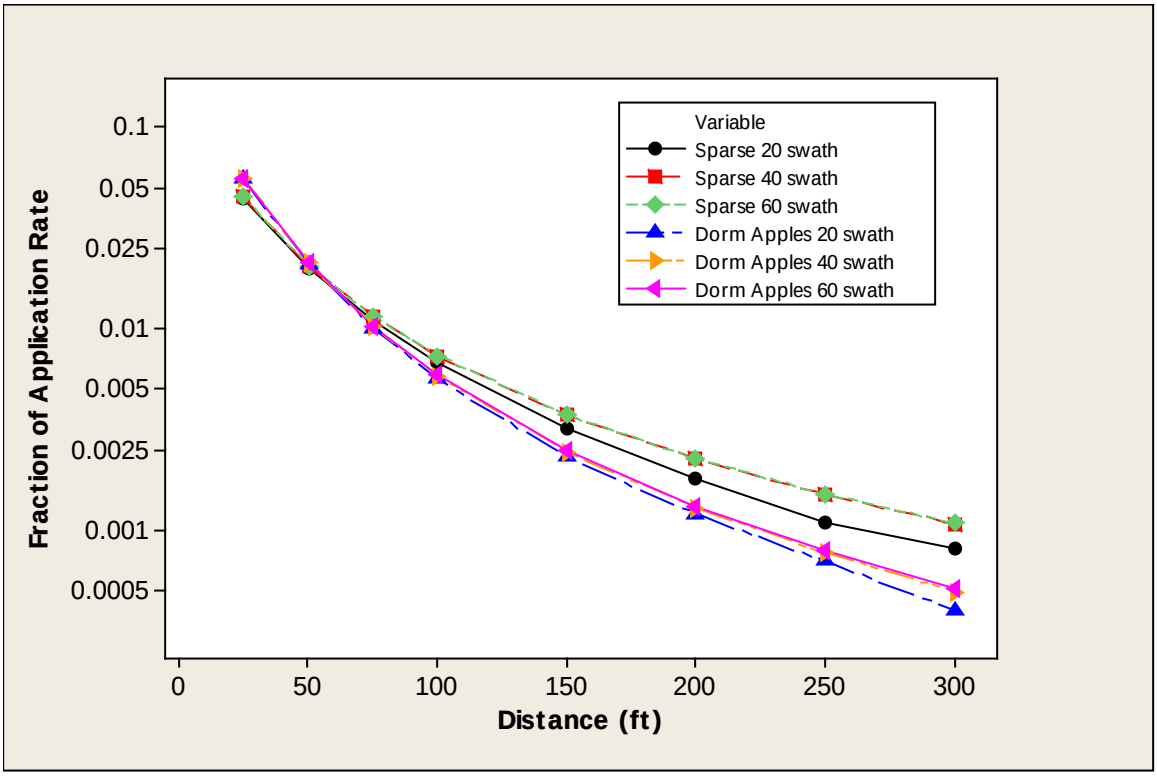
Table 13. Grape vineyard conventional sprayer 20 swath 50th percentile deposition estimates. The development procedure for these deposition estimates is described in the text.

Point Estimates				50 ft Wide Lawn Estimates			
				Location of 50 ft wide Lawn		50 ft Width Average Deposition	
Dist (ft)	Fraction of Rate	2 lb/ac µg/cm^2		Start	End	Fraction of Rate	2 lb/ac µg/cm^2
25	0.0047	0.10000		25	75	0.0022	0.04960
50	0.0019	0.04290		50	100	0.0012	0.02660
75	0.0011	0.02500		75	125	0.0008	0.01770
100	0.0008	0.01710		100	150	0.0006	0.01300
150	0.0004	0.01000		150	200	0.0004	0.00828
200	0.0003	0.00687		200	250	0.0003	0.00592
250	0.0002	0.00511		250	300	0.0002	0.00451
300	0.0002	0.00399		300	350	0.0002	0.00359

Table 14. Grape vineyard wrap-around sprayer 20 swath 50th percentile deposition estimates. The development procedure for these deposition estimates is described in the text.

Point Estimates				50 ft Wide Lawn Estimates			
				Location of 50 ft wide Lawn		50 ft Width Average Deposition	
Dist (ft)	Fraction of Rate	2 lb/ac µg/cm^2		Start	End	Fraction of Rate	2 lb/ac µg/cm^2
25	0.0007	0.01620		25	75	0.0004	0.00971
50	0.0004	0.00902		50	100	0.0003	0.00646
75	0.0003	0.00624		75	125	0.0002	0.00487
100	0.0002	0.00478		100	150	0.0002	0.00392
150	0.0001	0.00325		150	200	0.0001	0.00283
200	0.0001	0.00247		200	250	0.0000	0.00221
250	0.00009	0.00199		250	300	0.0000	0.00182
300	0.00007	0.00166		300	350	0.0000	0.00154

Figure 4. Orchard airblast application 50 ft width average deposition. Comparison between sparse orchard and dormant apples. The development procedure for these deposition estimates is described in the text.



Ground Boom. Low boom (Tables 15 and 16) and high boom (Tables 17 and 18) applications were simulated. A comparison of all deposition estimates is shown in Figure 5. As expected, high boom shows higher deposition than low boom both in the near field and the far field. The 40 swath applications show only slightly higher deposition than the 20 swath applications. This is expected because the 20 swath application is 900 feet wide, only 97 feet less than the domain of the Set 2 deposition curve.

Table 15. Ground boom deposition. Low boom and medium/coarse spray quality 20 swath 50th percentile. The development procedure for these deposition estimates is described in the text.

Point Estimates				50 ft Wide Lawn Estimates			
				Location of 50 ft wide Lawn		50 ft Width Average Deposition	
Dist (ft)	Fraction of Rate	2 lb/ac µg/cm^2		Start	End	Fraction of Rate	2 lb/ac µg/cm^2
25	0.0083	0.1861		25	75	0.0047	0.1054
50	0.0043	0.0964		50	100	0.0032	0.0717
75	0.0031	0.0695		75	125	0.0024	0.0538
100	0.0024	0.0538		100	150	0.0020	0.0448
150	0.0017	0.0381		150	200	0.0015	0.0336
200	0.0013	0.0291		200	250	0.0012	0.0269
250	0.0011	0.0247		250	300	0.0010	0.0224
300	0.0009	0.0202		300	350	0.0009	0.0202

Table 16. Ground boom deposition. Low boom and medium/coarse spray quality 40 swath 50th percentile. The development procedure for these deposition estimates is described in the text.

Point Estimates				50 ft Wide Lawn Estimates			
				Location of 50 ft wide Lawn		50 ft Width Average Deposition	
Dist (ft)	Fraction of Rate	2 lb/ac µg/cm^2		Start	End	Fraction of Rate	2 lb/ac µg/cm^2
25	0.0085	0.1898		25	75	0.0050	0.1119
50	0.0046	0.1029		50	100	0.0034	0.0767
75	0.0034	0.0753		75	125	0.0026	0.0582
100	0.0026	0.0573		100	150	0.0020	0.0459
150	0.0017	0.0381		150	200	0.0015	0.0340
200	0.0014	0.0304		200	250	0.0012	0.0274
250	0.0011	0.0247		250	300	0.0010	0.0228
300	0.0009	0.0212		300	350	0.0009	0.0197

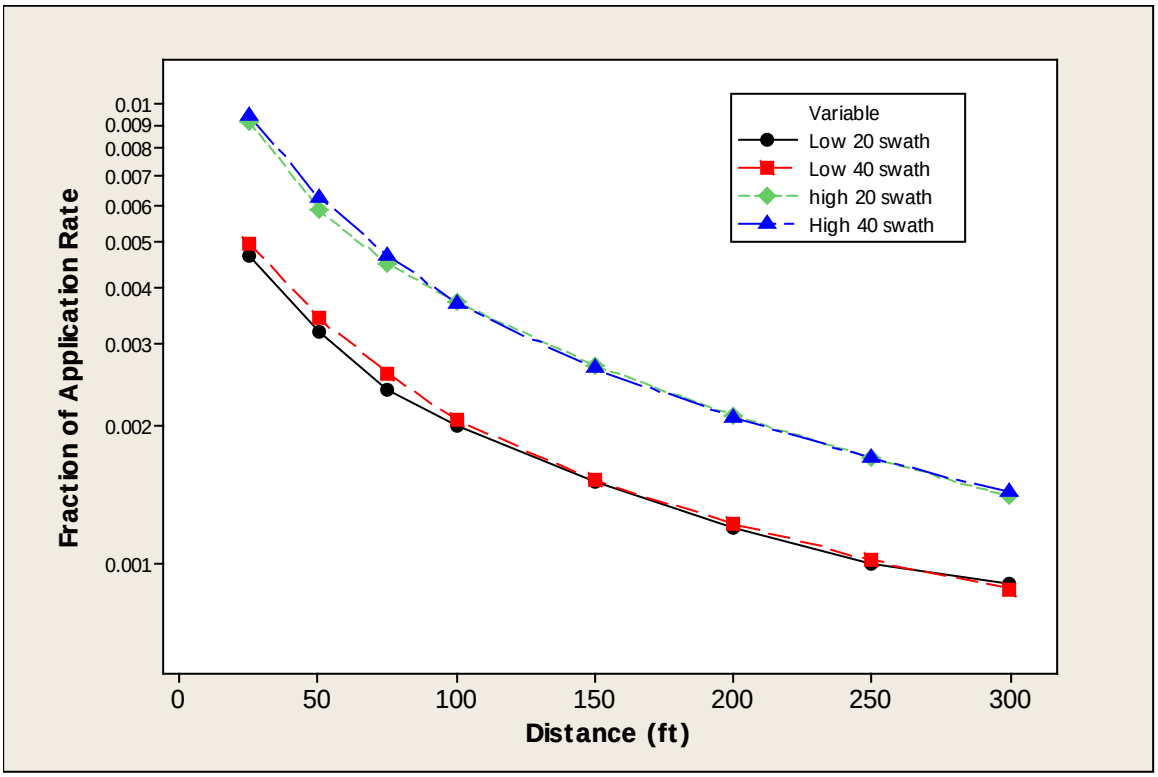
Table 17. Ground boom deposition. High boom and medium/coarse spray quality 20 swath 50th percentile. The development procedure for these deposition estimates is described in the text.

Point Estimates				50 ft Wide Lawn Estimates			
				Location of 50 ft wide Lawn		50 ft Width Average Deposition	
Dist (ft)	Fraction of Rate	2 lb/ac µg/cm^2		Start	End	Fraction of Rate	2 lb/ac µg/cm^2
25	0.0165	0.3699		25	75	0.0092	0.2062
50	0.0083	0.1861		50	100	0.0059	0.1323
75	0.0057	0.1278		75	125	0.0045	0.1009
100	0.0044	0.0986		100	150	0.0037	0.0829
150	0.0031	0.0695		150	200	0.0027	0.0605
200	0.0023	0.0516		200	250	0.0021	0.0471
250	0.0019	0.0426		250	300	0.0017	0.0381
300	0.0015	0.0336		300	350	0.0014	0.0314

Table 18. Ground boom deposition. High boom and medium/coarse spray quality 40 swath 50th percentile. The development procedure for these deposition estimates is described in the text.

Point Estimates				50 ft Wide Lawn Estimates			
				Location of 50 ft wide Lawn		50 ft Width Average Deposition	
Dist (ft)	Fraction of Rate	2 lb/ac µg/cm^2		Start	End	Fraction of Rate	2 lb/ac µg/cm^2
25	0.0166	0.3716		25	75	0.0095	0.2121
50	0.0086	0.1937		50	100	0.0063	0.1408
75	0.0061	0.1375		75	125	0.0047	0.1054
100	0.0046	0.1034		100	150	0.0037	0.0827
150	0.0030	0.0679		150	200	0.0027	0.0596
200	0.0023	0.0524		200	250	0.0021	0.0467
250	0.0019	0.0417		250	300	0.0017	0.0380
300	0.0016	0.0348		300	350	0.0014	0.0321

Figure 5. Ground boom 50 foot width average deposition. Medium/coarse spray quality. Comparison between low boom and high boom. The development procedure for these deposition estimates is described in the text.



Aerial. Deposition estimates for the fixed wing and helicopter scenarios are shown in Tables 19 and 20. A comparison between the AT802A fixed wing aircraft and the Bell 205 helicopter is shown in Figure 6. With the exception of the field edge, the Bell 205 helicopter generally shows less deposition than AT802A fixed wing. The application efficiency is approximately 98% for both the AT802A fixed wing aircraft and the Bell 205 helicopter. This means approximately 98% of the active ingredient released during the application is deposited on-site and 2% is lost by spray drift. The aerial application scenario is 50 swaths, so the application efficiency is higher than a smaller application. For example, a 20 swath application of the same aircraft scenario shows an application efficiency of approximately 95%. However, due to the higher total number of swaths, the downwind horizontal deposition is higher at all distances for the 50 swath application. Therefore, the 50 swath application is the reasonable worst case scenario.

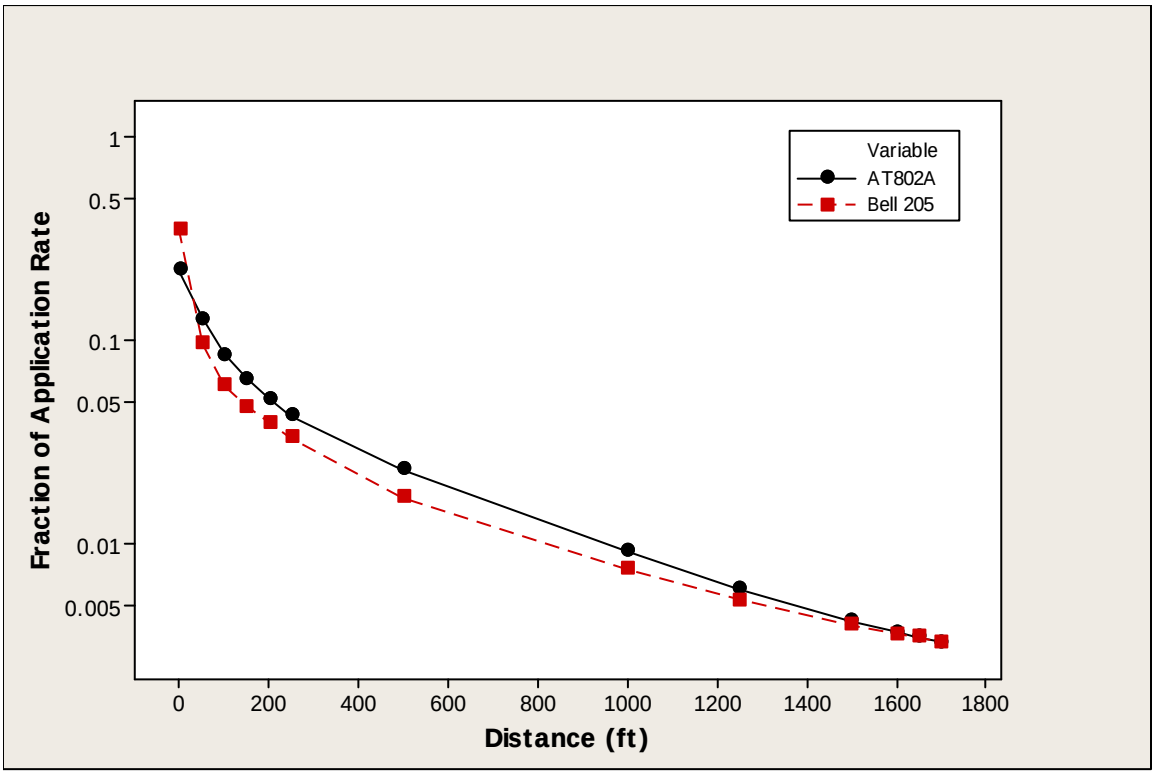
Table 19. Fixed wing aerial application deposition - AT802A medium spray quality 50 swath 50th percentile. The development procedure for these deposition estimates is described in the text.

Point Estimates				50 ft Wide Lawn Estimates			
				Location of 50 ft wide Lawn		50 ft Width Average Deposition	
Dist (ft)	Fraction of Rate	2 lb/ac µg/cm^2		Start	End	Fraction of Rate	2 lb/ac µg/cm^2
0	0.3945	8.8435		0	50	0.2259	5.0640
50	0.1644	3.6854		50	100	0.1286	2.8828
100	0.1026	2.3000		100	150	0.0859	1.9256
150	0.0733	1.6432		150	200	0.0652	1.4616
200	0.0577	1.2935		200	250	0.0524	1.1747
250	0.047	1.0536		250	300	0.043	0.9639
500	0.0245	0.5492		500	550	0.0234	0.5246
1000	0.0096	0.2152		1000	1050	0.0092	0.2062
1250	0.0062	0.1390		1250	1300	0.006	0.1345
1500	0.0043	0.0964		1500	1550	0.0042	0.0942
1600	0.0038	0.0852		1600	1650	0.037	0.8294
1650	0.0036	0.0807		1650	1700	0.0035	0.0785
1700	0.0034	0.0762		1700	1750	0.033	0.0740

Table 20. Helicopter aerial application deposition. Bell 205 medium spray quality 50 swath 50th percentile. The development procedure for these deposition estimates is described in the text.

Point Estimates				50 ft Wide Lawn Estimates			
				Location of 50 ft wide Lawn		50 ft Width Average Deposition	
Dist (ft)	Fraction of Rate	2 lb/ac µg/cm^2		Start	End	Fraction of Rate	2 lb/ac µg/cm^2
0	0.8698	19.4983		0	50	0.3584	8.0343
50	0.1427	3.1989		50	100	0.0969	2.1722
100	0.0683	1.5311		100	150	0.0603	1.3517
150	0.0535	1.1993		150	200	0.0479	1.0738
200	0.0434	0.9729		200	250	0.0396	0.8877
250	0.0363	0.8137		250	300	0.0334	0.7487
500	0.018	0.4035		500	550	0.0171	0.3833
1000	0.0077	0.1726		1000	1050	0.0075	0.1681
1250	0.0055	0.1233		1250	1300	0.0053	0.1188
1500	0.0041	0.0919		1500	1550	0.004	0.0897
1600	0.0037	0.0829		1600	1650	0.0036	0.0807
1650	0.0035	0.0785		1650	1700	0.0035	0.0785
1700	0.0034	0.0762		1700	1750	0.0033	0.0740

Figure 6. Aerial application 50 foot width average deposition. Comparison between fixed wing (AT802A) and helicopter (Bell 205). The development procedure for these deposition estimates is described in the text.



Air Concentration Estimates

The AGDISP model produces estimated 1-hr time weighted average (TWA) air concentrations in a vertical plane at user specified downwind distances from the application edge. The air concentration estimates for both the AT802A and Bell 205 were obtained from the same model runs that produced the deposition estimates. Thus, air concentrations were estimated for both the AT802A and Bell 205 aircraft using the 10 mph, 90 deg F, and 20% humidity weather scenario. The vertical plane was set at selected downwind distances, starting with the minimum federal label buffer zone of 10 ft from the application area edge. The 1-hr TWA air concentrations for the vertical plane at the minimum federal buffer zones of 10 ft and at selected heights above ground level are shown in Table 21. Figure 7 shows the change in 1-hr TWA air concentration with height for the vertical planes between 10 ft and 1000 ft downwind of the application edge. At the minimum federal label buffer zone of 10 ft, for the breathing heights of toddlers to adults (1.7 ft and 5 ft, respectively) the Bell 205 helicopter shows the highest 1-hr TWA air

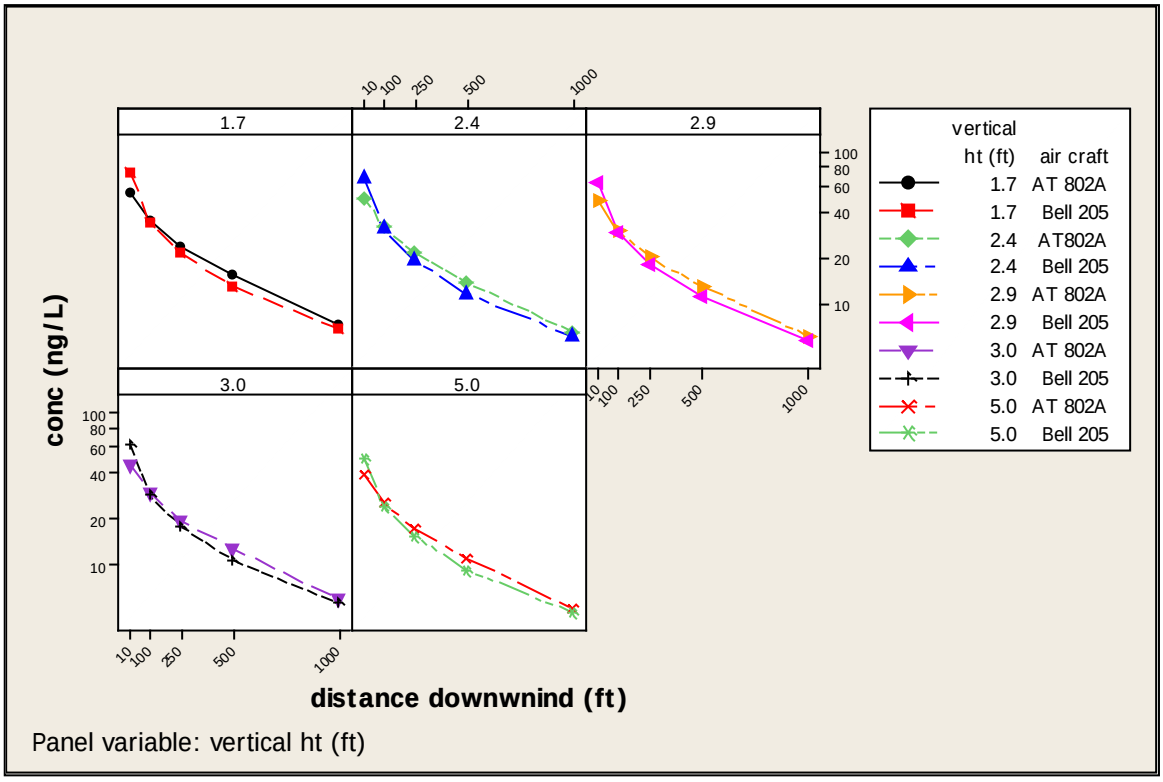
concentration in the vertical plane. As the elevation above ground level increases, however, the 1-hr TWA air concentrations for the AT802A become higher than the Bell 205. The switch occurs at approximately 10 ft above ground level. The AGDISP user manual defines the 1-hr TWA air concentration as: "average concentration of active spray material through a vertical plane at the Transport Distance." Not all the mass in the cloud passing through the vertical plan at a particular distances will be contained is droplets that are in the inhalable size range. The AGDISP model can output the droplet spectra present and the air concentration vertical plan. Therefore, if desired, a respirable fraction adjustment can be made to the concentration passing through a vertical plan. Complete AGDISP aerial application results are shown in Appendix A.

Table 21. Selected 1-hr time weighted average (TWA) air concentrations (ng/L) in a vertical plane at the federal label minimum buffer zone distance of 10 feet downwind of a 206.6 acres application (20 swaths) with the AT802A fixed wind air craft and a 190.4 acre (20 swaths) application with the Bell 205 helicopter. Development procedures for these air concentration estimates are described in the text.

Height Above Ground		1-Hr TWA Air Concentration (ng/L)	
		Aircraft Model	
Inches	Feet	AT802A Fixed Wing[1]	Bell 205 Helicopter[2]
0	0	n/a[3]	n/a[3]
20	1.7	54.6	72.8
29	2.4	49.6	66.4
35	2.9	47.0	62.5
36	3.0	46.5	61.8
60	5.0	39.9	50.0

[1]Fraction of droplets 10µm or less = 0.0285
[2]Fraction of droplets 10µm or less = 0.0366
[3]The AGDISP model does not estimate air concentrations at ground level.

Figure 7. One hour time weighted air concentrations (ng/L) in a vertical plane at distances between 10 ft and 1000 ft downwind of a 206.6 acres application (20 swaths) with the AT802A fixed wind air craft and a 190.4 acre (20 swaths) application with the Bell 205 helicopter. The development procedure for these air concentration estimates is described in the text.



Comparison of Deposition and Air Concentrations as a function of Finished Spray Volume (GPA) and Application Rate (lb/ac)

The effects of finished spray expressed as gallons per acre (GPA) and the active ingredient (ai) application rate (lb ai/ac) within the same aircraft type and meteorological conditions are examined in this section. There is at least one chlorpyrifos label that requires a minimum of 15 GPA finished spray for certain aerial applications (Cheminova NUFOS 4E USEPA Reg. No. 67760- 28-AA). Based on this label, the two levels of finished spray are modeled: 2GPA (US EPA default) and 15 GPA. Three levels of application rate are also modeled: 1 lb ai/ac, 2 lb ai/ac, and 2.3 lb ai/ac.

The application tank mix scenarios shown in Table 22 were simulated using AGDISP for the fixed wing aircraft AT802A and the rotary wing aircraft Bell205. The 2 GPA tank mix scenarios retain the original aircraft set-ups used in sections above for the chlorpyrifos spray drift analysis.

The 15 GPA scenarios used an aircraft set-up with 60 nozzles on the boom to deliver the higher spray volume. This 60 nozzle spray boom set-up is typical of spray booms used for application of products that require a high GPA finished spray. For example, most propanil labels require a minimum of 10 GPA finished spray for aerial applications with 12-15 GPA recommended in low humidity conditions (e.g. SuperWham!CA EPA Reg. No. 71085-5-ZA and Stam 80 EDF-CA EPA Reg. No. 710085-38-AA). Booms on aircraft performing propanil applications are typically equipped with 50 to 70 nozzles (Rice Research Board, 2001; Rice Research Board, 2002).

The CPF 60 nozzle medium ASAE spray quality aerial boom set-up parameters for the 15 GPA scenario were input into the Aircraft Calibration, Droplet Calculator, and USDA Atomization Model Excel files available for download from the Transland/CP Products Droplet Calculation Tools – Aerial Spray Systems website (http://www.translandllc.com/download/ - Accessed August 8, 2017). The calculators show that several nozzles exist that can deliver a 15 GPA finished spray in the ASAE medium spray quality range using the recommended pressure between 25 and 60 psi. The AGDISP model uses generic inputs of ASAE spray quality, number of nozzles, nozzle spacing, and boom length together with air speed and release height independent of a specific brand of nozzle. Therefore, use of the CP Product calculators is employed simply as a boom system check. It is not required to assume that CP Product nozzles are actually used for this scenario to the exclusion of other nozzle brands.

The base scenario of 2 GPA finished spray volume is the default in both the AGDISP and AgDRIFT models and is the default finished spray volume typically used by USEPA (Dawson et al., 2012). The base scenario application rate is designated as 2 lb ai/ac. Thus, for this analysis the base scenario tank mix is 2 GPA finished spray volume and 2 lb ai/ac. All other tank mix combinations are compared to this base. As stated above, the Cheminova NUFOS 4E insecticide chlorpyrifos formulation (EPA Reg. No. 67760- 28-AA) that has 4 lb ai/gallon (0.5 lb/pint) was used for this simulation because this label requires a minimum of 15 GPA finished spray for some aerial applications. The ai is 45% by volume in this formulation. For all tank mix scenarios the ai is declared non-volatile. The remainder of the product is assumed to be volatile. While other components of the NUFOS 4E formulation may be non-volatile, the exact properties are unknown so the remainder of the formulation is considered volatile. In addition, it is assumed no tank mix additives were used so only the ai is non-volatile.

Table 22. Tank mix calculations for the AGDISP tank mix comparison runs. Cheminova NUFOS 4E insecticide chlorpyrifos formulation (US EPA Registration Number 67760- 28-AA).

2 GPA Finished Spray (16 pints)			
ai[1] rate per acre	formulation volume per acre	Proportion of ai in the tank mix volume	Percent ai in the tank mix volume[2]
1 lb	2 pints	2/16*0.45 = 0.56	6%
2 lb	4 pints	4/16*0.45 = 0.113	12%
2.3 lb	4.6 pints	4.6/16*0.45 = 0.129	13%
15 GPA Finished Spray (120 pints)			
ai rate per acre	formulation volume per acre	Proportion of ai in the tank mix volume	Percent ai in the tank mix volume[3]
1 lb	2 pints	2/120*0.45 = 0.008	0.8%
2 lb	4 pints	4/120*0.45 = 0.015	1.5%
2.3 lb	4.6 pints	4.6/120*0.45 = 0.017	1.7%

[1]Active ingredient
[2]Rounded up to the nearest 1%
[3]Not rounded up to the nearest 1% because the proportion of ai in the tank mix is small.

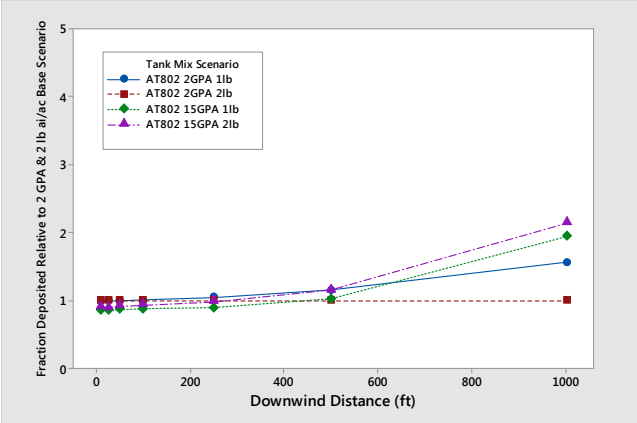
Figure 8 presents results for the AT802A fixed-wing aircraft tank mix scenarios relative to the base tank mix of 2GPA and 2 lb ai/ac (at each distance the scenario result is divided by the result for 2GPA and 2 lb/ac). Comparison of relative changes with scenario and distance can be made between horizontal fraction deposition, horizontal mass deposition, and air concentration in Figure 8 because the results are ratios and the plots are on the same scale. Figure 8a and 8b show the relative deposition of fraction and mass for each scenario, respectively. Figure 8c shows the relative air concentration for each scenario.

Across combinations of finished spray volume and application rates, near field (within about 200 ft of the application edge) the relative horizontal fraction results are reasonably similar (e.g., the fraction of application rate deposition ratio of base tank mix to scenario tank mix is close to 1.0) (Figure 8a). However, the far field results differ between scenarios, ranging from about 1.5 to 2 times the base scenario. Changes in relative fraction deposition are not proportional to differences in tank mix scenarios. Figures 8b and 8c show that changes in relative mass deposition and air concentrations are also not proportional to tank mix scenarios. The 15 gal/ac scenarios show the largest differences regardless of application rate. These results indicate: 1) simple multiplication of a base application rate deposition curve (fraction or mass) to obtain other application rates at the same GPA volume does not produce the same results compared to running the AGDISP model (or AgDRIFT model) separately for each tank mix scenario and 2)

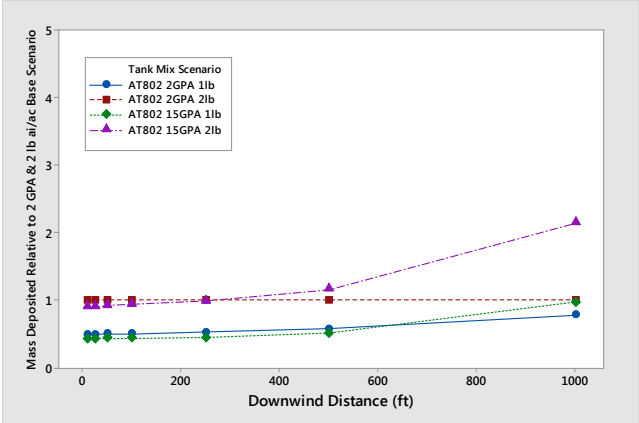
finished spray volume likely affects deposition and air concentration results through differences in the percent of ai in the tank mix. Therefore, these results imply a potential tank mix effect that is not considered if the default inputs alone are used to produce horizontal deposition and air concentration estimates. The higher finished spray volume per acre appears to increase deposition in the far field and increase air concentrations throughout the model domain.

Figure 8. Horizontal deposition (fraction of application rate and mass) and air concentration relative to the base scenario of AT802A aircraft 2GPA finished spray and 2 lb ai/ac application rate (AT802A 2GPA 2lb). Additional scenarios vary combinations of volume of finished spray (GPA) and application rate (lb ai/ac). Results at each distance for each scenario are divided by the result for the base scenario (the vertical axis is dimensionless).

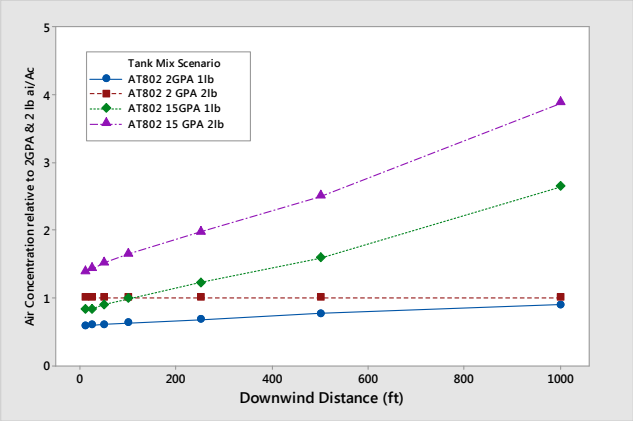
a. Horizontal Fraction Deposition



b. Horizontal Mass Deposition



c. Air Concentration



Comparison with US EPA Results

Both this analysis and the analysis from US EPA used computer simulation models to produce horizontal deposition and air concentration estimates for chlorpyrifos. Inputs for some scenarios modeled were similar. For other scenarios the inputs were quite different.

For orchard airblast and ground boom this analysis used AgDRIFT 2.0.05 because when this analysis was conducted staff did not have access to AgDRIFT 2.1.1 regulatory version. For orchard airblast and ground boom AgDRIFT 2.0.05 yielded identical results to AgDRIFT 2.1.1 public version. After this analysis was finished staff obtained the regulatory version of AgDRIFT 2.1.1. As expected, results for orchard airblast and ground boom were identical between AgDRIFT 2.0.05 and AgDRIFT 2.1.1 regulatory version. That is because the empirical models that produce the orchard airblast and ground boom results have not changed since the versions of AgDRIFT developed following the expert panel review in the mid-1990's. The user manual supplied with AgDRIFT 2.1.1 is the user manual for AgDRIFT 2.0.07 (Teske et al., 2003).

Orchard Airblast. This analysis and US EPA orchard airblast simulations used consistent inputs. The only differences are due to US EPA rounding up to 2 decimal places for the horizontal deposition. US EPA presented only the sparse orchard scenario. This analysis presents sparse orchard, dormant apples, and grape vineyard (non-wrap-around). A side-by-side comparison for sparse orchard and 2 lb ai/ac application rate is shown in Table 23.

Table 23. Comparison of 50th percentile sparse orchard horizontal deposition (lb ai/ac) across a 50ft wide lawn for 20 rows and 2 lb ai/ac application rate as estimated using the AgDRIFT model.

Distance Downwind (ft)	This Analysis	USEPA
0	*[1]	0.57[2]
10	*	0.16
25	0.0886	0.09
50	0.04	0.04
75	0.022	0.02
100	0.0136	0.01
125	0.009	0.01
150	0.0064	0.01
200	0.0036	0.00
250	0.0022	0.00
300	0.0016	0.00

[1]This analysis did not report estimates for empirical model fits between 0 and 25 feet because no field measurements were made within that distance range. The empirical model fit starts at 25 ft downwind of the treated field.
[2]The US EPA field edge horizontal deposition estimates are in error (References: Personal Communication with Charles Peck; US EPA 2014).

Ground Boom. There are no differences between this analysis and USEPA for ground boom simulation inputs. Both used the same scenarios of ASAE Fine to Medium/Coarse droplet spectra for low and high boom applications. However, USEPA reported the 90th percentile estimates. This analysis reported the 50th percentile estimates because the orchard airblast and aerial are both 50th percentile estimates. The use of the 50th percentile estimate puts ground boom on the same estimation basis as orchard airblast and aerial. Table 24 shows a side-by-side comparison of ground boom horizontal deposition (lb ai/ac) across a 50ft wide lawn for 20 swaths and 2 lb ai/ac application rate as estimated using the AgDRIFT model.

Table 24. Comparison of ground boom horizontal deposition (lb ai/ac) across a 50ft wide lawn for 20 swaths and 2 lb ai/ac application rate as estimated using the AgDRIFT model.

Distance Downwind (ft)	This Analysis Low Boom[1] 50th Percentile	USEPA Low Boom 90th Percentile	This Analysis High Boom[2] 50th Percentile	USEPA High Boom 90th Percentile
0	*[3]	0.46[4]	*	0.54[4]
10	*	0.02	*	0.04
25	0.0094	0.02	0.0184	0.03
50	0.0064	0.01	0.0118	0.02
75	0.0048	0.01	0.009	0.02
100	0.0040	0.01	0.0074	0.01
125	0.0034	0.01	0.0062	0.01
150	0.0030	0.01	0.0054	0.01
200	0.0024	0.00	0.0042	0.01
250	0.0020	0.00	0.0034	0.01
300	0.0018	0.00	0.0028	0.01

[1]Low boom height is 20 inches above the target.
[2]High boom is 50 inches above the target.
[3]This analysis did not report estimates for empirical model fits between 0 and 25 feet because no field measurements were made within that distance range. The empirical model fit starts at 25 ft downwind of the treated field.
[4]US EPA field edge deposition estimates are in error (References: Personal Communication with Charles Peck; US EPA 2014).

Aerial. Differences between aerial simulation inputs for this analysis and USEPA produces differences in the horizontal deposition. One difference is that this analysis used AGDISP 8.28 (Teske and Curbishley, 2013) to simulate the aerial application scenarios while USEPA used AgDRIFT 2.1.1 regulatory version. Table 25 follows the format of the AgDRIFT 2.0.05 user's manual and shows the AgDRIFT and AGDISP model inputs (Teske et al., 2002). The format of the AgDRIFT user's manual does not change with model version and the Tier I default parameter are the same between AgDRIFT 2.0.05 and AgDRIFT 2.1.1. The AgDRIFT Tier I

default inputs shown in Table 25 were not changed by USEPA from those defaults for the AgDRIFT Tier II model runs.

Table 25. Details of Aerial Application inputs for AGDISP and AgDRIFT this analysis and USEPA, respectively.

	This Analysis AGDISP	USEPA AgDRIFT
Aircraft Model	AT802A	AT401
Weight	11160 lbs	6000 lbs
Wing Semispan	29 ft	24.5 ft
Flight Speed	144.99 mph	119.99 mph
Release Height	10 ft	10 ft
Number of Nozzles	39	42
Vertical Offset	-0.6601 ft	-1.51 ft
Horizontal Offset	-0.5 ft	-0.83 ft
Boom Span	76.3%	76.32%
Spacing (even)	14 inches	11 inches
ASABE[1] Droplet Spectra Classification	Medium	Tier I Fine to Medium Tier II Medium
Wind Speed at 2 m	10 mph	10 mph
Wind Direction	Perpendicular to Flight Path	Perpendicular to Flight Path
Surface Roughness	0.12 ft (low crops)	0.0246 ft (bare soil)
Stability	Overcast (Neutral)	Overcast (Neutral)
Relative Humidity	20%	50%
Temperature	90 deg F	86 deg F
Specific Gravity	1.0	1.0
Spray Volume Rate	2 gal/ac	2 gal/ac
Application Rate	2 lb/ac[2]	2 lb/ac
Nonvolatile Rate	2 lb/ac	3 lb/ac[3]
Active Solution % of Tank Mix	12%	12%
Additive Solution % of Tank Mix	0%	5%
Nonvolatile Active	12%	12%
Volatile Fraction	0.88	.83
Nonvolatile Fraction	0.12	.17
Swath Width	60 ft	60 ft
Swath Displacement	37%	37%
Number of Flight Lines	50	20

[1]American Society of Agricultural and Biological Engineers. Formerly American Society of Agricultural Engineers (ASAE). The organization change names in 2005.

[2]Application rates of 1, 2, 2.3, 4, and 6 lb/ac were simulated both 2 gal/ac and 15 gal/ac spray volume.

[3]US EPA indicates in D3399483. AppendixF.CPOSDrift.xlsx "…DAS Error Correction Comments/Meetings" for this tank mix but there is no accompanying documents to explain the "correction." Not all chlorpyrifos products are Dow products so this analysis does not include the 1 lb/ac of non-ai nonvolatile material in the tank mix. https://www.regulations.gov/document?D=EPA-HQ-OPP-2008-0850-0107

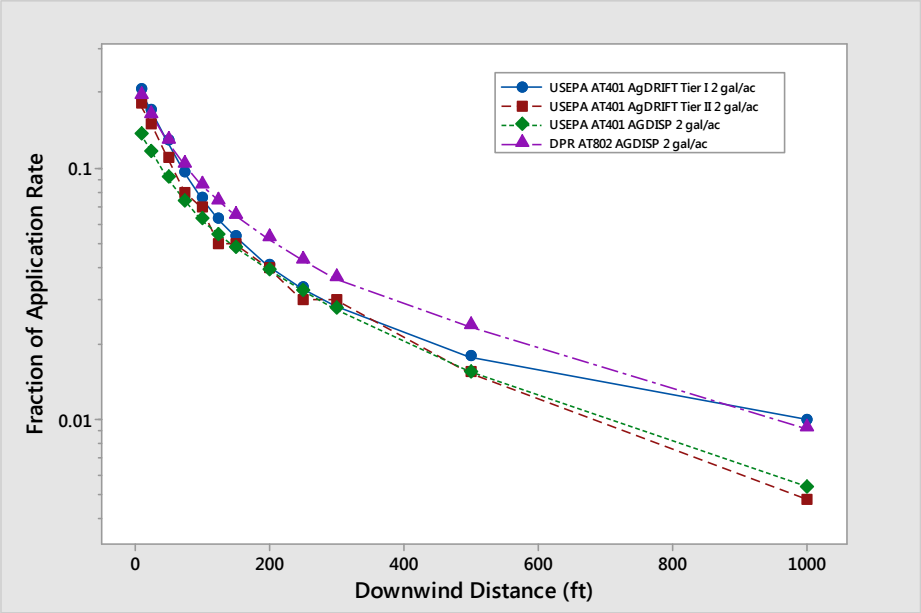
Deposition estimates for 2 lb ai/ac application rate are compared in Table 26 and shown in Figure 9. For this comparison, USEPA AgDRIFT estimates were extended to 1000 ft downwind to match the AGDISP estimates. In addition, the USEPA AgDRIFT inputs were used in AGDISP to provide a comparison of AgDRIFT and AGDISP horizontal deposition estimate for the AT401 aircraft. The AgDRIFT 2.1.1 aerial algorithm does not include an evaporation time-step refinement that was incorporated into AGDISP 8.28 to improve mass accountancy (H. Thistle, pers. comm., 2014). This results in the AgDRIFT horizontal deposition being higher than AGDISP for the same scenario (AT401 aircraft/20 swaths) due to the lack of the refined evaporation time-step. This effect is apparent in Figure 9 because the AGDISP results using the USEPA AT401 inputs show lower horizontal deposition relative to the AgDRIFT AT401horizontal deposition results. This analysis used AGDISP. However, the horizontal deposition estimates reported in this analysis are higher relative to USEPA horizontal deposition estimates for several reasons: 1) the AT802A was selected as the California aircraft based on common use in California and higher horizontal deposition estimates, 2) this analysis used 50 swathes (USEPA used 20 swaths) to reflect the largest application sizes in California, 3) the meteorological conditions used in this analysis are California specific, and 4) the tank mix fractions used in this analysis are California specific.

Table 26. Comparison of aerial horizontal deposition (fraction of application rate) across a 50ft wide lawn for 2 lb ai/ac application rate as estimated using the AgDRIFT and AGDISP models.

Downwind Distance (ft)	USEPA AgDRIFT 2 gal/ac 20 swath AT401 Tier I	USEPA AgDRIFT 2 gal/ac 20 swath AT401 Tier II	USEPA Inputs AGDISP 2 gal/ac 20 swath AT401	This Analysis AGDISP 2 gal/ac 50 swath AT802A
10	0.20	0.1840	0.1374	0.1929
25	0.17	0.1475	0.1170	0.1640
50	0.13	0.1125	0.0914	0.1286
75	0.10	0.0854	0.0742	0.1034
100	0.08	0.0682	0.0627	0.0859
125	0.06	0.0570	0.0546	0.0739
150	0.05	0.0496	0.0483	0.0652
200	0.04	0.0394	0.0394	0.0524
250	0.03	0.0324	0.0327	0.0430
300	0.03	0.0271	0.0275	0.0365
500	0.02	0.0154	0.0155	0.0234
1000	*[1]	0.0048	0.0054	0.0092

[1]AgDRIFT Tier I does not estimate to 1000 ft.

Figure 9. Aerial application horizontal deposition estimates expressed as fraction of 2 lb ai/ac application rate as modeled by 4 different AgDRIFT and AGDISP scenarios.



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Appendix A – AGDISP Full Results for Aerial Application Scenarios

AT802A
2 GPA
1 lb ai/ac

distance downwind (ft)	horizontal deposition (fraction)	Air concentration (ng/L) at 1.7 ft	Air concentration (ng/L) at 5.0 ft	fraction <=10um
10	0.1922	31.8	23.4	0.0341
25	0.1639	29.2	21.8	0.0357
50	0.1290	26.4	19.4	0.0376
100	0.0869	22.0	16.3	0.0406
250	0.0453	16.1	11.8	0.0471
500	0.0270	11.7	8.5	0.0570
1000	0.0144	6.5	4.7	0.0852
1320	0.0094	4.6	3.3	0.1072
2608	0.0017	1.6	1.2	0.2290

Bell205
2 GPA
1 lb ai/ac

distance downwind (ft)	horizontal deposition (fraction)	Air concentration (ng/L) at 1.7 ft	Air concentration (ng/L) at 5.0 ft	fraction <=10um
10	0.2454	40.9	28.8	0.0440
25	0.1553	33.6	24.0	0.0472
50	0.0951	27.4	19.7	0.0510
100	0.0578	21.9	15.8	0.0558
250	0.0369	15.3	11.1	0.0662
500	0.0219	10.2	7.4	0.0831
1000	0.0107	5.8	4.2	0.1178
1320	0.0075	4.5	3.2	0.1410
2608	0.0012	2.0	1.5	0.2500

AT802A
2 GPA
2 lb ai/ac

distance downwind (ft)	horizontal deposition (fraction)	Air concentration (ng/L) at 1.7 ft	Air concentration (ng/L) at 5.0 ft	fraction <=10um
10	0.1929	54.6	39.9	0.0285
25	0.1640	49.3	36.7	0.0300
50	0.1286	43.7	32.0	0.0321
100	0.0859	35.0	25.9	0.0355
250	0.0430	23.7	17.4	0.0440
500	0.0234	15.3	11.1	0.0589
1000	0.0092	7.2	5.2	0.0999
1320	0.0054	4.9	3.6	0.1300
2608	0.0010	1.6	1.2	0.2800

Bell205

2 GPA
2 lb ai/ac

distance downwind (ft)	horizontal deposition (fraction)	Air concentration (ng/L) at 1.7 ft	Air concentration (ng/L) at 5.0 ft	fraction <=10um
10	0.2471	72.8	50.0	0.0366
25	0.1574	58.0	40.4	0.0400
50	0.0969	45.8	32.2	0.0445
100	0.0603	34.5	24.6	0.0500
250	0.0334	21.5	15.4	0.0640
500	0.0171	13.0	9.3	0.0867
1000	0.0075	6.8	4.9	0.1329
1320	0.0048	4.99	3.61	0.1600
2608	0.0008	2.19	1.59	0.2887

AT802A
2 GPA
2.3 lb ai/ac

distance downwind (ft)	horizontal deposition (fraction)	Air concentration (ng/L) at 1.7 ft	Air concentration (ng/L) at 5.0 ft	fraction <=10um
10	0.1929	58.3	42.8	0.0283
25	0.1639	52.6	39.4	0.0302
50	0.1284	46.4	34.1	0.0324
100	0.0856	37.1	27.5	0.0360
250	0.0428	25.0	18.3	0.0451
500	0.0227	15.9	11.5	0.0605
1000	0.0088	7.5	5.4	0.1026
1320	0.0050	5.1	3.7	0.1333
2608	0.0011	1.7	1.2	0.2951

Bell205
2 GPA
2.3 lb ai/ac

distance downwind (ft)	horizontal deposition (fraction)	Air concentration (ng/L) at 1.7 ft	Air concentration (ng/L) at 5.0 ft	fraction <=10um
10	0.2472	77.1	53.8	0.0376
25	0.1575	61.1	43.5	0.0413
50	0.0970	48.2	34.5	0.0458
100	0.0605	36.2	26.0	0.0521
250	0.0328	22.2	16.0	0.0675
500	0.0165	13.3	9.6	0.0915
1000	0.0071	6.9	5.0	0.1405
1320	0.0045	5.0	3.7	0.1753
2608	0.0009	2.3	1.6	0.3127

AT802A
15 GPA
1 lb ai/ac

distance downwind (ft)	horizontal deposition (fraction)	Air concentration (ng/L) at 1.7 ft	Air concentration (ng/L) at 5.0 ft	fraction <=10um
10	0.1671	44.3	32.3	0.0737
25	0.1409	41.3	30.6	0.0749
50	0.1127	39.1	28.7	0.0765
100	0.0754	34.8	25.6	0.0788
250	0.0387	28.9	21.2	0.0826
500	0.0240	24.3	17.7	0.0863
1000	0.0179	19.0	13.8	0.0944
1320	0.0162	16.4	11.9	0.1011
2608	0.0048	9.0	6.5	0.1468

Bell205
15 GPA
1 lb ai/ac

distance downwind (ft)	horizontal deposition (fraction)	Air concentration (ng/L) at 1.7 ft	Air concentration (ng/L) at 5.0 ft	fraction <=10um
10	0.2281	68.5	48.7	0.0920
25	0.1403	59.2	42.6	0.0958
50	0.0814	51.7	37.3	0.0994
100	0.0472	44.8	32.5	0.1026
250	0.0328	36.7	26.6	0.1102
500	0.0246	28.8	20.9	0.1200
1000	0.0161	20.2	14.7	0.1410
1320	0.0129	15.0	10.8	0.1558
2608	0.0021	8.0	6.4	0.2140

AT802A
15 GPA
2 lb ai/ac

distance downwind (ft)	horizontal deposition (fraction)	Air concentration (ng/L) at 1.7 ft	Air concentration (ng/L) at 5.0 ft	fraction <=10um
10	0.1738	75.8	55.3	0.0565
25	0.1472	70.3	52.2	0.0577
50	0.1186	66.0	48.4	0.0590
100	0.0808	57.9	42.6	0.0615
250	0.0425	46.8	34.2	0.0677
500	0.0271	38.1	27.8	0.0710
1000	0.0197	27.9	20.2	0.0835
1320	0.0171	22.7	16.5	0.0936
2608	0.0041	10.3	7.5	0.1606

Bell205
15 GPA
2 lb ai/ac

distance downwind (ft)	horizontal deposition (fraction)	Air concentration (ng/L) at 1.7 ft	Air concentration (ng/L) at 5.0 ft	fraction <=10um
10	0.2343	96.7	68.6	0.0708
25	0.1461	82.8	59.6	0.0741
50	0.0870	71.5	51.6	0.0776
100	0.0515	61.2	44.3	0.0814
250	0.0360	48.8	35.3	0.0889
500	0.0256	37.3	27.0	0.1008
1000	0.0155	25.2	18.3	0.1240
1320	0.0118	20.7	15.0	0.1390
2608	0.0021	11.5	8.3	0.2040

AT802A
15 GPA
2.3 lb ai/ac

distance downwind (ft)	horizontal deposition (fraction)	Air concentration (ng/L) at 1.7 ft	Air concentration (ng/L) at 5.0 ft	fraction <=10um
10	0.1745	84.1	61.4	0.0574
25	0.1480	77.9	57.9	0.0587
50	0.1194	73.0	53.6	0.0602
100	0.0813	63.7	46.9	0.0629
250	0.0429	51.3	37.5	0.0676
500	0.0273	41.5	30.3	0.0735
1000	0.0198	29.9	21.7	0.0875
1320	0.0167	24.1	17.5	0.1001
2608	0.0041	10.6	7.7	0.1740

Bell205
15 GPA
2.3 lb ai/ac

distance downwind (ft)	horizontal deposition (fraction)	Air concentration (ng/L) at 1.7 ft	Air concentration (ng/L) at 5.0 ft	fraction <=10um
10	0.2355	107.4	76.2	0.0732
25	0.1472	91.7	65.9	0.0759
50	0.0879	78.9	56.9	0.0804
100	0.0522	67.1	48.5	0.0851
250	0.0362	53.2	38.5	0.0926
500	0.0254	40.2	29.1	0.1058
1000	0.0154	26.9	19.5	0.1313
1320	0.0117	22.0	15.9	0.1481
2608	0.0021	12.7	9.2	0.1769

APPENDIX 3.

ASCIX INPUT FILE (M-FILE) FOR USE IN GENERATING THE INHALATION POINT-OF-DEPARTURE

Appendix 3: asclX Input file (m-file) for use in generating the inhalation point-of-departure

```
Human_Parameters_MRP                    % Sets up all human parameters
preg_female_parameters                  % US EPA used female
BWSW=1;                                 % Sets model to run based on body weight or age
BWST=11;                                % Body weight, children 1-2 years old
VVOL=0.025;                             % Child urinary volume approx.
AGE0=1.5;
CONCMGM=2.85;
CINT=2;
TSTOP=504;                              % 504 hours = 21 days
%exposure timing commands
D3IN=7;  % DAYS/WEEK  for acute, set =1, for every day = 7
P2IN=1;  % HRS/DAY for acute, set =1, for 1 hr daily set =1, to match EPA Table 1 =2 hr/day
W2IN=21; % Days of repeated exposure

prepare @clear@all
start @NoCallback

simall = [_time _rbcce _urinetcpy _cv*350.6 _cvo*334.5 _blauc*350.6 _blauco*334.5];%conc unit = ug/L
URINETCPY  %ug/L
min(_rbcce)
!! plo rbcce
!! plo urinetcpy

save simall @file='Inhalation_Child_SS_DPR' @format=ascii
```

PUBLIC HEALTH RESEARCH

Chlorpyrifos Blood Level and Exposure Symptoms among Paddy Farmers in Sabak Bernam, Malaysia

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ABSTRACT

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Introduction The extensive and intensive use of pesticides in agricultural practices has exposed farmers to various hazards resulting in varying degrees of health outcomes.

Methods We conducted a cross-sectional study among paddy farmers in Sabak Bernam district, Malaysia. The objective of this study was to gather baseline information on chlorpyrifos blood level and its relationship with pesticides exposure symptoms.

Results We detected chlorpyrifos in farmers' blood in 7 percent of the respondents, with mean 7.29 nanogram per millilitre blood (sd 5.84 nanogram per millilitre). The percentage of farmers who experienced at least one pesticide exposure symptoms was 75 percent. However, we found no significant association between chlorpyrifos blood level and its exposure symptoms. The farmers had low scores on safe practice of pesticide use even though they have high marks on knowledge and attitude. We found no significant association between the scores on knowledge, attitude and practice on pesticide use and the chlorpyrifos blood level.

Conclusions The presence of pesticide exposure symptoms proved that most of the farmers were exposed to hazardous effects of pesticides. Specific trainings on safe use and handling of pesticides should be given on regular basis to these farmers to ensure they are protected from hazardous effects of pesticides exposure.

Keywords Chlorpyrifos - paddy farmers - Sabak Bernam - pesticides exposure symptoms

INTRODUCTION

Chlorpyrifos is a broad-spectrum organophosphate insecticide. It is effective in controlling cutworms, corn rootworms, cockroaches, grubs, flea beetles, flies, termites, fire ants and lice. Some farmers use it as an insecticide on grain, cotton, field, fruit, nut and vegetable crops, and well as on lawns and ornamental plants. Others use it on sheep and turkeys, for horse site treatment, dog kennels, domestic homes, farm buildings, storage bins and commercial establishments. Chlorpyrifos acts on pests mainly as a contact poison, with some action as a stomach poison. It is available as granules, wettable powder, dustable powder and emulsifiable concentrate. In Sabak Bernam, 90 per cent of the paddy farmers used chlorpyrifos as insecticide on the paddy stalks[1]. It is popular because of its availability and reasonable price.

Preventive treatment with insecticides such as chlorpyrifos at high dose before the planting season of a new crop (soil drenching) is a common practice in some tropical intensive cropping systems. This practice may increase the risk of leaching and pesticide uptake by the new crop. The half-life of the chlorpyrifos in Malaysian soil was reported as 19.8 days[2]. In Sabak Bernam, farmers plant the paddy every 8 to 10 months because of the availability of modern farming methods. For example, they use machines like tractors to plant the paddy plant, unlike the traditional manual method that use a special hand-held tool, called *kuku kambing*. They use modern techniques to increase the rice production. We conducted this study to set up a database on the impact of chlorpyrifos exposure as well as objectively measure the chlorpyrifos blood level among the farmers.

Chlorpyrifos is moderately toxic to human beings[3]. Various studies have reported adverse effects of chlorpyrifos on human body such as the central nervous system, the cardiovascular system, the respiratory system as well as skin and eye irritant [4,5,6,7]. However, studies have shown that skin absorption in human is limited[8]. The exposure symptoms include numbness, tingling sensation, incoordination, headache, dizziness, tremor, nausea, abdominal cramps, sweating and blurring of vision. Vulnerable groups would include people with respiratory problem, recent exposure to cholinesterase inhibitors, having cholinesterase impairment, or liver function disruption. There is no recorded LD_{50} for humans but animal studies have reported oral LD_{50} as 32 mg per kg in chickens, and 60mg per kg in mice[9]. Chronic toxicity because of prolonged or repeated exposure may cause impaired memory and concentration, disorientation, severe depression, irritability, confusion, headache, speech difficulties, delayed reaction times, nightmares, sleepwalking, drowsiness or insomnia. They can also experience influenza-like condition with headache, nausea, weakness, loss of appetite and malaise.

There are many overseas studies that estimate and measure the exposure routes and biological monitoring of chlorpyrifos. However, in Malaysia, these studies are quite limited. It is impotant to assess the exposure of chlorpyrifos especially among paddy farmers since they are using this pesticide extensively. The main objective of this cross sectional study is to measure chlorpyrifos blood level among paddy farmers in Selangor and to determine its relationship with the exposure symptoms.

METHODS

Sabak Bernam district has the largest number of paddy farmers in Selangor. There were a total of 19, 665 farmers registered in Selangor and out of these, 10, 213 farmers were in Sabak Bernam[10]. This was a cross sectional study. By using multistage random sampling from the list of sub-districts in Sabak Bernam, six sub-districts were selected. A total of 100 respondents were recruited into the study. The inclusion criteria were farmers using chlorpyrifos for the past six months, did not have any medical problem and agreed to give blood samples. The study tool consisted of questionnaire which the respondents filled up. The questionnaire contains information on sociodemography, use of pesticides as well as symptoms of exposure to pesticides. Written consent was obtained from the respondents for the blood sampling procedure. The respondents were given appointment date for the blood sampling. A sample of 5 ml venous blood was taken from each respondent, and stored in a glass vial containing lithium heparin which acts as anti-coagulant. The blood was centrifuged at 150 rotation per minute for 10 minutes. After this process, the venous blood separated into 2 parts, red blood cells and plasma. Using a pipett, 2 ml plasma was extracted and stored in an empty glass vial, and these samples were stored below -20^0C before undergoing analysis for chlorpyrifos level. Analysis for *chlorpyrifos* plasma level in humans was performed using liquid extraction and analysis using Gas Chromatography Shimadzu Model QP5000 GCMS. Using computerized method, calibration curve was obtained from the graph. The detection limit in this measurement was 0.1 ng/ml. For the exposure symptoms, questions asked were based on wether the respondents had experienced exposure symptoms such as headache, giddiness, eye irritation or skin irritation after pesticides application. Data analysis was performed using SPSS version 11.0. The blood samples were taken within 24 hours after the application of chlorpyrifos.

RESULTS

Table 1 shows the sociodemographic characteristics of the respondents. The mean and standard deviation for age was 46.0 ± 12.9 years. The median and interquartile range (IQR) for household monthly income was Ringgit Malaysia 666.00 (IQR Ringgit Malaysia 500.00, 1000.00). For gender, 99 percent of respondents were males. All of the respondents were Malays. Most of the respondents (52 percent) had secondary education. Only 4 percent had no formal schooling at all. Majority of the respondents (90 percent) were married. The mean duration for having worked in the agricultural sector was 21.4 years and standard deviation was 13.5 years. The mean duration of having and are still using Chlorpyrifos was 5.5 years with standard deviation of 4.9 years.

Table 2 showed the distribution of respondents based on the use of Personal Protective Equipment (PPE) by the farmers, the occurrence of pesticide exposure symptoms (health hazards effects) and the practice at the pesticide application sites.

Table 1 Sociodemographic characteristics of the respondents (n=100).

Variable	Mean(SD)	Median(IQR)	n(%)
Age (year)	46.0 (12.90)		100 (100.0)
Household income (RM)		666.00 (IQR500.00–1000.00)	100 (100.0)
Gender			
Male			99(99.0)
Female			1(1.0)
Ethnicity			
Malay			100(100.0)
Others			0 (0.0)
Education level			
No schooling			4(4.0)
Primary			44(44.0)
Secondary/higher			52(52.0)
Marital status			
Married			90(90.0)
Single/widower			10(10.0)
Duration of working in agricultural sector (year)	21.4(13.5)		100(100.0)
Duration of using Chlorpyrifos(year)	5.5(4.9)		100(100.0)

Table 2 Distribution of respondents by use of personal protective equipments (PPE), occurrence of health hazards effects and by habits at the pesticide application sites.

Variable	(%)
	n=100
PPE	
Respirator	(0.0)
Full PPE attire	(38.0)
Sunshade glasses/goggles	(54.0)
Rubber gloves/hand gloves	(77.0)
Rubber boots/jungle boots	(92.0)
Long sleeves shirt	(98.0)
Trousers	(99.0)
Nose/mouth cover/mask	(100.0)
Health hazards' effects	**n= 100**
Giddiness	(41.0)
Redness of eyes	(40.0)
Headache	(25.0)
Skin rashes	(24.00
Sneezing/cough	(23.0)
Nausea	(9.0)
Blurring of vision	(7.0)

Numbness	(7.0)
Muscle cramp	(6.0)
Lethargy	(6.0)
Abdominal pain	(2.0)
Breathing difficulty	(2.0)
Diarrhoea	(1.0)
Habits	**n=100**
Eating/drinking/smoke	(6.0)
Spraying against the wind	(20.0)
Spraying below the knee level	(32.0)
Throw empty containers in the open area	(54.0)
Mixing more than 2 pesticides	(83.0)
Re-use the pesticide container	(99.0)

*Multiple response were recorded.

From this study, it was found that 75 percent of the respondents had experienced at least one of the numerous exposure symptoms. Respondents were asked what were the symptoms they had experienced within 24 hours after a pesticide application session. The most common symptom was giddiness (41 percent), redness of eyes (40%) and headache (25%). The results about habits at pesticide application sites showed that 83% of the farmers admitted they mixed more than 2 pesticides, 99% said they used the empty containers for other purposes and 54% threw the empty containers in open dumping sites.

Blood samples were taken from the farmers and out of these, 7% were detected to have *chlorpyrifos* with mean chorpyrifos level of 7.29ng/ml and standard deviation of 5.84ng/ml. The range was from 0.23ng/ml to 18.37ng/ml. The safe level for chlorpyrifos either from single exposure or repeated exposures, is not known (IPCS 1975).

Table 3 showed the comparison of various variables between the group that was detected to have chlorpyrifos in their blood, and the other group who were not detected. The variables tested were age, monthly income, number of years working in agricultural sector, number of years using chlorpyrifos, knowledge scores, attitude scores and practice scores. All the variables tested were found to be not significant.

Table 3 Comparing variables between the detected groups and the non detected groups.

	Chlorpyrifos blood levels			
Variable	**Detected n=7 Median(IQR)**	**Not detected n=93 Median(IQR)**	**Z statistics[a]**	**p value[a]**
Age(years)	43(20)	44(19.50)	-0.939	0.348
Income(RM)	600(116)	700(683.00)	-1.199	0.231
Number of years working in farms	20(6)	20(20.5)	-4.47	0.655
Number of years using Chlorpyrifos	2(3)	4(4.5)	-1.265	0.206
Knowledge scores	12(2)	14(4)	-1.265	0.206
Attitude scores	6(4)	6(2)	-0.758	0.449
Practice scores	18(2)	14(4)	-.905	0.366

[a]Mann –Whitney test *Significant at $p < 0.05$

DISCUSSION

Exposure symptoms varied depending on properties of the chemical compound. A study[11] found that 95 percent of the farmers experienced body pain while 82 percent had eye redness after pesticide application activities. Our study found that the percentage of farmers experiencing giddiness and redness of eyes were 41 percent and 40 percent respectively.

Organophosphorus compounds have been widely established as chemicals which have potent neurotoxic effects. They are widely used in both the industrial as well as the agricultural sectors. The neurotoxic effects can be divided into few actions[6].The primary action is the irreversible inhibition of acetylcholinesterase, resulting in acetylcholine accumulation and overstimulation of nicotinic and muscarinic receptors. This results in cholinergic effects. A delayed onset of ataxia, with

axon and myelin degeneration is another form of organophosphorus (OP) neurotoxic action. It is known as OP ester-induced delayed neurotoxicity (OPIDN). Large toxic doses of OP because acute neuronal cell death in brain, but sublethal dose produces neuronal cell death and involve oxidative stress. The exact mechanism has yet to be explored.

In this study, the exposure opportunity of farmers and their family members to be exposed to the hazards of pesticides are high, as most of the farmers store the pesticides either in their houses or near a shed behind their houses. The farmers' houses are located adjacent to the paddy fields and when the wind blows recently pesticide-sprayed paddy fields, the potential of residential areas to get pesticide mists are certainly high. Similar findings were reported[12] in which discovered 21 percent of the farmers studied were living less than 50 yards away from the pesticide mixing areas.

The percentage of respondents detected to have chlorpyrifos in their blood was 7.0%. This number is much lower compared to previous studies done in various settings and populations. A study[13] done among Malaysian residents living adjacent to agricultural areas in 2000 found 7.3% of the respondents had chlorpyrifos in their blood. In the United States[14] it was recorded as 50.0% and another study found 74.0% the respondents living in urban areas which received termite control services using chlorpyrifos had detectable level of chlorpyrifos in their blood[15]. Another study conducted among pregnant mothers and their babies found 98.0% of the respondents had detectable chlorpyrifos in them[16]. There were also studies[17] that reported chlorpyrifos blood levels of 3.9± 4.8 pg/g among exposed population and the personal air chlorpyrifos measurement recorded a mean of 14.3± 30.7 ng/m^3. Personal air sampling was found to be weakly correlated with chlorpyrifos blood level. In this study however personal air sampling was not done due to financial constraint.

Another study done among paddy farmers in Thailand yielded 58% of the farmers had been detected to have chlorpyrifos in their blood[18]. Air sampling mean was 0.062±0.092mg/m^3 and this was highly correlated with cholinesterase level (r=0.872, p=0.01).

Chlorpyrifos is an irreversible inhibitor of cholinesterase (ChE). In humans, the inhibition of ChE is believed to be the most sensitive effect of Chlorpyrifos exposure. Epidemiological studies on human populations discovered an association between umbilical cord blood chlorpyrifos level with fetal outcomes such as birth weight [17, 19, 20] However, there were debates wether low birth weight is a more critical effect compared to inhibition of ChE (Zhao et al. 2005) and which should be studied further in detail.

Comparing the variables between those detected and not detected having chlorpyrifos in their blood, there were no significant differences for variables such as age, monthly income, duration of working in agricultural sector, duration of using chlorpyrifos, knowledge scores, attitude scores and practice scores.

CONCLUSIONS

Farmers all over the world are still exposed to various exposure risks, namely pesticides. This is especially true in many poor and developing countries which rely greatly on their agricultural products as means of sustaining their population as well as to generate income for their country.

A large number of farmers are still exposed to the unsafe use of pesticides. Various studies on knowledge, attitude and practice indicate that the unsafe use of pesticides is still a dominant issue especially in developing countries. There are still high rates of acute poisoning due to chlorpyrifos exposure. Intervention studies are few but demonstrate the need for evaluation of current preventive measures and as well as policies related to pesticide usage.

ACKNOWLEDGEMENT

The authors wish to thank the Faculty of Medicine, Universiti Kebangsaan Malaysia for funding this research (Grant FF-134-2005). Our gratitude also goes to the Department of Health and the Department of Agriculture, Selangor, Sabak Bernam Agriculture Office, the village Heads and farmers from villages in Sabak Bernam especially residents of Kg Tebuk Pulai, Kg Parit 1, Kg Parit 2 (Timur) and Kg Parit 2 (Barat).

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COMMISSION IMPLEMENTING REGULATION (EU) 2020/17

of 10 January 2020

concerning the non-renewal of the approval of the active substance chlorpyrifos-methyl, in accordance with Regulation (EC) No 1107/2009 of the European Parliament and of the Council concerning the placing of plant protection products on the market, and amending the Annex to Commission Implementing Regulation (EU) No 540/2011

(Text with EEA relevance)

THE EUROPEAN COMMISSION,

Having regard to the Treaty on the Functioning of the European Union,

Having regard to Regulation (EC) No 1107/2009 of the European Parliament and of the Council of 21 October 2009 concerning the placing of plant protection products on the market and repealing Council Directives 79/117/EEC and 91/414/EEC ([1]), and in particular Article 20(1) and Article 78(2) thereof,

Whereas:

(1) Commission Directive 2005/72/EC ([2]) included chlorpyrifos-methyl as an active substance in Annex I to Council Directive 91/414/EEC ([3]).

(2) Active substances included in Annex I to Directive 91/414/EEC are deemed to have been approved under Regulation (EC) No 1107/2009 and are listed in Part A of the Annex to Commission Implementing Regulation (EU) No 540/2011 ([4]).

(3) The approval of the active substance chlorpyrifos-methyl, as set out in Part A of the Annex to Implementing Regulation (EU) No 540/2011, expires on 31 January 2020.

(4) Applications for the renewal of the approval of the active substance chlorpyrifos-methyl were submitted in accordance with Article 1 of Commission Implementing Regulation (EU) No 844/2012 ([5]) within the time period provided for in that Article.

(5) The applicants submitted the supplementary dossiers required in accordance with Article 6 of Implementing Regulation (EU) No 844/2012. The applications were found to be complete by the rapporteur Member State.

(6) The rapporteur Member State prepared a renewal assessment report in consultation with the co-rapporteur Member State and submitted it to the European Food Safety Authority ('the Authority') and the Commission on 3 July 2017.

(7) The Authority made the supplementary summary dossier available to the public. The Authority also circulated the renewal assessment report to the applicants and to the Member States for comments and launched a public consultation on it. The Authority forwarded the comments received to the Commission.

(8) On 4 July 2018, the Authority requested that the applicants supply additional information to the Member States, the Commission and the Authority. The assessment of the additional information by the rapporteur Member State was submitted to the Authority in the form of an updated renewal assessment report.

([1]) OJ L 309, 24.11.2009, p. 1.

([2]) Commission Directive 2005/72/EC of 21 October 2005 amending Council Directive 91/414/EEC to include chlorpyrifos, chlorpyrifos-methyl, mancozeb, maneb, and metiram as active substances. (OJ L 279, 22.10.2005, p. 63).

([3]) Council Directive 91/414/EEC of 15 July 1991 concerning the placing of plant protection products on the market (OJ L 230, 19.8.1991, p. 1).

([4]) Commission Implementing Regulation (EU) No 540/2011 of 25 May 2011 implementing Regulation (EC) No 1107/2009 of the European Parliament and of the Council as regards the list of approved active substances (OJ L 153, 11.6.2011, p. 1).

([5]) Commission Implementing Regulation (EU) No 844/2012 of 18 September 2012 setting out the provisions necessary for the implementation of the renewal procedure for active substances, as provided for in Regulation (EC) No 1107/2009 of the European Parliament and of the Council concerning the placing of plant protection products on the market (OJ L 252, 19.9.2012, p. 26).

(9) The Authority organised an expert discussion in April 2019, to discuss certain elements related to the human health risk assessment. Due to concerns about genotoxicity and developmental neurotoxicity raised during that discussion, on 1 July 2019 the Commission sent a mandate to the Authority requesting a statement on the available outcomes of the human health assessment and an indication whether the active substance can be expected to meet the approval criteria which are applicable to human health as laid down in Article 4 of Regulation (EC) No 1107/2009.

(10) On 31 July 2019, the Authority sent its initial statement ([6]) to the Commission on the available outcomes of the human health assessment. On 11 November 2019, the Authority sent its updated statement ([7]) to the Commission following an additional expert discussion held in September 2019. In its updated statement, the Authority confirmed its conclusions on the human health assessment that critical areas of concerns exist. A genotoxic potential of chlorpyrifos-methyl cannot be ruled out, when taking into account the concerns raised for chlorpyrifos and the available scientific open literature on chlorpyrifos-methyl in a weight of evidence approach. During the peer review, experts considered a read-across approach between the two substances justified as they are structurally similar and have similar toxicokinetic behaviour. Consequently, it is not possible to establish health-based reference values for chlorpyrifos-methyl and to conduct the relevant consumer and non-dietary risk assessments. Furthermore, concerns were identified concerning developmental neurotoxicity (DNT) for which epidemiological evidence exists, showing an association between exposure to chlorpyrifos and/or chlorpyrifos-methyl during development and adverse neurodevelopmental outcomes in children. Moreover, the peer review experts indicated that it may be appropriate to classify chlorpyrifos-methyl as toxic for reproduction, category 1B, in accordance with the criteria established under Regulation (EC) No 1272/2008 of the European Parliament and of the Council ([8]).

(11) The Commission invited the applicants to submit their comments on the statements of the Authority. Furthermore, in accordance with the third subparagraph of Article 14(1) of Implementing Regulation (EU) No 844/2012, the Commission invited the applicants to submit comments on the draft renewal report. The applicants submitted their comments, which have been carefully examined.

(12) However, despite the arguments put forward by the applicants, the concerns regarding the active substance could not be eliminated.

(13) Consequently, it has not been established, with respect to one or more representative uses of at least one plant protection product that the approval criteria provided for in Article 4 of Regulation (EC) No 1107/2009 are satisfied. The environmental risk assessment, although not finalised, cannot alter this conclusion since the approval criteria related to the effects on human health are not satisfied and should therefore not delay further the decision-making on the renewal of the approval of the active substance. It is therefore appropriate not to renew the approval of the active substance chlorpyrifos-methyl in accordance with Article 20(1)(b) of that Regulation.

(14) Implementing Regulation (EU) No 540/2011 should therefore be amended accordingly.

(15) Member States should be given sufficient time to withdraw authorisations for plant protection products containing chlorpyrifos-methyl.

(16) For plant protection products containing chlorpyrifos-methyl, where Member States grant any grace period in accordance with Article 46 of Regulation (EC) No 1107/2009, that period should not exceed 3 months from the date of entry into force of this Regulation.

(17) Commission Implementing Regulation (EU) 2018/1796 ([9]) extended the approval period of chlorpyrifos-methyl to 31 January 2020, in order to allow the renewal process to be completed before the expiry of the approval period of that substance. However, given that a decision on the non-renewal of the approval is being taken ahead of the expiry of that extended approval period, this Regulation should apply as soon as possible.

([6]) EFSA (European Food Safety Authority), 2019. Statement on the available outcomes of the human health assessment in the context of the pesticides peer review of the active substance chlorpyrifos-methyl. *EFSA Journal* 2019;17(5):5810. https://doi.org/10.2903/j.efsa.2019.5810.

([7]) European Food Safety Authority (EFSA), 2019. Updated statement on the available outcomes of the human health assessment in the context of the pesticides peer review of the active substance chlorpyrifos-methyl. *EFSA Journal* 2019;17(11):5908, 21 pp. https://doi.org/10.2903/ j.efsa.2019.5908.

([8]) Regulation (EC) No 1272/2008 of the European Parliament and of the Council of 16 December 2008 on classification, labelling and packaging of substances and mixtures, amending and repealing Directives 67/548/EEC and 1999/45/EC, and amending Regulation (EC) No 1907/2006 (OJ L 353, 31.12.2008, p. 1).

([9]) Commission Implementing Regulation (EU) 2018/1796 of 20 November 2018 amending Implementing Regulation (EU) No 540/2011 as regards the extension of the approval periods of the active substances amidosulfuron, bifenox, chlorpyrifos, chlorpyrifos-methyl, clofentezine, dicamba, difenoconazole, diflubenzuron, diflufenican, dimoxystrobin, fenoxaprop-p, fenpropidin, lenacil, mancozeb, mecoprop-p, metiram, nicosulfuron, oxamyl, picloram, pyraclostrobin, pyriproxyfen and tritosulfuron (OJ L 294, 21.11.2018, p. 15).

(18) This Regulation does not prevent the submission of a further application for the approval of chlorpyrifos-methyl pursuant to Article 7 of Regulation (EC) No 1107/2009.

(19) The measures provided for in this Regulation are in accordance with the opinion of the Standing Committee on Plants, Animals, Food and Feed,

HAS ADOPTED THIS REGULATION:

Article 1

Non-renewal of the approval of the active substance

The approval of the active substance chlorpyrifos-methyl is not renewed.

Article 2

Amendment to Implementing Regulation (EU) No 540/2011

In Part A of the Annex to Implementing Regulation (EU) No 540/2011, row 112, on chlorpyrifos-methyl, is deleted.

Article 3

Transitional measures

Member States shall withdraw authorisations for plant protection products containing chlorpyrifos-methyl as an active substance by 16 February 2020.

Article 4

Grace period

Any grace period granted by Member States in accordance with Article 46 of Regulation (EC) No 1107/2009 shall expire by 16 April 2020.

Article 5

Entry into force

This Regulation shall enter into force on the third day following that of its publication in the *Official Journal of the European Union*.

This Regulation shall be binding in its entirety and directly applicable in all Member States.

Done at Brussels, 10 January 2020.

For the Commission
The President
Ursula VON DER LEYEN

European Food Safety Authority

EFSA Journal 2011;9(1):1961

CONCLUSION ON PESTICIDE PEER REVIEW

Conclusion on the peer review of the pesticide risk assessment of the active substance chlorpyrifos[1]

European Food Safety Authority[2]

European Food Safety Authority (EFSA), Parma, Italy

SUMMARY

Chlorpyrifos is one of the substances of the first stage of the review programme covered by Commission Regulation (EEC) No 3600/92[3], as last amended by Commission Regulation (EC) No 416/2008[4].

Chlorpyrifos was included in Annex I to Directive 91/414/EEC on 1 July 2006 by Commission Directive 2005/72/EC[5]. It was a specific provision of the inclusion, that notifiers were required to submit to the Commission of the European Communities (hereinafter referred to as 'the Commission') further studies to confirm the risk assessment for birds and mammals within two years from the entry into force of the inclusion Directive.

In accordance with the specific provision, Dow AgroSciences, on behalf of the Chlorpyrifos Task Force, submitted further studies in June 2008, which were evaluated by the designated rapporteur Member State (RMS), Spain, in the form of an Addendum to the assessment report. In compliance with Guidance Document SANCO 5634/2009 rev.3, the RMS distributed the Addendum to Member States and the EFSA for comments on 30 June 2009. The RMS collated all comments in the format of a Reporting Table, which was submitted to the Standing Committee on the Food Chain and Animal Health (SCFCAH) in November 2009.

Following consideration of the comments received, and the further discussions in the SCFCAH, the Commission requested the EFSA to organise a peer review of the RMS's evaluation of the confirmatory data and to deliver its conclusions on the risk assessment for birds and mammals.

The conclusions laid down in this report were reached on the basis of the evaluation of the representative use of chlorpyrifos as an insecticide on grape vines, as proposed by the notifiers. Full details of the representative use can be found in Appendix A to this report.

A high acute risk to birds and small herbivorous mammals such as voles cannot be excluded on the basis of the available data. A high long-term risk to mammals was identified in the refined risk assessment. Risk mitigation measures, such as no-spray buffer zones, are needed to protect fish-eating birds and mammals.

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[1] On request from the European Commission, Question No EFSA-Q-2010-00910, issued on 16 December 2010.

[2] Correspondence: praper@efsa.europa.eu

[3] OJ L 366, 15.12.1992, p. 10

[4] OJ L 125, 9.5.2008, p. 25

[5] OJ L 279, 22.10.2005, p. 63

For citation purposes: European Food Safety Authority; Conclusion on the peer review of the pesticide risk assessment of the active substance chlorpyrifos. EFSA Journal 2011;9(1):1961. [14 pp.]. doi:10.2903/j.efsa.2011.1961. Available online: www.efsa.europa.eu/efsajournal

KEY WORDS

Chlorpyrifos, peer review, risk assessment, pesticide, insecticide

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BACKGROUND

Chlorpyrifos is one of the substances of the first stage of the review programme covered by Commission Regulation (EEC) No 3600/92[6], as last amended by Commission Regulation (EC) No 416/2008[7].

Chlorpyrifos was included in Annex I to Directive 91/414/EEC on 1 July 2006 by Commission Directive 2005/72/EC[8]. It was a specific provision of the inclusion that notifiers were required to submit to the Commission of the European Communities (hereinafter referred to as 'the Commission') further studies to confirm the risk assessment for birds and mammals within two years from the entry into force of the inclusion Directive.

In accordance with the specific provision, Dow AgroSciences, on behalf of the Chlorpyrifos Task Force, submitted further studies in June 2008, which were evaluated by the designated Rapporteur Member State (RMS) Spain in the form of an Addendum to the assessment report (Spain, 2009).

In compliance with Guidance Document SANCO 5634/2009 rev.3 (European Commission, 2009), the RMS distributed the Addendum to Member States and the EFSA for comments on 30 June 2009. The RMS collated all comments in the format of a Reporting Table, which was submitted to the Standing Committee on the Food Chain and Animal Health (SCFCAH) in November 2009.

Following consideration of the comments received, and the further discussions in the SCFCAH, the Commission decided to further consult the EFSA. By written request, received by the EFSA on 15 June 2010, the Commission requested the EFSA to organise a peer review of the RMS's evaluation of the confirmatory data, and to deliver its conclusions on the risk assessment for birds and mammals.

The Addendum and the Reporting Table were discussed at the PRAPeR 80 Experts' Meeting on ecotoxicology in August 2010. Details of the issues discussed, together with the outcome of these discussions were recorded in the meeting report.

A final consultation on the conclusions arising from the peer review of the risk assessment for birds and mammals took place with Member States via a written procedure in November 2010.

This conclusion report summarises the outcome of the peer review of the risk assessment for birds and mammals evaluated on the basis of the representative use as an insecticide on grape vines, as proposed by the notifiers. A list of the relevant end points for the active substance as well as the formulation is provided in Appendix A. In addition, a key supporting document to this conclusion is the Peer Review Report, which is a compilation of the documentation developed to evaluate and address all issues raised in the peer review, from the compilation of comments in the Reporting Table to the conclusion. The Peer Review Report (EFSA, 2010) comprises the following documents:

- the Reporting Table (revision 3; August 2010),
- the report of the scientific consultation with Member State experts.

Given the importance of the Addendum and the Peer Review Report, both documents are considered respectively as background documents A and B to this conclusion.

[6] OJ L 366, 15.12.1992, p. 10
[7] OJ L 125, 9.5.2008, p. 25
[8] OJ L 279, 22.10.2005, p. 63

THE ACTIVE SUBSTANCE AND THE FORMULATED PRODUCT

Chlorpyrifos is the ISO common name for *O,O*-diethyl-*O*-3,5,6-trichloro-2-pyridyl phosphorothioate (IUPAC).

The representative formulated product for the evaluation was 'Dursban 480 EC', an emulsifiable concentrate (EC), containing 480 g/l chlorpyrifos.

The representative use evaluated comprises application to grape vines to control post-blossom pests in Northern and Southern Europe.

CONCLUSIONS OF THE EVALUATION

The risk assessment was based on the following documents: European Commission (2002a), EFSA (2009).

The refined risk assessment for birds and mammals was discussed in the PRAPeR 80 ecotoxicology experts' meeting in August 2010.

To refine the acute risk assessment for birds an LD_{50} from a 1 hour dietary study on Bobwhite quail (*Colinus virginianus)* was proposed. The majority of the experts were of the opinion that this dietary study could be considered as valid but uncertainties remained with regard to the actual uptake of treated food by birds. It was noted that avoidance was observed in the study. Therefore, the experts concluded that the endpoint from such a study cannot be used to replace the standard acute LD50 in TER calculations due to uncertainties in the exposure actually encountered in the study and also likely to occur in the field due to differences in feeding rates. However the study may be used in a weight of evidence approach if the TER would be close to the trigger.

As an alternative approach, a geometric mean or an HC5 (hazardous concentration 5%) of acute endpoints from 20 different bird species was proposed by the RMS. However, the experts noted that many of the acute studies used to derive a geometric mean or an HC5 were not performed according to the standard test guidelines, with endpoints sourced from open literature. Therefore, due to the uncertainties within the database of acute studies it was suggested that the data could only be used in a qualitative way as additional information.

It was agreed that residue data in insects should include residues in dead insects, since residues in dead insects were 3-6 times higher than in live insects. It was suggested that the measured residues in ground-dwelling arthropods should be adjusted using a mean factor of 3.4 (based on 6 trials) to account for only live insects being caught in pitfall traps. It was noted that using the mean value would not be a conservative approach, and that this should be taken into account in the decision whether it is appropriate to follow a weight of evidence approach.

The refined acute risk assessment (including focal species, PD refinement and measured residues) resulted in a TER of 4.2, which is significantly below the Annex VI trigger of 10. The short-term risk to insectivorous birds was assessed as low based on refined insect residue data. The focal species Black Redstart (*Phoenicuros ochruros*) and the suggested PD refinement were accepted for refinement of the long-term risk. The refined risk assessment for Cirl Bunting (*Emberiza cirlus*) was not sufficiently supported by data and hence was not further considered in the refined risk assessment. The refined long-term risk assessment resulted in TERs above the Annex VI trigger of 5 for Black Redstart.

A field study was submitted. The study was conducted in vineyards in southern Europe at an application rate of 2 x 360 g a.s./ha. Of the radio-tracked birds, only one bird was found dead but there was no evidence that the death was related to the application of chlorpyrifos. It was noted that the study was conducted at a higher application rate than the representative use rate. However several

uncertainties were identified by the experts: the study covered short-term effects on adults but not nestlings; the study might not cover Northern Europe due to slower degradation rates in cooler climates, different bird species and different agricultural practices; the study was conducted in June while the proposed GAP is for late applications (21 days pre-harvest). It was finally concluded that the study is useful as additional information but is not sufficient to give a clear indication of low risk to birds.

Overall it is concluded that the short-term and long-term risk to birds is low. Since uncertainties remain with regard to the acute risk to birds, a high acute risk to birds cannot be excluded on the basis of the available data.

The risk to earthworm-eating birds and mammals from secondary poisoning was assessed as low. The risk to fish-eating birds and mammals was assessed as high at tier 1. Risk mitigation such as no-spray buffer zones are needed to minimize entry into surface water. The available risk assessment suggests that a concentration in surface water equivalent to 10 times the EAC (environmentally acceptable concentration, which should not be exceeded in the aquatic environment) would result in TERs above the trigger of 5 for fish-eating birds and mammals.

The acute risk to mammals was assessed as low for rabbit (*Oryctolagus cuniculus*), wood mouse (*Apodemus sylvaticus*) and common shrew (*Sorex araneus*) including refinement of residues in food items. However, a high acute risk was still indicated in the refined risk assessment for small herbivorous mammals such as common vole (*Microtus arvalis*). A field study conducted in orchards in Germany was submitted and discussed in the meeting of experts. A higher application rate (1 x 500 g a.s./ha) was applied in the study but several shortcomings were noted: only small numbers of voles were caught in individual plots and a high variability was observed; the timing of the study (application in October) did not match the proposed GAP; the application was made during a period where vole populations were also declining in control plots; the population decline in the treated plots was higher than in control plots. The population decline in the controls (due to autumn season) means that there is a low probability of detecting adverse effects in this study. Overall it was concluded that there was a trend for an effect in the treated plots, and that the study does not provide evidence that the acute risk to small herbivorous mammals is low.

The long-term endpoint to be used in the risk assessment for mammals was discussed in the meeting of experts. It was agreed that the NOAEL from the 2-generation rat study of 1 mg a.s./kg bw/d based on reduced pup survival should be used in the long-term risk assessment. This is in line with the toxicology evaluation of the available data.

The refined long-term TERs, including residue decline, exceeded the trigger of 5 only for common shrew, however the TERs for vole, rabbit and wood mouse were still significantly below the Annex VI trigger of 5, indicating a high long-term risk to mammals.

LIST OF STUDIES TO BE GENERATED, STILL ONGOING OR AVAILABLE BUT NOT PEER REVIEWED

- The acute risk to birds needs to be addressed further (relevant for the representative use evaluated; submission date proposed by the notifier: none; see section 5).
- The acute risk to small herbivorous mammals needs to be addressed further (relevant for the representative use evaluated; submission date proposed by the notifier: none; see section 5).
- The long-term risk to mammals needs to be addressed further (relevant for the representative use evaluated; submission date proposed by the notifier: none; see section 5).

PARTICULAR CONDITIONS PROPOSED TO BE TAKEN INTO ACCOUNT TO MANAGE THE RISK(S) IDENTIFIED

- Risk mitigation measures, such as no-spray buffer zones, are required to protect fish-eating birds and mammals. The concentration in surface water must not exceed 1 µg a.s./L. (see section 5).

ISSUES THAT COULD NOT BE FINALISED

None.

CRITICAL AREAS OF CONCERN

- A high acute risk to birds cannot be excluded.
- A high acute risk to small herbivorous mammals cannot be excluded
- A high long-term risk to mammals was indicated.

REFERENCES

EFSA (European Food Safety Authority), 2010. Peer Review Report to the conclusion regarding the peer review of the pesticide risk assessment of the active substance chlorpyrifos.

Spain, 2009. Addendum to the assessment report on the active substance chlorpyrifos prepared by the rapporteur Member State Spain in the framework of Directive 91/414/EEC, updated September 2010 (rev. 4).

Guidance documents[9]:

EFSA (European Food Safety Authority), 2009. Guidance Document on Risk Assessment for Birds and Mammals on request of EFSA. EFSA Journal 2009; 7(12):1438

European Commission, 2002a. Guidance Document on Risk Assessment for Birds and Mammals Under Council Directive 91/414/EEC. SANCO/4145/2000.

European Commission, 2009. Guidance document on the procedures for submission and assessment of confirmatory data following inclusion of an active substance in Annex I of Council Directive 91/414/EEC. SANCO/5634/2009 rev.3.

FOCUS (2007). "Landscape And Mitigation Factors In Aquatic Risk Assessment. Volume 1. Extended Summary and Recommendations". Report of the FOCUS Working Group on Landscape and Mitigation Factors in Ecological Risk Assessment, EC Document Reference SANCO/10422/2005 v2.0. 169 pp.

[9] For further guidance documents see http://ec.europa.eu/food/plant/protection/resources/publications_en.htm#council (EC) or http://www.oecd.org/document/59/0,3343,en_2649_34383_1916347_1_1_1_1,00.html (OECD)

APPENDICES

APPENDIX A – LIST OF END POINTS FOR THE ACTIVE SUBSTANCE AND THE REPRESENTATIVE FORMULATION

Summary of representative uses evaluated

(Emboldened values are GAP, other applications details are consequential to the spray volumes)

Crop and/or situation	Member State or Country	Product Name	F G or I	Pests or Group of pests controlled	Formulation		Application				Application rate per treatment			PHI (days)	Remarks
(a)			(b)	(c)	Type (d-f)	Conc. of a.s. (i)	Method Kind (f-h)	Growth stage & season (j)	Number min max (k)	Interval between apps. (min)	kg a.s./hL min max	water (L/ha) min max	kg a.s./ha min max	(l)	(m)
Grape vines	N. & S. Europe	Dursban 480 EC	F	Post-blossom pests	EC	480 g/L	Abmb, HL	Fruiting#	1	N/A	**0.0408**	600	0.245	21	# Timing of application to be consistent with minimal exposure to bees. [1] [2]

[1] A high long-term risk is identified for mammals.

[2] A high acute risk to birds and small herbivorous mammals cannot be excluded

Remarks
(a) For crops the EU and Codex classifications (both) should be used.
(b) Outdoor or field use (F), glasshouse application (G) or indoor application (I)
(c) e.g. biting and sucking insects, soil borne insects, foliar fungi, weeds
(d) e.g. wettable powder (WP),emulsifiable concentrate (EC), granule (GR)
(e) GIFAP Codes - GIFAP Technical Monograph No. 2, 1989
(f) All abbreviations must be explained
(g) Method, e.g. high volume spraying, low volume spraying, spreading, dusting, drench
(h) Kind, e.g. overall, broadcast, aerial spraying, row, individual plant, between the plants
(i) g/kg or g/l
(j) Growth stage at last treatment, including where relevant information on season at time of application
(k) The minimum and maximum number of applications possible under practical conditions must be given
(l) PHI - Pre-harvest interval
(m) Remarks may include: Extent of use/ economic importance/restrictions (e.g. feeding/grazing)/minimal intervals between applications

Abmb – Air blast mist blower; Fbs – Field boom sprayer; HL – Hand lance.

Section 3: Ecotoxicology

Effects on terrestrial vertebrates (Annex IIA, point 8.1, Annex IIIA, points 10.1 and 10.3)

Acute toxicity to mammals	Mouse (females) LD50= 64 mg/kg b.w.
Long-term toxicity to mammals	Rat 2 generations NOAEL = 1 mg/kg bw/day
Acute toxicity to birds	Active substance: *Passer domesticus* LD50 = 122 mg as/kg *Coturnix coturnix* LD50 = 13.3 mg/kg bw 95th percentile of the Species Sensitivity Distribution, 6.9 mg as/kg bw Geometric mean: 25.4 mg/kg bw (to be used only in a qualitative way - PRAPeR 80) Formulation: *Phasianus colchicus* LD50 =8.41 mg/kg bw
Acute dietary toxicity to birds	Bobwhite quail: 1h-LD50 = 75 mg as/kg bw (To be used only in a weight of evidence approach - PRAPeR 80)
Dietary toxicity to birds	Mallard duck LC50= 203 ppm (= 71 mg as/kg bw/d) (a value of 180 was obtained in another study not fully validated)
Reproductive toxicity to birds	Mallard duck NOEC = 25 ppm (2.88 mg as/kg bw/d)
Field effects study	**Field study:** vineyards South Europe (Brown et al., 2007) **Radio-trackers:** Before treatment (34 birds), 10 days after treatment (19 birds). **Focal species on vines:** Black Redstart. **Application rate:** Dursban 480 EC. 2x 360 g as/ha. Summer application (11 and 27 June). **Results:** For 56 birds radio-tracked only 1 was dead after application, and there is no evidence that the death was related to treatment. No abnormal behaviour was observed. The foraging time spent on the crop was very low (90^{th} PT = 0.75, mean PT = 0.28) There is clear preference for off-crop land (low exposure scenario). **Conclusion:** 2 sequential applications of chlorpyrifos to vines at 360 g as/ha had no discernible short-term impact on the survival or behaviour of birds frequenting the vineyards. The mortality was not significantly increased but some uncertainties within the study were indicated. The conclusion in the meeting of experts was that the study is useful as additional information but is not an indication of low risk to birds.

Toxicity/exposure ratios for terrestrial vertebrates (Annex IIIA, points 10.1 and 10.3)

Toxicity/exposure ratios for terrestrial vertebrates (Annex IIIA, points 10.1 and 10.3) from confirmatory data for birds and mammals- Acute Toxicological endpoint used for calculations is 13.3 mg as/kg.

Application rate (kg as/ha)	Crop	Category (*e.g.* insectivorous bird)	Time-scale	TER	Annex VI Trigger
0.245	Vineyards	Insectivorous bird-Tier I	Acute 13.3 mg as/kg bw	1	10
0.245	Vineyards	Insectivorous bird-Tier II	Acute 13.3 mg as/kg bw	Refined for measured residues accounting for dead arthropods TER = 2.1	10
0.245	Vineyards	Insectivorous bird-Tier II	Acute 13.3 mg as/kg bw	Black Redstart (PD 50% foliage-dwelling arthropods, 50% ground-dwelling arthropods), and residue accounting for dead arthropods TER = 4.2	10
0.245	Vineyards	Insectivorous bird-Tier I	Short-term	9.6	10
0.245	Vineyards	Insectivorous bird-Tier II	Short-term	Refined for measured residues TER = 11	10
0.245	Vineyards	Insectivorous bird-Tier I	Long-term	0.73	5
0.245	Vineyards	Insectivorous birds-Tier II	Long-term	Black Redstart. PD: 50% ground-dwelling arthropods, 50% foliage-dwelling arthropods. Real residues accounting for dead arthropods, PT = 0.75, FIR/bw= 0.82 TER = 6.7	5
0.245	Vineyards	Earthworm-eating birds	Long-term	8.33	5
0.245	Vineyards	Fish-eating birds-Tier I	Long -term	4.05	5

Application rate (kg as/ha)	Crop	Category (*e.g.* insectivorous bird)	Time-scale	TER	Annex VI Trigger
0.245	Vineyards	Fish-eating birds-Tier II	Long-term	Refined for buffer zone (PECsw of 10 times EAC of 0.1 µg as/L) TERlt = 10	5
0.245	Vineyards	Small Herbivorous mammals-vole-Tier I	Acute	2.2	10
0.245	Vineyards	Small Herbivorous mammals-vole-Tier II	Acute	Refined using specific residues TER = 3.9	10
0.245	Vineyards	Medium herbivorous mammals-Rabbit-Tier II	Acute	Refined using specific residues TER = 11.9	10
0.245	Vineyards	Omnivorous mammals-wood mouse-Tier II	Acute	Refined using specific residues TER = 10.6	10
0.245	Vineyards	Insectivorous mammals-common shrew-Tier II	Acute	Refined using specific residues TER = 69	10
0.245	Vineyards	Small herbivorous mammals-vole-Tier I	Long-term	0.12	5
0.245	Vineyards	Medium herbivorous mammals-Rabbit-Tier II	Long-term	1.9	5
0.245	Vineyards	Omnivorous mammals-wood mouse-Tier II	Long-term	1.43	5
0.245	Vineyards	Insectivorous mammals-common shrew-Tier II	Long-term	8.4	5
0.245	Vineyards	Earthworm-eating mammals-Tier I	Long-term	2.27	5
0.245	Vineyards	Earthworm-eating mammals-Tier II	Long-term	Refined for measured residues (BCF = 1.26) TER = 5.5	5
0.245	Vineyards	Fish-eating mammals-Tier I	Long -term	2.27	5
0.245	Vineyards	Fish-eating mammals-Tier II	Long -term	Refined for buffer zone (PECsw of 10 times EAC of 0.1 µg as/L) TER = 5.6	5

ABBREVIATIONS

µg	microgram
a.s.	active substance
AF	assessment factor
AV	avoidance factor
BCF	bioconcentration factor
bw	body weight
CAS	Chemical Abstract Service
d	day
DM	dry matter
DT_{50}	period required for 50 percent disappearance (define method of estimation)
DT_{90}	period required for 90 percent disappearance (define method of estimation)
dw	dry weight
EAC	environmentally acceptable concentration
EbC_{50}	effective concentration (biomass)
EC_{50}	effective concentration
EEC	European Economic Community
ER_{50}	emergence rate/effective rate, median
ErC_{50}	effective concentration (growth rate)
EU	European Union
FAO	Food and Agriculture Organisation of the United Nations
FIR	Food intake rate
FOCUS	Forum for the Co-ordination of Pesticide Fate Models and their Use
g	gram
GAP	good agricultural practice
GM	geometric mean
GS	growth stage
h	hour(s)
ha	hectare
L	litre
LD_{50}	lethal dose, median; dosis letalis media
LOAEL	lowest observable adverse effect level
LOD	limit of detection
m	metre
MAF	multiple application factor
mg	milligram
mL	millilitre
mm	millimetre
MTD	maximum tolerated dose
MWHC	maximum water holding capacity
ng	nanogram
NOAEC	no observed adverse effect concentration
NOAEL	no observed adverse effect level
NOEC	no observed effect concentration
NOEL	no observed effect level
OM	organic matter content
Pa	Pascal
PD	proportion of different food types
PEC	predicted environmental concentration
PEC_{air}	predicted environmental concentration in air
PEC_{gw}	predicted environmental concentration in ground water
PEC_{sed}	predicted environmental concentration in sediment
PEC_{soil}	predicted environmental concentration in soil

PEC_{sw}	predicted environmental concentration in surface water
pH	pH-value
PHI	pre-harvest interval
pK_a	negative logarithm (to the base 10) of the dissociation constant
P_{ow}	partition coefficient between *n*-octanol and water
ppm	parts per million (10^{-6})
ppp	plant protection product
PT	proportion of diet obtained in the treated area
r^2	coefficient of determination
RUD	residue per unit dose
SD	standard deviation
SFO	single first-order
SSD	species sensitivity distribution
$t_{1/2}$	half-life (define method of estimation)
TER	toxicity exposure ratio
TER_A	toxicity exposure ratio for acute exposure
TER_{LT}	toxicity exposure ratio following chronic exposure
TER_{ST}	toxicity exposure ratio following repeated exposure
TLV	threshold limit value
TRR	total radioactive residue
TWA	time weighted average
UV	ultraviolet
W/S	water/sediment
w/v	weight per volume
w/w	weight per weight
WHO	World Health Organisation
wk	week
yr	year

European Parliament
2014-2019

TEXTS ADOPTED

P8_TA(2019)0082

Sustainable use of pesticides

European Parliament resolution of 12 February 2019 on the implementation of Directive 2009/128/EC on the sustainable use of pesticides (2017/2284(INI))

The European Parliament,

– having regard to Directive 2009/128/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for Community action to achieve the sustainable use of pesticides[1],

– having regard to Regulation (EC) No 850/2004 of the European Parliament and of the Council of 29 April 2004 on persistent organic pollutants and amending Directive 79/117/EEC[2],

– having regard to Regulation (EC) No 396/2005 of the European Parliament and of the Council of 23 February 2005 on maximum residue levels of pesticides in or on food and feed of plant and animal origin and amending Council Directive 91/414/EEC (Maximum Residue Level Regulation)[3],

– having regard to Article 191 of the Treaty on the Functioning of the European Union,

– having regard to Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC[4],

– having regard to Regulation (EC) No 1107/2009 of the European Parliament and of the Council of 21 October 2009 concerning the placing of plant protection products on the market and repealing Council Directives 79/117/EEC and 91/414/EEC[5];

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1 OJ L 309, 24.11.2009, p. 71.
2 OJ L 158, 30.4.2004, p. 7.
3 OJ L 70, 16.3.2005, p. 1.
4 OJ L 136, 29.5.2007, p. 3.
5 OJ L 309, 24.11.2009, p. 1.

– having regard to the European Implementation Assessment on the Regulation and to its relevant annexes, as published by the European Parliamentary Research Service (EPRS) in April 2018,

– having regard to Regulation (EU) No 1307/2013 of the European Parliament and of the Council of 17 December 2013 establishing rules for direct payments to farmers under support schemes within the framework of the common agricultural policy and repealing Council Regulation (EC) No 637/2008 and Council Regulation (EC) No 73/2009[1],

– having regard to Council Directive 98/24/EC of 7 April 1998 on the protection of the health and safety of workers from the risks related to chemical agents at work[2] and to Directive 2004/37/EC of the European Parliament and of the Council of 29 April 2004 on the protection of workers from the risks related to exposure to carcinogens and mutagens at work[3],

– having regard to Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (the Habitats Directive)[4] and to Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds (the Wild Birds Directive)[5],

– having regard to Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption[6],

– having regard to Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy[7],

– having regard to Commission Directive 2009/90/EC of 31 July 2009 laying down, pursuant to Directive 2000/60/EC of the European Parliament and of the Council, technical specifications for chemical analysis and monitoring of water status[8],

– having regard to Directive 2009/127/EC of the European Parliament and of the Council of 21 October 2009 amending Directive 2006/42/EC with regard to machinery for pesticide application[9],

– having regard to Directive 2013/39/EU of the European Parliament and of the Council of 12 August 2013 amending Directives 2000/60/EC and 2008/105/EC as regards priority substances in the field of water policy[10],

– having regard to the Proposal for a Regulation of the European Parliament and of the Council establishing rules on support for strategic plans to be drawn up by Member

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1 OJ L 347, 20.12.2013, p. 608.
2 OJ L 131, 5.5.1998, p. 11.
3 OJ L 229, 29.6.2004, p. 23.
4 OJ L 206, 22.7.1992, p. 7.
5 OJ L 20, 26.1.2010, p. 7.
6 OJ L 330, 5.12.1998, p. 32.
7 OJ L 327, 22.12.2000, p. 1.
8 OJ L 201, 1.8.2009, p. 36.
9 OJ L 310, 25.11.2009, p. 29.
10 OJ L 226, 24.8.2013, p. 1.

States under the common agricultural policy (CAP Strategic Plans) and financed by the European Agricultural Guarantee Fund (EAGF) and by the European Agricultural Fund for Rural Development (EAFRD) and repealing Regulation (EU) No 1305/2013 of the European Parliament and of the Council and Regulation (EU) No 1307/2013 of the European Parliament and of the Council (COM(2018)0392),

– having regard to the Commission Staff Working Document entitled 'Agriculture and Sustainable Water Management in the EU' (SWD(2017)0153),

– having regard to the communication of 12 July 2006 from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions entitled 'A thematic strategy on the sustainable use of pesticides' (COM(2006)0373 - SEC(2006)0894 - SEC(2006)0895 - SEC(2006)0914),[1]

– having regard to its resolution of 7 June 2016 on enhancing innovation and economic development in future European farm management[2],

– having regard to its resolution of 7 June 2016 on technological solutions for sustainable agriculture in the EU[3],

– having regard to its resolution of 15 February 2017 on low-risk pesticides of biological origin[4],

– having regard to its resolution of 24 October 2017 on the draft Commission implementing regulation renewing the approval of the active substance glyphosate in accordance with Regulation (EC) No 1107/2009 of the European Parliament and of the Council concerning the placing of plant protection products on the market, and amending the Annex to Implementing Regulation (EU) No 540/2011[5],

– having regard to its resolution of 1 March 2018 on prospects and challenges for the EU apiculture sector[6],

– having regard to its resolution of 13 September 2018 on the implementation of the Plant Protection Products Regulation (EC) No 1107/2009[7],

– having regard to the ongoing European Implementation Assessment on Directive 2009/128/EC on establishing a framework for Community action to achieve the sustainable use of pesticides and to the report published by the European Parliamentary Research Service (EPRS) on 15 October 2018,

– having regard to Regulation (EC) No 1185/2009 of the European Parliament and of the Council of 25 November 2009 concerning statistics on pesticides[8],

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1 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52006DC0372
2 OJ C 86, 6.3.2018, p. 62.
3 OJ C 86, 6.3.2018, p. 51.
4 OJ C 252, 18.7.2018, p. 184.
5 OJ C 346, 27.9.2018, p. 117.
6 Texts adopted, P8_TA(2018)0057.
7 Texts adopted, P8_TA(2018)0356.
8 OJ L 324, 10.12.2009, p. 1

– having regard to the report from the Commission to the European Parliament and the Council on the implementation of Regulation (EC) No 1185/2009 of the European Parliament and of the Council of 25 November 2009 concerning statistics on pesticides (COM(2017)0109),

– having regard to the Special Report of 2014 of the European Court of Auditors entitled 'Integration of EU water policy objectives with the CAP: a partial success',

– having regard to the Commission report of 10 October 2017 on Member State National Action Plans and on progress in the implementation of Directive 2009/128/EC on the sustainable use of pesticides (COM(2017)0587),

– having regard to the overview report of October 2017 by the Commission's Directorate-General for Health and Food Safety (DG SANTE) on the implementation of Member States' measures to achieve the sustainable use of pesticides under Directive 2009/128/EC[1],

– having regard to the Commission communication of 22 November 2016 entitled 'Next steps for a sustainable European future: European Action for Sustainability' (COM(2016)0739),

– having regard to the 7th Environment Action Programme[2],

– having regard to the 2017 UN report of the Special Rapporteur on the Right to Food drafted pursuant to UN Human Rights Council resolutions 6/2, 31/10 and 32/8[3],

– having regard to the Implementation Plan on increasing low-risk plant protection product availability and accelerating integrated pest management implementation in Member States, developed by the Expert Group on Sustainable Plant Protection and endorsed by the Council on 28 June 2016[4],

– having regard to the resolution of the French Senate of 19 May 2017 on limiting the use of pesticides in the European Union[5],

– having regard to its resolution of 16 January 2019 on the Union's authorisation procedure for pesticides[6]

– having regard to the scientific study on flying insect biomass published on 18 October 2017[7],

– having regard to Rule 52 of its Rules of Procedure, as well as Article 1(1)(e) of, and

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1 http://ec.europa.eu/food/audits-analysis/overview_reports/details.cfm?rep_id=114
2 OJ L 354, 28.12.2013, p. 171.
3 http://www.pan-uk.org/site/wp-content/uploads/United-Nations-Report-of-the-Special-Rapporteur-on-the-right-to-food.pdf
4 http://data.consilium.europa.eu/doc/document/ST-10041-2016-ADD-1/en/pdf
5 http://www.senat.fr/leg/ppr16-477.html
6 Texts adopted, P8_TA(2019)0023.
7 Caspar A. Hallmann et al., 'More than 75 % decline over 27 years in total flying insect biomass in protected areas', PLOS, 18 October 2017 - https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0185809

Annex 3 to, the decision of the Conference of Presidents of 12 December 2002 on the procedure for granting authorisation to draw up own-initiative reports,

– having regard to the report of the Committee on the Environment, Public Health and Food Safety and the opinion of the Committee on Agriculture and Rural Development (A8-0045/2019),

A. whereas Directive 2009/128/EC of the European Parliament and of the Council on the sustainable use of pesticides (hereinafter 'the Directive') provides for a range of actions to achieve a sustainable use of pesticides in the EU, by reducing the risks and impacts of pesticide use on human health and the environment and promoting the use of Integrated Pest Management (IPM) and alternative plant protection approaches or techniques, such as non-chemical alternatives and low-risk plant protection products (PPPs) as defined in Regulation (EC) No 1107/2009, the aim being to reduce pesticide dependency and safeguard human and animal health and the environment;

B. whereas the Directive is a valuable tool for ensuring that the environment, ecosystems, and human and animal health are well protected from hazardous substances in pesticides, while providing sustainable and ecological solutions for a larger and more varied toolbox to eliminate and prevent yield losses caused by pests, disease, weeds and invasive alien species and combating pathogen resistance build-up; whereas a full and comprehensive implementation of the Directive is a prerequisite for achieving a high degree of protection and accomplishing a transition towards sustainable agriculture, the production of safe and healthy food, and a non-toxic environment which ensures a high level of protection for human and animal health;

C. whereas whilst IPM can help to prevent yield losses caused by pests, its main purposes is to enable users of pesticides to switch to practices and products with the lowest risk to human health and the environment, as outlined in Article 14 of the Directive; notes that, in any case, many studies have shown that pesticide use can be significantly reduced without any negative impacts on yield;

D. whereas the Directive has to be read in conjunction with the other two main pieces of legislation covering the complete lifecycle of a pesticide, starting from its placing on the market (Regulation (EC) No 1107/2009) and ending with the setting of maximum residue levels (Regulation (EC) No 396/2005); whereas it is therefore impossible to achieve the Directive's objective of protecting human health and the environment from the risks associated with the use of pesticides without fully implementing and properly enforcing the entire 'pesticides package';

E. whereas, in order to reduce the risks and impacts of pesticide use on human health and the environment, the Commission and the Member States should address the issue of counterfeit and illegal pesticides, as well as the worrying problem of imported agricultural products treated with chemicals that are either banned or restricted in the EU;

F. whereas the current practices of the Commission and the Member States regarding the approval of active substances and authorisation of plant protection products are not compatible with the objectives and purpose of the directive; whereas these current practices impede attaining the highest possible level of protection and achieving the transition to a sustainable agricultural sector and a non-toxic environment;

G. whereas the available evidence clearly shows that the implementation of the directive is not sufficiently aligned with related EU policies in the field of pesticides, agriculture and sustainable development, notably but not exclusively the common agricultural policy (CAP) and the Plant Protection Products Regulation; whereas the directive, alongside related actions at EU level, has great potential to further enhance and add value to national efforts and actions in the agricultural sector and strengthen protection for the environment and human health;

H. whereas the current regulatory framework, including the data requirements, was designed for the assessment and management of chemical PPPs, and is thus ill-fitting for low-risk biological active substances and products; whereas this ill-fitting framework is significantly slowing down the market entry of low-risk biological PPPs, often deterring applicants; whereas this hinders innovation and hampers the competitiveness of EU agriculture; whereas this also leads to over 60 active substances identified by the European Commission as candidates for substitution not being replaced given the lack of safer alternatives, including low-risk biological active substances;

I. whereas there is a lack of availability of low-risk PPPs, including biological ones; whereas only 13 substances are approved as low-risk active substances, 12 of these being biological, out of a total of almost 500 available on the EU market; whereas the insufficient implementation of the directive has de facto created an unlevelled playing field in Europe with diverging national practices impeding the optimal uptake of sustainable alternatives on the market; whereas this situation has made it difficult for alternative low-risk and non-chemical products to sufficiently penetrate the EU market, which reduces their attractiveness to farmers, who may instead opt for more cost-effective alternatives in the short term; whereas the lack of availability of low-risk PPPs, including biological ones, hinders the development and implementation of integrated pest management (IPM);

J. whereas organic agriculture plays an important role as a low-pesticide input system and should be further encouraged;

K. whereas there is increasing evidence of an ongoing massive decline in the insect population in Europe, which is being linked to current levels of pesticide use; whereas the observed sharp decline in insect numbers has negative impacts on the entire ecosystem and on biological diversity, but also on the agricultural sector and its future economic wellbeing and output;

L. whereas Europe currently stands at a crossroads that will determine the future of the agriculture sector and the Union’s possibilities of achieving a sustainable use of pesticides, most notably through the reform of the CAP; whereas reforming the CAP brings with it a substantial potential to strengthen the streamlining and harmonisation of policies as well as the implementation of the directive, and to facilitate the transition towards more environmentally sustainable agricultural practices;

M. whereas the use of conventional PPPs is increasingly subject to public debate, owing to the potential risks they pose to human and animal health and the environment;

N. whereas it is important to promote the development of alternative procedures or techniques in order to reduce dependence on conventional pesticides and deal with the

rising resistance to conventional PPPs;

O. whereas Regulation (EC) No 1107/2009 obliges the Council to ensure that the statutory management requirement as laid down in Annex III to Council Regulation (EC) No 1782/2003 of 29 September 2003 establishing common rules for direct support schemes under the common agricultural policy and establishing certain support schemes for farmers[1] incorporates the principles of IPM, including good plant protection practice and non-chemical methods of plant protection and pest and crop management;

P. whereas IPM implementation is mandatory in the EU, in line with the directive; whereas Member States and local authorities should place more emphasis on the sustainable use of pesticides, including low-risk plant protection alternatives;

Q. whereas the 'sustainable use' of pesticides cannot be realised without taking into account human exposure to combinations of active substances and co-formulants, as well as their cumulative and possible aggregate and synergistic effects on human health;

Main conclusions

1. Recalls the specific objectives of the Thematic Strategy on the Sustainable Use of Pesticides as, inter alia, the minimisation of hazards and risks to health and the environment from the use of pesticides; improved controls on the use and distribution of pesticides; reduction in the levels of harmful active substances including through substituting the most dangerous with safer, including non-chemical alternatives; encouraging low-input or pesticide free cultivation; and the establishment of a transparent system for reporting and monitoring progress towards the fulfilment of the objectives of the strategy, including through the development of suitable indicators;

2. Considers it essential to evaluate the implementation of the Directive in conjunction with the EU's overarching pesticides policy, including the rules laid down by the Plant Protection Products Regulation, by Regulation (EU) No 528/2012 (the Biocides Regulation)[2], by the Maximum Residue Level Regulation, and by Regulation (EC) No 178/2002 (the General Food Law)[3];

3. Regrets that, despite efforts made, the overall degree of progress in implementation by the Member States is insufficient to meet the Directive's main objectives and to unlock its full potential to reduce the overall risks deriving from pesticide use while also reducing pesticide dependency, promote the transition towards ecologically sustainable and safe plant protection techniques, and achieve the urgently needed environmental and health improvements the Directive was specifically designed for; deplores the three-year delay in submission of the implementation report on the directive by the Commission;

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1 OJ L 270, 21.10.2003, p. 1.

2 Regulation (EU) No 528/2012 of the European Parliament and of the Council of 22 May 2012 concerning the making available on the market and use of biocidal products, OJ L 167, 27.6.2012, p. 1.

3 Regulation (EC) No 178/2002 of the European Parliament and of the Council of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety, OJ L 31, 1.2.2002, p. 1.

4. Emphasises that the implementation of the Directive must be comprehensive and cover all the required aspects, and that partial implementation, i.e. of certain elements but not others, is insufficient to realise the Directive's overarching purpose of achieving a sustainable use of pesticides; underlines the fact that the implementation of IPM practices, such as non-chemical alternatives and low-risk PPPs, plays a particularly important role in efforts to achieve this objective;

5. Notes that the Commission's 2017 progress report identifies significant gaps in the National Action Plans (NAPs) of Member States, suggesting a lower commitment to protecting the environment and health in some countries, possibly resulting in unfair market competition and an undermining of the single market; reserves the right to refer non-compliant Member States to the Commissioner for competition;

6. Expresses concern at the fact that approximately 80 % of Member States' NAPs contain no specific information on how to quantify the achievement of many of the objectives and targets, particularly as regards targets for IPM and aquatic protection measures; stresses that this greatly complicates the process of measuring the progress made by Member States in fulfilling the main objectives and purpose of the Directive;

7. Is concerned by the fact that the NAPs are inconsistent as regards the establishment of quantitative objectives, targets, measures and timetables for the various action areas, making it impossible to assess the progress made; regrets that only five NAPs set high-level measurable targets, of which four relate to risk reduction and only one to use reduction; regrets the fact that only 11 Member States have produced a revised NAP to date, although the deadline for revision was the end of 2017;

8. Regrets the fact that in many Member States there is not sufficient commitment to IPM practices based on its eight principles with the prioritisation of non-chemical alternatives to pesticides; regrets that one of the main challenges regarding the implementation of IPM, which is the cornerstone of the Directive, seems to be the current lack of appropriate control instruments and methods to assess compliance in the Member States, as well as of clear rules and guidance; underlines the fact that comprehensive implementation of IPM is one of the key measures for reducing dependency on pesticide use in sustainable agriculture, which is environmentally friendly, economically viable and socially responsible and contributes to Europe's food security while strengthening biodiversity and human and animal health, boosting the rural economy and reducing costs for farmers by facilitating the market uptake of non-chemical alternatives and low-risk PPPs in the different European zones; stresses that additional financial incentives and educational measures are needed to strengthen the uptake of IPM practices by individual farms;

9. Considers that IPM represents a valuable tool for farmers to combat pests and disease and to ensure production yields; notes that an increased uptake of IPM serves the dual purpose of strengthening the protection of the environment and biodiversity, as well as reducing costs for farmers to switch to more sustainable alternatives and reduce the use of conventional pesticides; believes that a greater effort is needed to encourage the uptake of IPM, via research and through Member States' advisory bodies; recalls that IPM can play an important role in reducing the quantities and varieties of pesticides used;

10. Notes that within the IPM toolkit, biological control involves boosting or introducing

beneficial species that predate upon and therefore regulate pest populations, keeping them in check; emphasises, therefore, the importance of preferring sustainable biological, physical and other non-chemical methods to chemical pesticides if they provide satisfactory pest control; stresses also the importance of applying chemical pesticides in a selective and targeted manner, since otherwise those beneficial pest control agents risk being wiped out, leaving the crops more susceptible to future attacks;

11. Is concerned that very little progress has been made in promoting and incentivising the innovation, development and uptake of low-risk and non-chemical alternatives to conventional pesticides; notes that a mere handful of NAPs contain incentives for the registration of such alternative products and methods; emphasises that minor uses are particularly vulnerable owing to the scarcity of the relevant active substances;

12. Highlights that sustainable and responsible use of pesticides is a precondition for the authorisation of PPPs;

13. Regrets the lack of availability of low-risk active substances and PPPs, mainly caused by the lengthy evaluation, authorisation and registration process due partly to the fact that the shorter authorisation time-frame of 120 days for such cases is rarely fulfilled at Member State level; emphasises that the current situation is not compliant with the principles of promoting and implementing IPM, and stresses the importance of the availability of low-risk pesticides, adequate research and the sharing of best practices within and among Member States in order to fully utilise the potential of IPM; considers that a faster approval process would stimulate industry research into the development of new low-risk active ingredients, including innovative low-risk substances, thus ensuring that farmers have sufficient plant protection tools at their disposal and enabling them to switch more rapidly to sustainable PPPs and increase IPM's efficacy;

14. Recalls that increased pesticide resistance creates increased use and dependency; notes that greater use of and dependency on pesticides come at a high cost to farmers, both through high input costs and owing to the loss in yields arising from the depletion of soil and reduced soil quality;

15. Notes that increased availability of low-risk PPPs on the market would reduce the risk of resistance to active ingredients, as well as the effects on non-target species linked to commonly used PPPs;

16. Notes in this respect that resistance to pesticide active substances is a biological inevitability in fast-reproducing pests and diseases and is a growing problem; stresses, therefore, that sustainable biological, physical and other non-chemical methods must be preferred to chemical pesticides if they provide satisfactory pest control; recalls that chemical pesticides should be used selectively and in a targeted manner; stresses that otherwise these beneficial pest control agents risk being wiped out, leaving the crops more susceptible to future attacks;

17. Notes further that the best pesticide volume reductions are likely to arise from systemic changes that reduce susceptibility to pest attack, favour structural and biological diversity over monocultures and continuous cropping, and reduce pest resistance to active ingredients; highlights, therefore, the need to focus on, fund and mainstream agro-ecological methods which make the whole farming system more resilient to pests;

18. Stresses that the CAP in its current form does not sufficiently encourage and incentivise the reduction of farms' dependency on pesticides and the uptake of organic production techniques; considers that specific policy instruments in the post-2020 CAP are required in order to help change farmers' behaviour as regards pesticide use;

19. Deplores the fact that the Commission proposal on the new post-2020 CAP does not incorporate the principle of IPM in the statutory management requirements referred to in Annex III of that proposal; stresses that lack of linkage between the directive and the new CAP model will effectively hamper the reduction of pesticide dependency;

20. Notes that most Member States use national risk indicators to assess, either entirely or in part, the adverse impact of pesticide use; recalls that in spite of the explicit obligation laid down in Article 15 of the Directive, EU-wide harmonised risk indicators have still not been agreed on by the Member States, which makes it all but impossible to compare the progress made in different Member States and across the Union as a whole; welcomes the adoption, on 25 January 2019, of harmonised risk indicators by the Standing Committee on Plants, Animals, Food and Feed (PAFF Committee);

21. Emphasises the fundamental importance of biodiversity and of robust ecosystems, most notably in the case of bees and other pollinating insects, which are essential in order to ensure a healthy and sustainable agricultural sector; underlines that the protection of biodiversity is not exclusively a matter of protecting the environment, but is also a means to ensure Europe's sustained food security in the future;

22. Is deeply concerned about the continuous and potentially irreversible loss of biodiversity in Europe and about the alarming decline of winged insects, including pollinators, as evidenced by the findings of the October 2017 scientific study on flying insect biomass,[1] according to which the flying insect population in 63 nature protection areas in Germany has plummeted by more than 75 % in 27 years; stresses, further, the important decline in common bird species across Europe, possibly arising from the reduced insect population; notes, moreover, the unintentional effects of pesticides on soil and soil organisms[2] and other non-target species; considers that pesticides are one of the main factors responsible for the decline of insects, farmland bird species and other non-target organisms, and further underlines the need for Europe to switch to more sustainable pesticide use and increase the number of non-chemical alternatives and low-risk PPPs for farmers;

23. Maintains that neonicotinoid-based pesticides are playing a particular role in the worrying decline in bee populations across Europe, as can be seen from a range of international studies which have formed the basis for petitions from citizens bearing hundreds of thousands of signatures from all over the continent;

24. Recognises the importance of NAPs and IPM in significantly reducing pesticide usage in order to avoid irreversible biodiversity loss while favouring agro-ecological measures and organic farming wherever possible;

25. Further emphasises that the development of sustainable agricultural choices is necessary to reduce climate change impacts on food security;

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1 https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0185809

2 https://esdac.jrc.ec.europa.eu/public_path/shared_folder/doc_pub/EUR27607.pdf

26. Expresses particular concern at the continued use of pesticides with active substances that are mutagenic, carcinogenic or toxic for reproduction, or have endocrine-disrupting characteristics and are damaging to humans or animals; emphasises that the use of such pesticides is incompatible with the objectives and purpose of the Directive;

27. Emphasises that the aquatic environment is particularly sensitive to pesticides; welcomes the fact that some Member States have taken a range of measures to protect it from them; regrets, however, that most Member States have not established quantitative targets and timetables for measures to protect the aquatic environment from pesticides, and those that have done so have not specified how the achievement of targets or objectives would be measured; believes that the monitoring of currently used pesticides in the aquatic environment should be improved;

28. Notes that agriculture is one of the main sources that cause water bodies to fail to achieve good chemical status, as it leads to pollution by pesticides; highlights that preventing pesticides entering freshwater systems is more cost-effective than removal technologies, and that Member States must provide appropriate incentives in this regard to farmers; in this regard, also recognises the importance of the implementation of the Water Framework Directive for improving water quality; welcomes the progress made by Member States in tackling priority substances, which has led to fewer water bodies failing to meet standards for substances such as cadmium, lead and nickel, as well as pesticides;

29. Regrets the fact that the deterioration of water resources has increasingly led to additional treatment by drinking water operators in order to ensure that water intended for human consumption complies with the pesticides limits as enshrined in Council Directive 98/83/EC on the quality of water intended for human consumption, with the costs being borne by consumers, not polluters;

30. Stresses that some pesticides are internationally recognised as persistent organic pollutants (POPs), owing to their potential for long-range transport, persistence in the environment and ability to bio-magnify throughout the food chain and bio-accumulate in ecosystems, as well as their significant negative effects on human health;

31. Welcomes the fact that all Member States have established training and certification schemes regarding the use of PPPs, but regrets that in some Member States training obligations are not met for all required subjects listed in Annex I; underlines the importance of training of users in order to ensure the safe and sustainable use of PPPs; considers it fitting to distinguish between professional and amateur users, given that they are not subject to the same obligations; emphasises that both professional and non-professional users of PPPs should receive adequate training;

32. Notes the potential of using intelligent technology and precision farming as means to better administer PPPs and to prevent the dispersion thereof in areas where they are not needed, for instance by means of drone or GPS precision technology; stresses, moreover, that the uptake of such solutions could be improved in Member States if better incorporated into training courses and certification schemes for pesticides users in the NAPs;

33. Stresses that PPPs are used not only in agriculture but also for weed and pest control in areas used by the general public or vulnerable groups as defined in Article 12a of the

Directive, including public parks and railways; whereas the use of PPPs in such areas is inappropriate; welcomes the fact that several Member States and numerous regional and local governments have taken action to restrict or prohibit pesticide use in areas used by the general public or vulnerable groups; notes, however, the absence of measurable targets in the majority of Member States;

34. Expresses concern that many Member States have not interpreted the requirement of Article 12(a) correctly, reading it as referring only to non-agricultural use, while in fact vulnerable groups such as those defined in Regulation (EC) No 1107/2009 include residents subject to high pesticide exposure over the long term; notes in addition that the Commission has confirmed that there is no legal reason why agricultural application should be excluded from the provisions of Article 12;

35. Notes Member States' continued support for organic agriculture as a low-pesticide input system; welcomes the fact that the number of organic farms has continued to increase in the Union, but notes that progress still varies considerably between Member States;

36. Notes that organic farmers suffer economic losses when their soil and organic produce are contaminated by pesticide use on neighbouring farms via, for example, drift from pesticide spraying and movement of persistent active substances in the environment; points out that, consequently, due to actions beyond their control, organic farmers may be forced to sell their produce as conventional, losing out on their price premium, or may even be decertified;

37. Notes that, while Member States generally have systems to gather information on acute pesticide poisoning, the accuracy of this data and its use is questioned; highlights the fact that systems for gathering such information on chronic poisoning have not been widely implemented;

38. Highlights the fact that EFSA's latest report on pesticide residues in food showed that 97,2 % of samples throughout Europe were within the legal limits under the EU legislation, which bears witness to an extremely rigorous and safe food production system;

Recommendations

39. Calls on the Member States to complete the implementation of the Directive without further delay;

40. Calls on the Commission and the Member States to ensure that all relevant stakeholders are included in any stakeholder activities on pesticides, including the public, as provided for in Directive 2003/35/EC and the Aarhus Convention;

41. Calls on the Member States to take a proactive role in the practical implementation of the Directive in order to identify gaps and specific areas which require particular attention with respect to the protection of human health and the environment, and not to confine themselves to the usual national transposition and control mechanisms;

42. Calls on the Member States to acknowledge that the EU must act without delay to transition to a more sustainable use of pesticides, and that the main responsibility for implementing such practices lies with the Member States; emphasises that swift action

is essential;

43. Calls on the Member States to adhere to the established timelines for delivering revised NAPs; urges those Member States that have not yet done so to deliver without further delay, this time with clear quantitative targets and a measurable overall objective of an immediate and long-term effective reduction in the risks and impacts of pesticide use, including clearly defined annual reduction targets and with special attention to the possible effects on pollinators and the fostering and uptake of sustainable non-chemical alternatives and low-risk PPPs, in line with the IPM principles;

44. Calls on the Commission to propose an ambitious EU-wide binding target for the reduction of pesticide use;

45. Calls on the Commission to further develop guidance on all the IPM principles and their implementation; asks the Commission in this regard to establish guidelines on the establishment of criteria for measuring and assessing the implementation of IPM in the Member States;

46. Calls on the Commission and the Member States to take all requisite measures to promote low-risk pesticides, and to prioritise non-chemical options and methods which entail the least risk of harm to health and the natural environment, while ensuring effective and efficient crop protection; stresses that for this to be successful, the economic incentives for farmers to choose such options must be strengthened;

47. Calls on the Commission and the Member States to place greater emphasis on the promotion of the development, research, registration and marketing of low-risk and biological alternatives, including by increasing funding opportunities within Horizon Europe and the Multiannual Financial Framework 2021-2027; recalls the importance of preferring sustainable biological, physical and other non-chemical methods to chemical pesticides if they provide satisfactory pest control; recalls the importance of the added value of ecologically sustainable and safe plant protection techniques;;

48. Calls on the Commission, without further delay, to deliver on its commitment under the 7th Environment Action Programme to put forward a Union strategy for a non-toxic environment that is conducive to innovation and the development of sustainable substitutes, including non-chemical solutions; expects the Commission to take particular account in this strategy of the impacts of pesticides on the environment and human health;

49. Encourages more focus on risk reduction, as extensive use of low-risk substances might be more harmful than limited use of high-risk substances;

50. Calls on the Commission and the Member States to ensure better coherence of the Directive and its implementation with related EU legislation and policies, most notably the provisions of the CAP and Regulation (EC) No 1107/2009, and in particular to integrate the IPM principles as legal requirements under the CAP, pursuant to Article 14 of the directive;

51. Calls on the Commission and the Member States to strictly limit the number of essential use derogations under Regulation (EC) No 1107/2009 and update the relevant guidance documents so as to ensure that the risk assessment of pesticides reflects real-life

exposure and conditions and takes into account all possible impacts on health and the environment;

52. Recommends giving Member States the flexibility to apply IPM as part of the greening measures under the CAP;

53. Welcomes the recent adoption of harmonised risk indicators by the Standing Committee on Plants, Animals, Food and Feed (PAFF Committee) and calls on the Member States to move forward with the adoption and implementation of harmonised risk indicators as recently proposed by the Commission, in order to properly monitor the reduction impacts of pesticides;

54. Calls on the Commission to establish a fully operational and transparent system for the regular collection of statistical data on pesticide use, impacts of occupational and non-occupational exposure to pesticides on human and animal health, and presence of pesticide residues in the environment, especially in soil and water;

55. Calls on the Commission and the Member States to promote research programmes aimed at determining the impacts of pesticide use on human health, taking into account the full range of toxicological and long-term effects, including immunotoxicity, endocrine disruption and neurodevelopmental toxicity, and focusing on the effects of prenatal exposure to pesticides on children's health;

56. Urges the Commission to take a risk-based approach to the management and use of commonly used PPPs that is justified by independent, peer-reviewed scientific evidence;

57. Calls on the Commission to submit, before the end of its current mandate, a specific legislative proposal amending Regulation (EC) No 1107/2009, outside of the general revision in connection with the REFIT initiative, with a view to adding a definition and a separate category for ‘naturally occurring substances’ and ‘nature-identical substances’, the criterion for which would be the existing presence and exposure of the substance in nature, as well as to establishing a rigorous fast-track evaluation, authorisation and registration procedure for low-risk biological pesticides, in line with Parliament’s resolutions of 15 February 2017 on low-risk pesticides of biological origin and 13 September 2018 on the implementation of the Plant Protection Products Regulation (EC) No 1107/2009;

58. Calls on the Commission and the Member States to ensure the effective implementation of the Union’s obligations under the Protocol to the 1979 Convention on Long-range Transboundary Air Pollution and the 2004 Stockholm Convention on Persistent Organic Pollutants, and therefore to scale up their efforts to eliminate the manufacturing, placing on the market and use of POP pesticides, together with the establishment of provisions on the disposal of waste containing or contaminated by any of those substances;

59. Calls on the Member States to ensure that professionally qualified and independent advisory services are available to provide advice and training to end-users on the sustainable use of pesticides, and on IPM in particular;

60. Calls on the Commission and the Member States to place greater emphasis on further investment and research into the development and uptake of precision and digital

farming technologies in order to render PPPs more efficient and thus significantly reduce pesticide dependency, as per the aims of the directive, thereby reducing the exposure of both professional users and the general public; considers that the use of digitisation or precision farming should not lead to dependency on inputs or financial indebtedness for farmers;

61. Calls on the Commission and the Member States to no longer allow the use of PPPs in areas used by the general public or vulnerable groups as defined by Article 3(14) of Regulation (EC) No 1107/2009;

62. Calls on the Commission and the Member States to pay particular attention to the protection of vulnerable groups, as defined by Article 3(14) of Regulation (EC) No 1107/2009, especially considering the existing lack of protection of rural residents living in the locality of crops; calls, therefore, on the Commission and the Member States to propose immediate bans on the use of pesticides within substantial distances of residents' homes, schools, playgrounds, nurseries and hospitals;

63. Calls on the Commission and the Member States to invest in further research on the impact of pesticides on non-target species and to take immediate action to minimise it;

64. Calls on the Commission and the Member States to promote an agricultural model which relies on preventive and indirect plant protection strategies aimed at reducing the use of external inputs, and on multifunctional naturally occurring substances; acknowledges the need for more research in and development of preventive and indirect agro-ecological plant health care strategies;

65. Calls on the Member States to increase their investment in adaptation practices that prevent agro-chemical substances from reaching surface and deep water, as well as in measures aimed at containment of possible leaching of these substances into watercourses, rivers and seas; recommends that their use be prohibited in soils potentially draining into groundwater;

66. Stresses the essential need for regular assessment of proportionality between the quantity of pesticides sold and the agricultural area of application, based on user databases and sales records;

67. Calls on the Commission and the Member States to ensure full and uniform application of the hazard-based cut-off criteria for active substances that are mutagenic, carcinogenic or toxic for reproduction, or that have endocrine-disrupting properties;

68. Calls on the Member States to strictly follow the ban on imports of prohibited pesticides into the EU from third countries, and to increase controls on imported food;

69. Calls on the Commission to carefully consider all measures available to ensure compliance, including launching infringement proceedings against Member States which fail to comply with the obligation to fully implement the Directive;

70. Calls on the Commission to take vigorous action against Member States that are systematically abusing derogations concerning banned pesticides containing neonicotinoids;

71. Calls on the Commission and the Member States to ensure that the 'polluter pays'

principle is fully implemented and effectively enforced as regards the protection of water resources;

72. Calls for Horizon Europe to provide sufficient funding to promote the development of plant health care strategies based on a systemic approach combining innovative agro-ecological techniques and preventive measures aimed at reducing the use of external inputs to a minimum;

73. Calls on the Commission to set up a pan-European Platform on Sustainable Pesticides Use that would bring together sectorial stakeholders and representatives at local and regional level so as to facilitate information-sharing and exchange of best practices in reducing pesticides use;

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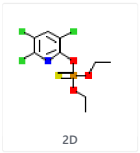
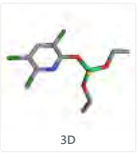
74. Instructs its President to forward this resolution to the Council and the Commission.

PubChem

COMPOSÉ RÉSUMÉ

Chlorpyrifos

CID PubChem	2730
Structure	 2D  3D Trouver des structures similaires
Sécurité chimique	 Acute Toxic Environmental Hazard Fiche technique du résumé de sécurité chimique en laboratoire (LCSS)
Formule moléculaire	$C_9H_{11}Cl_3NO_3PS$
Synonymes	chlorpyrifos 2921-88-2 Dursban Chlorpyriphos Lorsban Plus...
Masse moléculaire	350.6
Date s	Modifier 2023-03-11 Créer 2005-03-25

Le chlorpyrifos est un insecticide qui est un solide cristallin blanc avec une forte odeur. Il ne se mélange pas bien avec l'eau , il est donc généralement mélangé à des liquides huileux avant d'être appliqué sur les cultures ou les animaux. Il peut également être appliqué sur les cultures sous forme de capsules. Le chlorpyrifos a été largement utilisé dans les maisons et les fermes. À la maison, il est utilisé pour contrôler les cafards, les puces et les termites ; il est également utilisé dans certains colliers anti-puces et anti-tiques pour animaux de compagnie. À la ferme, il est utilisé pour lutter contre les tiques sur le bétail et en pulvérisation pour lutter contre les ravageurs des cultures.

▸ Portail des substances toxiques CDC-ATSDR

Le chlorpyrifos est un organophosphate synthétique inhibiteur de l'acétylcholinestérase, toxique pour la reproduction et neurotoxique utilisé comme pesticide. Il se caractérise par un solide cristallin incolore, blanc ou brun clair hautement toxique avec une légère odeur d'œuf pourri, et l'exposition se produit par inhalation, ingestion ou contact.

▸ Thésaurus NCI (NCIt)

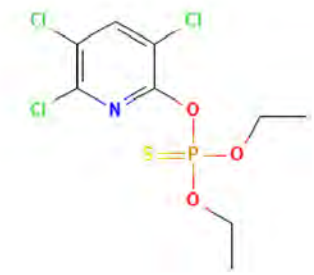
Le chlorpyrifos est un solide blanc cristallin ou en flocons irréguliers. Il a une très faible odeur de type mercaptan. Il n'est pas soluble dans l'eau . Il peut provoquer une légère irritation des yeux et de la peau.

▸ Produits chimiques CAMEO

1 Ouvrages

1.1 Structure 2D

Représentation de la structure chimique

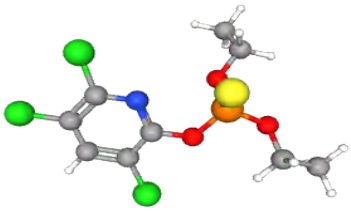


PubChem

1.2 Conformateur 3D

Modèle interactif de structure chimique

- (•) Balle et Bâton
- ( ) Des bâtons
- ( ) fil de fer
- ( ) Remplissage d'espace
- [x] Afficher Hydrogènes
- [ ] Animer



PubChem

2 Noms et identifiants

2.1 Descripteurs calculés

2.1.1 Nom IUPAC

diéthoxy-sulfanylidène-(3,5,6-trichloropyridin-2-yl)oxy-λ ^{5} -phosphane

Calculé par Lexichem TK 2.7.0 (version PubChem 2021.05.07)

PubChem

2.1.2 InChI

InChI=1S/C9H11Cl3NO3PS/c1-3-14-17(18,15-4-2)16-9-7(11)5-6(10)8(12)13-9/h5H,3-4H2, 1-2H3

Calculé par InChI 1.0.6 (version PubChem 2021.05.07)

PubChem

2.1.3 InChIKey

SBPBAQFWLVIOKP-UHFFFAOYSA-N

Calculé par InChI 1.0.6 (version PubChem 2021.05.07)

PubChem

2.1.4 SOURIRES canoniques

CCOP(=S)(OCC)OC1=NC(=C(C=C1Cl)Cl)Cl

Calculé par OEChem 2.3.0 (version PubChem 2021.05.07)

PubChem

2.2 Formule moléculaire

C9H11Cl3NO3PS

Produits chimiques CAMEO ; Fiches internationales de sécurité chimique (ICSC) de l'OIT ; PubChem

2.3 Autres identifiants

2.3.1 CAS

2921-88-2

CAMEO Chemicals; CAS Common Chemistry; DTP/NCI; EPA DSSTox; European Chemicals Agency (ECHA); FDA Global Substance Registration System (GSRS); Hazardous Substances Data Bank (HSDB); Human Metabolc

2.3.2 Deprecated CAS

12768-48-8

EPA DSSTox

2.3.3 European Community (EC) Number

220-864-4

European Chemicals Agency (ECHA)

2.3.4 ICSC Number

0851

ILO International Chemical Safety Cards (ICSC)

2.3.5 NSC Number

755891

DTP/NCI

2.3.6 RTECS Number

TF6300000

The National Institute for Occupational Safety and Health (NIOSH)

2.3.7 UN Number

2783

ILO International Chemical Safety Cards (ICSC); NJDOH RTK Hazardous Substance List; The National Institute for Occupational Safety and Health (NIOSH)

2.3.8 UNII

JCS58I644W

FDA Global Substance Registration System (GSRS)

2.3.9 DSSTox Substance ID

DTXSID4020458

EPA DSSTox

2.3.10 Nikkaji Number

J3.041D

Japan Chemical Substance Dictionary (Nikkaji)

2.3.11 Wikipedia

Chlorpyrifos

Wikipedia

2.3.12 Wikidata

Q414915

Wikidata

2.3.13 NCI Thesaurus Code

C163641

NCI Thesaurus (NCIt)

2.3.14 Metabolomics Workbench ID

49582

Metabolomics Workbench

2.4 Synonyms

2.4.1 MeSH Entry Terms

Chlorpyrifos
Dursban
Lorsban

Medical Subject Headings (MeSH)

2.4.2 Depositor-Supplied Synonyms

chlorpyrifos	Lentrek	Radar	Chlorpyriphos-ethyl	m-Chlorpyrifos	JCS5
2921-88-2	Pyrinex	Terial	Ethyl chlorpyriphos	XRM 429	O,O-I
Dursban	Stipend	Zidil	Dursban 10CR	OMS-0971	Clorp
Chlorpyriphos	Lock-On	Suscon blue	Chlorpyrifos (Dursban)	XRM 5160	O,O-(
Lorsban	Killmaster	Suscon green	Detmol U.A.	Dursban 2E	CHEE
Trichlorpyrphos	Bonidel	suSCon	Empire 20	ENT 27311	2-Py
Brodan	Danusban	Dursban F	Chlorpyrifos [BAN]	ENT-27311	Chlo
Coroban	Geodinfos	Dursban R	Chloropyriphos	O,O-Diethyl O-(3,5,6-trichloro-2-pyridinyl)phosphorothioate	Dhan
Chlorpyrifos-ethyl	Spannit	Chlorpyrifos ethyl	Chlorpyrofos	NSC-755891	o,o-D
Chloropyrifos	Tafaban	Phosphorothioic acid, O,O-diethyl O-(3,5,6-trichloro-2-pyridinyl) ester	Chlorpyrophos	Phosphorothioic acid, O,O-diethyl O-(3,5,6-trichloro-2-pyridyl) ester	SMR
Piridane	Dowco 179	Dursban 4E	Pageant	Bonidel; CPF Zamba; Chlora;	Grof
Equity	Durmet	O,O-Diethyl O-3,5,6-trichloro-2-pyridyl phosphorothioate	Silrifos	MLS001065609	O,O-(

PubChem

3 Chemical and Physical Properties

3.1 Computed Properties

Property Name	Property Value	Reference
Molecular Weight	350.6	Computed by PubChem 2.1 (PubChem release 2021.05.07)
XLogP3	5.3	Computed by XLogP3 3.0 (PubChem release 2021.05.07)
Hydrogen Bond Donor Count	0	Computed by Cactvs 3.4.8.18 (PubChem release 2021.05.07)
Hydrogen Bond Acceptor Count	5	Computed by Cactvs 3.4.8.18 (PubChem release 2021.05.07)
Rotatable Bond Count	6	Computed by Cactvs 3.4.8.18 (PubChem release 2021.05.07)
Exact Mass	348.926284	Computed by PubChem 2.1 (PubChem release 2021.05.07)
Monoisotopic Mass	348.926284	Computed by PubChem 2.1 (PubChem release 2021.05.07)
Topological Polar Surface Area	72.7 Å²	Computed by Cactvs 3.4.8.18 (PubChem release 2021.05.07)
Heavy Atom Count	18	Computed by PubChem
Formal Charge	0	Computed by PubChem
Complexity	303	Computed by Cactvs 3.4.8.18 (PubChem release 2021.05.07)
Isotope Atom Count	0	Computed by PubChem
Defined Atom Stereocenter Count	0	Computed by PubChem
Undefined Atom Stereocenter Count	0	Computed by PubChem
Defined Bond Stereocenter Count	0	Computed by PubChem
Undefined Bond Stereocenter Count	0	Computed by PubChem
Covalently-Bonded Unit Count	1	Computed by PubChem
Compound Is Canonicalized	Yes	Computed by PubChem (release 2021.05.07)

PubChem

3.2 Experimental Properties

3.2.1 Physical Description

Chlorpyrifos is a white crystalline or irregularly flaked solid. It has a very faint mercaptan-type odor. It is not soluble in **water**. It can cause slight irritation to the eye and skin.

CAMEO Chemicals

Colorless to white, crystalline solid with a mild, mercaptan-like odor. [pesticide] [NIOSH]

Haz-Map, Information on Hazardous Chemicals and Occupational Diseases

Solid

Human Metabolome Database (HMDB)

COLOURLESS-TO-WHITE CRYSTALS WITH CHARACTERISTIC ODOUR.

ILO International Chemical Safety Cards (ICSC)

Colorless to white, crystalline solid with a mild, mercaptan-like odor.

Occupational Safety and Health Administration (OSHA)

Colorless to white, crystalline solid with a mild, mercaptan-like odor. [pesticide] [Note: Commercial formulations may be combined with combustible liquids.]

The National Institute for Occupational Safety and Health (NIOSH)

3.2.2 Color/Form

White granular crystals

O'Neil, M.J. (ed.). The Merck Index - An Encyclopedia of Chemicals, Drugs, and Biologicals. Cambridge, UK: Royal Society of Chemistry, 2013., p. 390

Hazardous Substances Data Bank (HSDB)

Colorless crystals

MacBean C, ed; e-Pesticide Manual. 15th ed., ver. 5.1, Alton, UK; British Crop Protection Council. Chlorpyrifos (2921-88-2) (2008-2010

Hazardous Substances Data Bank (HSDB)

Colorless to white crystalline solid [Note: Commercial formulations may be combined with combustible liquids.]

*NIOSH. NIOSH Pocket Guide to Chemical Hazards. Department of Health & Human Services, Centers for Disease Control & Prevention. National Institute for Occupational Safety & Health. DHHS (NIOSH) Publication No. 2010-168 (2010). Available from: **https://www.cdc.gov/niosh/npg***

Hazardous Substances Data Bank (HSDB)

3.2.3 Odor

Mild mercaptan odor

MacBean C, ed; e-Pesticide Manual. 15th ed., ver. 5.1, Alton, UK; British Crop Protection Council. Chlorpyrifos (2921-88-2) (2008-2010

Hazardous Substances Data Bank (HSDB)

3.2.4 Boiling Point

320 °F at 760 mmHg (Decomposes) (NIOSH, 2022)

- CAMEO Chemicals

320 °F (decomp)

NIOSH. NIOSH Pocket Guide to Chemical Hazards. Department of Health & Human Services, Centers for Disease Control & Prevention. National Institute for Occupational Safety & Health. DHHS (NIOSH) Publication No. 2010-168 (2010). Available from: https://www.cdc.gov/niosh/npg

- Hazardous Substances Data Bank (HSDB)

375.90 °C. @ 760.00 mm Hg (est)

The Good Scents Company Information System

- Human Metabolome Database (HMDB)

No boiling point at normal pressure; decomposes at 160 °C

- ILO International Chemical Safety Cards (ICSC)

320 °F (decomposes)

- Occupational Safety and Health Administration (OSHA)

320 °F (Decomposes)

- The National Institute for Occupational Safety and Health (NIOSH)

3.2.5 Melting Point

108 to 110 °F (NTP, 1992)

National Toxicology Program, Institute of Environmental Health Sciences, National Institutes of Health (NTP). 1992. National Toxicology Program Chemical Repository Database. Research Triangle Park, North Carolina.

- CAMEO Chemicals

41-42 °C

O'Neil, M.J. (ed.). The Merck Index - An Encyclopedia of Chemicals, Drugs, and Biologicals. Cambridge, UK: Royal Society of Chemistry, 2013., p. 390

- Hazardous Substances Data Bank (HSDB); ILO International Chemical Safety Cards (ICSC)

42 °C

- Human Metabolome Database (HMDB)

108 °F

- Occupational Safety and Health Administration (OSHA); The National Institute for Occupational Safety and Health (NIOSH)

3.2.6 Flash Point

82 °F (CLOSED CUP) /DURSBAN 4E/

National Fire Protection Association. Fire Protection Guide on Hazardous Materials. 7th ed. Boston, Mass.: National Fire Protection Association, 1978., p. 96

- Hazardous Substances Data Bank (HSDB)

87 °F (CLOSED CUP) /LORSBAN 4E/

National Fire Protection Association. Fire Protection Guide on Hazardous Materials. 7th ed. Boston, Mass.: National Fire Protection Association, 1978., p. 154

- Hazardous Substances Data Bank (HSDB)

3.2.7 Solubility

approximately 2 mg/L at 77 °F (NTP, 1992)

National Toxicology Program, Institute of Environmental Health Sciences, National Institutes of Health (NTP). 1992. National Toxicology Program Chemical Repository Database. Research Triangle Park, North Carolina.

- CAMEO Chemicals

In water, 1.4 mg/L at 25 °C

MacBean C, ed; e-Pesticide Manual. 15th ed., ver. 5.1, Alton, UK; British Crop Protection Council. Chlorpyrifos (2921-88-2) (2008-2010)

- Hazardous Substances Data Bank (HSDB)

In water, 1.12 mg/L at 24 °C

Yalkowsky, S.H., He, Yan, Jain, P. Handbook of Aqueous Solubility Data Second Edition. CRC Press, Boca Raton, FL 2010, p. 586

- Hazardous Substances Data Bank (HSDB)

In water, 0.39 mg/L at 19.5 °C /OECD 105 method/

World Health Org; WHO Specifications and Evaluations for Public Health Pesticides. Chlorpyrifos (March 2009). Available from, as of April 2: 2014: https://www.who.int/whopes/quality/Chlorpyrifos_WHO_specs_eval_Mar_2009.pdf

- Hazardous Substances Data Bank (HSDB)

Solubility at 25 °C: isooctane 79% wt/wt; methanol 43% wt/wt

O'Neil, M.J. (ed.). The Merck Index - An Encyclopedia of Chemicals, Drugs, and Biologicals. Cambridge, UK: Royal Society of Chemistry, 2013., p. 390

- Hazardous Substances Data Bank (HSDB)

Solubility (g/100 g): acetone 650, benzene 790, carbon disulfide 590, carbon tetrachloride 310, chloroform 630, diethyl ether 510, ethanol 63, ethyl acetate >200, isooctane 79, kerosene 60, methanol 45, methylene chloride 400, propylene glycol 4, toluene 150, 1,1,1-trichloroethane 400, triethylene glycol 5, xylene 400. Readily soluble in other organic solvents.

O'Neil, M.J. (ed.). The Merck Index - An Encyclopedia of Chemicals, Drugs, and Biologicals. Cambridge, UK: Royal Society of Chemistry, 2013., p. 390

- Hazardous Substances Data Bank (HSDB)

0.00112 mg/mL at 24 °C

- Human Metabolome Database (HMDB)

Solubility in water, mg/l at 25 °C: 1.4 (very poor)

- ILO International Chemical Safety Cards (ICSC)

0.0002%

- The National Institute for Occupational Safety and Health (NIOSH)

3.2.8 Density

1.4 (Liquid at 110 °F) (NIOSH, 2022)

- CAMEO Chemicals

1.44 at 20 °C

MacBean C, ed; e-Pesticide Manual. 15th ed., ver. 5.1, Alton, UK; British Crop Protection Council. Chlorpyrifos (2921-88-2) (2008-2010

- Hazardous Substances Data Bank (HSDB)

1.4 g/cm³

- ILO International Chemical Safety Cards (ICSC)

1.40 (liquid at 110 °F)

- Occupational Safety and Health Administration (OSHA)

1.40 (Liquid at 110 °F)

- The National Institute for Occupational Safety and Health (NIOSH)

3.2.9 Vapor Density

12.09 (calculated) (NTP, 1992) (Relative to Air)

National Toxicology Program, Institute of Environmental Health Sciences, National Institutes of Health (NTP). 1992. National Toxicology Program Chemical Repository Database. Research Triangle Park, North Carolina.

- CAMEO Chemicals

12.09

- Occupational Safety and Health Administration (OSHA)

3.2.10 Vapor Pressure

1.87e-05 mmHg at 77 °F (NTP, 1992)

National Toxicology Program, Institute of Environmental Health Sciences, National Institutes of Health (NTP). 1992. National Toxicology Program Chemical Repository Database. Research Triangle Park, North Carolina.

- CAMEO Chemicals

0.00002 [mmHg]

- Haz-Map, Information on Hazardous Chemicals and Occupational Diseases

2.02X10-5 mm Hg at 25 °C

MacBean C, ed; e-Pesticide Manual. 15th ed., ver. 5.1, Alton, UK; British Crop Protection Council. Chlorpyrifos (2921-88-2) (2008-2010)

- Hazardous Substances Data Bank (HSDB)

Vapor pressure, Pa at 25 °C: 0.0024

- ILO International Chemical Safety Cards (ICSC)

0.00002 mmHg

- Occupational Safety and Health Administration (OSHA); The National Institute for Occupational Safety and Health (NIOSH)

3.2.11 LogP

log Kow = 4.96

*Sangster J; LOGKOW Database. A databank of evaluated octanol-water partition coefficients (Log P). Available from, as of April 2, 2014: **https://logkow.cisti.nrc.ca/logkow/search.html***

- Hazardous Substances Data Bank (HSDB)

4.96

- Human Metabolome Database (HMDB); ILO International Chemical Safety Cards (ICSC)

3.2.12 Henry's Law Constant

Henry's Law constant = 3.55X10-5 atm cu-m/mol at 25 °C

Cetin B et al; Atmos Environ 40: 4538-4546 (2006)

▸ Hazardous Substances Data Bank (HSDB)

3.2.13 Stability/Shelf Life

Stable under recommended storage conditions.

*Sigma-Aldrich Corp; Safety Data Sheet for Chlorpyrrifos (Product Number: 45395) Version 5.3 (June 27, 2014). Available from, as of June 18, 2014: **https://www.sigmaaldrich.com/safety-center.html***

▸ Hazardous Substances Data Bank (HSDB)

3.2.14 Decomposition

Decomposition temperature: approx 160 °C

Verschueren, K. Handbook of Environmental Data on Organic Chemicals. Volumes 1-2. 4th ed. John Wiley & Sons. New York, NY. 2001, p. 567

▸ Hazardous Substances Data Bank (HSDB)

160 °C. This produces toxic and corrosive fumes including hydrogen chloride, phosgene, phosphorus oxides, nitrogen oxides and sulfur oxides. Attacks copper and brass.

▸ ILO International Chemical Safety Cards (ICSC)

3.2.15 Corrosivity

Corrosive to copper and brass

*NIOSH. NIOSH Pocket Guide to Chemical Hazards. Department of Health & Human Services, Centers for Disease Control & Prevention. National Institute for Occupational Safety & Health. DHHS (NIOSH) Publication No. 2010-168 (2010). Available from: **https://www.cdc.gov/niosh/npg***

▸ Hazardous Substances Data Bank (HSDB)

3.2.16 Dissociation Constants

Practically non-dissociative by nature

*World Health Org; WHO Specifications and Evaluations for Public Health Pesticides. Chlorpyrifos (March 2009). Available from, as of April 2: 2014: **https://www.who.int/whopes/quality/Chlorpyrifos_WHO_specs_eval_Mar_2009.pdf***

▸ Hazardous Substances Data Bank (HSDB)

3.2.17 Collision Cross Section

201.7 Å² $[M+H]^+$ [CCS Type: TW, Method: calibrated with polyalanine and drug standards]

https://pubs.acs.org/doi/abs/10.1021/acs.analchem.7b01709

▸ CCSbase

163.12 Å² $[M+H]^+$

169.86 Å² $[M+Na]^+$

*S61 | UJICCSLIB | Collision Cross Section (CCS) Library from UJI | **DOI:10.5281/zenodo.3549476***

▸ NORMAN Suspect List Exchange

3.2.18 Kovats Retention Index

Standard non-polar	1947, 1967, 1951.4, 1927, 1997, 1940, 1955, 1982, 1966.1, 1956.9, 1971
Semi-standard non-polar	1971, 1976, 1975, 1970.5, 1956.8, 2007.6

▸ NIST Mass Spectrometry Data Center

3.2.19 Other Experimental Properties

Heat of sublimation 26,800 cal/mol /From table/

Nat'l Research Council Canada; Ecotoxicology of Chlorpyrifos p.210 (1978) NRCC No. 10679

▸ Hazardous Substances Data Bank (HSDB)

Amber solid cake with amber oil /Technical grade/

Verschueren, K. Handbook of Environmental Data on Organic Chemicals. Volumes 1-2. 4th ed. John Wiley & Sons. New York, NY. 2001, p. 567

▸ Hazardous Substances Data Bank (HSDB)

log Kow = 5.0 at 24.5 °C /OECD 117 method/; Vapor pressure: 1.91X10-5 mm Hg at 25 °C /OECD 104 method/; Melting point: 42-44 °C /OECD 102 method/

*World Health Org; WHO Specifications and Evaluations for Public Health Pesticides. Chlorpyrifos (March 2009). Available from, as of April 2: 2014: **https://www.who.int/whopes/quality/Chlorpyrifos_WHO_specs_eval_Mar_2009.pdf***

▸ Hazardous Substances Data Bank (HSDB)

Hydroxyl radical reaction rate constant = 7.6X10-11 cu cm/molec-sec at 60-80 °C

Hebert VR et al; J Agric Food Chem 48: 1922-1928 (2000)

▸ Hazardous Substances Data Bank (HSDB)

3.2.20 Chemical Classes

Pesticides -> Organophosphate Insecticides

- Haz-Map, Information on Hazardous Chemicals and Occupational Diseases

3.3 SpringerMaterials Properties

Fusion temperature
Melting temperature
Phase transition
Transition enthalpy

- SpringerMaterials

4 Spectral Information

4.1 1D NMR Spectra

1D NMR Spectra	NMRShiftDB Link

NMRShiftDB

4.1.1 1H NMR Spectra

Spectra ID	2321
Instrument Type	JEOL
Frequency	400 MHz
Solvent	CDCl3
Shifts [ppm]:Intensity	1.41:483.00, 1.42:475.00, 1.43:1000.00, 1.43:983.00, 1.45:486.00, 1.45:499.00, 4.34:20.00, 4.35:62.00, 4.36:69.00, 4.37:62.00, 4.38:213.00, 4.39:27.00, 4.39:70.00, 4.39:73.00, 4.40:201.00, 4.40:214.00, 4.40:219.00, 4.41:68.00, 4.42:201.00, 4.42:223.00, 4.42:73.00, 4.43:191.00, 4.43:26.00, 4.44:69.00, 4.44:75.00, 4.45:183.00, 4.45:63.00, 4.46:3.00, 4.46:4.00, 4.46:60.00, 4.47:60.00, 4.49:18.00, 7.85:443.00, 7.86:446.00
Thumbnail	

Human Metabolome Database (HMDB)

Instrument Name	Varian CFT-20
Copyright	Copyright © 2009-2021 John Wiley & Sons, Inc. All Rights Reserved.
Thumbnail	

SpectraBase

4.1.2 13C NMR Spectra

Spectra ID	3024
Instrument Type	JEOL
Frequency	100.40 MHz
Solvent	CDCl3
Shifts [ppm]:Intensity	120.23:195.00, 120.31:209.00, 126.59:241.00, 140.93:751.00, 143.77:170.00, 15.80:984.00, 15.88:941.00, 150.57:139.00, 150.62:125.00, 65.82:905.00, 65.87:1000.00
Thumbnail	

Human Metabolome Database (HMDB)

4.2 Mass Spectrometry

4.2.1 GC-MS

Showing 2 of 15 View More

Spectra ID	29695
Instrument Type	EI-B
Ionization Mode	positive
SPLASH	splash10-0002-2793000000-24fe8c73aae05cb109a6
Top 5 Peaks	197.0 99.99 199.0 96.16 314.0 77.14 97.0 75.85 316.0 58.45
Thumbnail	
Notes	instrument=JEOL JMS-DX-303

Human Metabolome Database (HMDB)

Spectra ID	29753
Instrument Type	EI-B
Ionization Mode	positive
SPLASH	splash10-0002-2794000000-df67df73c4dd26908db1
Top 5 Peaks	197.0 99.99 199.0 93.85 314.0 74.47 97.0 68.69 316.0 53.50
Thumbnail	
Notes	instrument=HITACHI M-80

Human Metabolome Database (HMDB)

4.2.2 MS-MS

Showing 2 of 7 View More

Spectra ID	2226813
Ionization Mode	Positive
SPLASH	splash10-00di-0119000000-9c6de680a79a370a9448
Top 5 Peaks	321.9025 100 293.871 18.71 197.9275 12.23 303.8919 3.70

Thumbnail	

Human Metabolome Database (HMDB)

Spectra ID	2227928
Ionization Mode	Positive
SPLASH	splash10-00di-0019000000-8f591ca38c38b7d4aefe
Top 5 Peaks	321.9021 100 293.8709 17.38 197.9275 11.31 303.8917 3.65 272.9821 1.17
Thumbnail	

Human Metabolome Database (HMDB)

4.2.3 LC-MS

Showing 2 of 21 View More

Accession ID	MSBNK-ACES_SU-AS000164
Authors	ACESx, Jonathan W. Martin Group
Instrument	QExactive Orbitrap HF-X (Thermo Scientific)
Instrument Type	LC-ESI-QFT
MS Level	MS2
Ionization Mode	POSITIVE
Ionization	ESI
Collision Energy	Ramp 20%-70% (nominal)
Fragmentation Mode	HCD
Column Name	Waters; Acquity UPLC BEH C18, 2.1 x 100 mm, 1.7 um, Waters
Retention Time	19.4137
Top 5 Peaks	114.9614 999 197.92825 722 96.95015 432 133.95598 216 179.9615 197
SPLASH	splash10-01ot-1900000000-b1422a65647f25e615b2
Thumbnail	

License	CC BY

MassBank Europe

Accession ID	MSBNK-CASMI_2016-SM817703
Authors	Krauss M, Schymanski EL, Weidauer C, Schupke H, UFZ and Eawag
Instrument	Q Exactive Plus Orbitrap Thermo Scientific
Instrument Type	LC-ESI-QFT
MS Level	MS2
Ionization Mode	POSITIVE
Ionization	ESI
Collision Energy	35 (nominal)
Fragmentation Mode	HCD
Column Name	Kinetex C18 EVO 2.6 um, 2.1x50 mm, precolumn 2.1x5 mm, Phenomenex
Retention Time	13.753 min
Precursor m/z	349.9336
Precursor Adduct	[M+H]+
Top 5 Peaks	114.9613 999 197.9274 949 349.9337 363 321.9023 257 171.0239 138
SPLASH	splash10-01ot-0912000000-574ee0c0da4a9208c364
Thumbnail	
License	CC BY
Reference	Schymanski, E. L.; Ruttkies, C.; Krauss, M.; Brouard, C.; Kind, T.; Dührkop, K.; Allen, F.; Vaniya, A.; Verdegem, D.; Böcker, S.; et al. Critical Assessment of Small Molecule Identification 2016: Automated Methods. Journal of Cheminformatics 2017, 9 (1). DOI:10.1186/s13321-017-0207-1

MassBank Europe

4.2.4 Other MS

Showing 2 of 5 View More

Accession ID	MSBNK-ACES_SU-AS000094
Authors	ACESx, Jonathan W. Martin Group
Instrument	QExactive Orbitrap HF-X (Thermo Scientific)
Instrument Type	LC-APCI-QFT
MS Level	MS2
Ionization Mode	POSITIVE
Ionization	APCI
Collision Energy	Ramp 20%-70% (nominal)
Fragmentation Mode	HCD
Column Name	Waters; Acquity UPLC BEH C18, 2.1 x 100 mm, 1.7 um, Waters
Retention Time	19.4019
Precursor m/z	349.9336
Top 5 Peaks	114.9614 999 197.92804 983 321.90234 254 171.02397 241 293.87167 204
SPLASH	splash10-01ot-0901000000-8cd0023dea305192e9f4
Thumbnail	

License	CC BY

MassBank Europe

Accession ID	MSBNK-Fac_Eng_Univ_Tokyo-JP010431
Authors	UOEH
Instrument	JEOL JMS-DX-303
Instrument Type	EI-B
MS Level	MS
Ionization Mode	POSITIVE
Ionization	ENERGY 70 eV
Top 5 Peaks	197 999 199 962 314 771 97 759 316 585
SPLASH	splash10-0002-2793000000-24fe8c73aae05cb109a6
Thumbnail	
License	CC BY-NC-SA

MassBank Europe

4.3 UV Spectra

UV max: 208, 230, and 290 nm

O'Neil, M.J. (ed.). The Merck Index - An Encyclopedia of Chemicals, Drugs, and Biologicals. Cambridge, UK: Royal Society of Chemistry, 2013., p. 390

Hazardous Substances Data Bank (HSDB)

4.4 IR Spectra

4.4.1 FTIR Spectra

Technique	FILM
Source of Sample	The Dow Chemical Company, Agricultural Department
Copyright	Copyright © 1980, 1981-2021 John Wiley & Sons, Inc. All Rights Reserved.
Thumbnail	

SpectraBase

4.4.2 ATR-IR Spectra

Instrument Name	Bio-Rad FTS
Technique	ATR-Neat
Source of Spectrum	Forensic Spectral Research
Source of Sample	Cayman Chemical Company
Catalog Number	21412
Lot Number	0499073-1
Copyright	Copyright © 2019-2021 John Wiley & Sons, Inc. All Rights Reserved.
Thumbnail	

SpectraBase

4.4.3 Vapor Phase IR Spectra

Technique	Vapor Phase
Source of Sample	The Dow Chemical Company
Copyright	Copyright © 1980, 1981-2021 John Wiley & Sons, Inc. All Rights Reserved.
Thumbnail	

SpectraBase

4.5 Raman Spectra

Technique	FT-Raman
Source of Spectrum	Forensic Spectral Research
Source of Sample	Cayman Chemical Company
Catalog Number	21412
Lot Number	0499073-1
Copyright	Copyright © 2015-2021 John Wiley & Sons, Inc. All Rights Reserved.
Thumbnail	

SpectraBase

4.6 Other Spectra

Intense mass spectral peaks: 97 m/z (100%), 197 m/z (97%), 199 m/z (94%), 314 m/z (64%)

Hites, R.A. Handbook of Mass Spectra of Environmental Contaminants. Boca Raton, FL: CRC Press Inc., 1985., p. 315

Hazardous Substances Data Bank (HSDB)

Intense mass spectral peaks: 286 m/z, 349 m/z

Pfleger, K., H. Maurer and A. Weber. Mass Spectral and GC Data of Drugs, Poisons and their Metabolites. Parts I and II. Mass Spectra Indexes. Weinheim, Federal Republic of Germany. 1985., p. 606

Hazardous Substances Data Bank (HSDB)

5 Related Records

5.1 Related Compounds with Annotation

PubChem

5.2 Related Compounds

Same Connectivity	2 Records
Same Parent, Connectivity	12 Records
Same Parent, Exact	11 Records
Mixtures, Components, and Neutralized Forms	80 Records
Similar Compounds	91 Records
Similar Conformers	997 Records

PubChem

5.3 Substances

5.3.1 Related Substances

All	342 Records
Same	211 Records
Mixture	131 Records

PubChem

5.3.2 Substances by Category

PubChem

5.4 Entrez Crosslinks

PubMed	2,588 Records
Taxonomy	55 Records
OMIM	22 Records
Gene	2,929 Records

PubChem

5.5 Associated Chemicals

2,3,6-Trichloropyridinol; 116184-17-9

- Hazardous Substances Data Bank (HSDB)

2,3,5-Trichloro-4-pyridinol; 1970-40-7

- Hazardous Substances Data Bank (HSDB)

2,5,6-Trichloro-2-pyridinol; 6515-38-4

- Hazardous Substances Data Bank (HSDB)

5.6 NCBI LinkOut

- NCBI

6 Chemical Vendors

PubChem

7 Drug and Medication Information

7.1 Reported Fatal Dose

300 mg/kg for an adult human. (T26)

- Toxin and Toxin Target Database (T3DB)

8 Agrochemical Information

8.1 Agrochemical Category

Insecticide

▸ EPA Pesticide Ecotoxicity Database

Pesticide active substances

▸ EU Pesticides Database

Insecticides

S69 | LUXPEST | Pesticide Screening List for Luxembourg | DOI:10.5281/zenodo.3862688

▸ NORMAN Suspect List Exchange

8.2 Agrochemical Transformations

Chlorpyrifos has known environmental transformation products that include 3,5,6-trichloro-2-pyridinol.

S78 | SLUPESTTPS | Pesticides and TPs from SLU, Sweden | DOI:10.5281/zenodo.4687924

▸ NORMAN Suspect List Exchange

Chlorpyrifos has known environmental transformation products that include 3,5,6-trichloro-2-pyridinol.

Chlorpyrifos is a known environmental transformation product of Chlorpyrifos-methyl.

S60 | SWISSPEST19 | Swiss Pesticides and Metabolites from Kiefer et al 2019 | DOI:10.5281/zenodo.3544759

▸ NORMAN Suspect List Exchange

8.3 EU Pesticides Data

Active Substance	chlorpyrifos
Status	Date of Approval: 01/07/2006 Expiration of Approval: 16/01/2020 [Reg. (EC) No 1107/2009]
Legislation	05/72/EC, Reg. (EU) 2018/1796, Reg. (EU) 2020/18, Reg. (EU) 84/2018, Reg. (EU) No 540/2011, Reg. (EU) No 762/2013

▸ EU Pesticides Database

8.4 USDA Pesticide Data Program

Pesticide	Chlorpyrifos
Apple Juice	EPA tolerance level: 0.1 [ppm] (Food/Feed Tolerance unless cov)
Blueberries, Cultivated,	EPA tolerance level: 0.1 [ppm] (Food/Feed Tolerance unless cov)
Bananas	EPA tolerance level: 0.1 [ppm]
Broccoli	EPA tolerance level: 1.0 [ppm]
Blueberries, Frozen	EPA tolerance level: 0.1 [ppm] (Food/Feed Tolerance unless cov)
Cauliflower	EPA tolerance level: 1.0 [ppm]
Cantaloupe	EPA tolerance level: 0.1 [ppm] (Food/Feed Tolerance unless cov)
Carrots	EPA tolerance level: 0.1 [ppm] (Food/Feed Tolerance unless cov)
Eggplant	EPA tolerance level: 0.1 [ppm] (Food/Feed Tolerance unless cov)
Green Beans	EPA tolerance level: 0.1 [ppm] (Food/Feed Tolerance unless cov)
Collard Greens	EPA tolerance level: 1.0 [ppm]
Kiwi Fruit	EPA tolerance level: 2.0 [ppm]
Orange Juice	EPA tolerance level: 1.0 [ppm]
Sweet Bell Peppers	EPA tolerance level: 1.0 [ppm]
Radishes	EPA tolerance level: 2.0 [ppm]
Summer Squash	EPA tolerance level: 0.1 [ppm] (Food/Feed Tolerance unless cov)
Tangerines	EPA tolerance level: 1.0 [ppm]
Tomato Paste	EPA tolerance level: 0.1 [ppm] (Food/Feed Tolerance unless cov)
Winter Squash	EPA tolerance level: 0.1 [ppm] (Food/Feed Tolerance unless cov)

▸ USDA Pesticide Data Program

9 Pharmacology and Biochemistry

9.1 MeSH Pharmacological Classification

Cholinesterase Inhibitors

Drugs that inhibit cholinesterases. The neurotransmitter ACETYLCHOLINE is rapidly hydrolyzed, and thereby inactivated, by cholinesterases. When cholinesterases are inhibited, the action of endogenously released acetylcholine at cholinergic synapses is potentiated. Cholinesterase inhibitors are widely used clinically for their potentiation of cholinergic inputs to the gastrointestinal tract and urinary bladder, the eye, and skeletal muscles; they are also used for their effects on the heart and the central nervous system. (See **all compounds classified as Cholinesterase Inhibitors**.)

▸ Medical Subject Headings (MeSH)

Insecticides

Pesticides designed to control insects that are harmful to man. The insects may be directly harmful, as those acting as disease vectors, or indirectly harmful, as destroyers of crops, food products, or textile fabrics. (See **all compounds classified as Insecticides**.)

▸ Medical Subject Headings (MeSH)

9.2 Absorption, Distribution and Excretion

... Five volunteers ingested 1 mg (2852 nmol) of chlorpyrifos. Blood samples were taken over 24 hours and total void volumes of urine were collected over 100 hours. Four weeks later 28.59 mg (81567 nmol) of chlorpyrifos was administered dermally to each volunteer for 8 hours. Unabsorbed chlorpyrifos was washed from the skin and retained for subsequent measurement. The same blood and urine sampling regime was followed as for the oral administration. Plasma and erythrocyte cholinesterase concentrations were determined for each blood sample. The concentration of two urinary metabolites of chlorpyrifos, **diethylphosphate** and diethyl-thiophosphate was determined for each urine sample. ... Most of the oral dose (mean (range) 93% (55-115%)) and 1% of the applied dermal dose was recovered as urinary metabolites. About half (53%) of the dermal dose was recovered from the skin surface. The absorption rate through the skin, as measured by urinary metabolites was 456 ng/sq cm/hr. ...

PMID:10341740
Full text: ***https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1757654***
Griffin P et al; Occup Environ Med 56(1): 10-3 (1999)

▸ Hazardous Substances Data Bank (HSDB)

Male volunteers received chlorpyrifos as an oral dose of 0.5 mg/kg bw and 1 month later a dermal dose of 5 mg/kg bw. The time to the maximal concentration of TCP in blood was 0.5 hr after oral dosing and 22 hr after dermal treatment. The elimination half-time, irrespective of the route of administration, was 27 hr. The percentage of the administered dose recovered from the urine was 70% after oral dosing and 1.3% after dermal administration.

FAO/WHO; Pesticide Residues in Food, Toxicological Evaluations, Chlorpyrifos (1999). Available from, as of September 17, 2007: ***https://www.inchem.org/documents/jmpr/jmpmono/v99pr03.htm***

▸ Hazardous Substances Data Bank (HSDB)

In persons poisoned with chlorpyrifos formulations, chlorpyrifos was detected in serum samples only and at lower concentration than the diethylphosphorus metabolites, which were excreted mainly in urine.

FAO/WHO; Pesticide Residues in Food, Toxicological Evaluations, Chlorpyrifos (1999). Available from, as of September 17, 2007: ***https://www.inchem.org/documents/jmpr/jmpmono/v99pr03.htm***

▸ Hazardous Substances Data Bank (HSDB)

By 72 hr after a single oral dose of 19 mg/kg bw [(14)C]ring-labelled chlorpyrifos was given by intubation to male Sprague-Dawley rats, 83-87% had been eliminated, mainly in the urine (68-70%), feces (14-15%), and expired air (0.15-0.39%). The residues found at this time represented about 1.7% of the total dose, and the concentration, while highest in fat, was < 1 ppm in any tissue.

FAO/WHO; Pesticide Residues in Food, Toxicological Evaluations, Chlorpyrifos (1999). Available from, as of September 17, 2007: ***https://www.inchem.org/documents/jmpr/jmpmono/v99pr03.htm***

▸ Hazardous Substances Data Bank (HSDB)

For more Absorption, Distribution and Excretion (Complete) data for CHLORPYRIFOS (21 total), please visit the **HSDB record page**.

▸ Hazardous Substances Data Bank (HSDB)

9.3 Metabolism/Metabolites

Metabolism of Dursban in fish was studied in a tank ... After exposure to Dursban, the fish were sacrificed and the fish and some **water** examined by paper chromatography. In addition to **oxygen** analog (ii) of Dursban, the monoethyl analog (iii) of Dursban and its **oxygen** analog (iv), 3,5,6-trichloro-2-pyridyl phosphate (v), and **3,5,6-trichloro-2-pyridinol** (vi) were also found. In the fish tissues themselves, compounds ii, iv, v, vi were found.

Menzie, C.M. Metabolism of Pesticides. U.S. Department of the Interior, Bureau of Sport Fisheries and Wildlife, Publication 127. Washington, DC: U.S. Government Printing Office, 1969., p. 194

▸ Hazardous Substances Data Bank (HSDB)

Two goats were fed [(14)C]ring labeled (positions 2 and 6) chlorpyrifos twice daily in capsules for 10 days at concentrations equivalent to 15-19 ppm in the feed. The majority (80%) of the radiolabel was recovered in urine, with smaller amounts in feces (3.6%), gut (0.9%), tissues (0.8%), and milk (0.1%). The major urinary metabolite (> 75% of the residual radiolabel) was the beta-glucuronide conjugate of TCP, with smaller amounts of unconjugated TCP. The major residue in fat was chlorpyrifos (0.12 ppm), while TCP was the major residue in liver and kidney. A similar pattern of elimination was seen in a study in which lactating goats were fed [(14)C]ring labeled chlorpyrifos twice daily by capsule; little radiolabel (0.05-0.14%), mainly associated with chlorpyrifos, was recovered in milk.

FAO/WHO; Pesticide Residues in Food, Toxicological Evaluations, Chlorpyrifos (1999). Available from, as of September 17, 2007: ***https://www.inchem.org/documents/jmpr/jmpmono/v99pr03.htm***

▸ Hazardous Substances Data Bank (HSDB)

Chlorpyrifos (CPF) is a commonly used diethylphosphorothionate organophosphorus (OP) insecticide. **Diethylphosphate** (DEP), **diethylthiophosphate** (**DETP**) and **3,5,6-trichloro-2-pyridinol** (**TCPy**) are products of metabolism and of environmental degradation of CPF and are routinely measured in urine as biomarkers of exposure. However, because these same chemicals can result from metabolism or by biodegradation, monitoring total urinary metabolite levels may be reflective of not only an individual's contact with the parent pesticide, but also exposure with the metabolites, which are present in the environment. The objective of the current study was to compare the pharmacokinetics of orally administered DEP, **DETP** and **TCPy** with their kinetics following oral dosing with the parent insecticide CPF in the rat. Groups of rats were orally administered CPF, DEP, **TCPy** or **DETP** at doses of 140 umol/kg body weight, and the time-courses of the metabolites were evaluated in blood and urine. Following oral administration, all three metabolites were well absorbed with peak blood concentrations being attained between 1 and 3 hr post-dosing. In the case of DEP and **TCPy** virtually all the administered dose was recovered in the urine by 72 hr post-dosing, suggesting negligible, if any, metabolism; whereas with **DETP**, approximately 50% of the orally administered dose was recovered in the urine. The CPF oral dose was likewise rapidly absorbed and metabolized to DEP, **TCPy** and **DETP**, with the distribution of metabolites in the urine followed the order: **TCPy** (22+/-3 umol)>**DETP** (14+/-2 umol)>DEP (1.4+/-0.7 umol). Based upon the total amount of **TCPy** detected in the urine a minimum of 63% of the oral CPF dose was absorbed. These studies support the hypotheses that DEP, **DETP** and **TCPy** present in the environment can be readily absorbed and eliminated in the urine of rats and potentially humans.

PMID:17590257
Timchalk C et al; Toxicology 237(1-3): 145-57 (2007).

Hazardous Substances Data Bank (HSDB)

Non-invasive biomonitoring approaches are being developed using reliable portable analytical systems to quantify dosimetry utilizing readily obtainable body fluids, such as saliva. In the current study, rats were given single oral gavage doses (1, 10, or 50 mg/kg) of the insecticide chlorpyrifos (CPF). Saliva and blood were then collected from groups of animals (4/time-point) at 3, 6, and 12 hr post-dosing, and were analyzed for the CPF metabolite trichloropyridinol (TCP). Trichloropyridinol was detected in both blood and saliva at all doses and the TCP concentration in blood exceeded saliva, although the kinetics in blood and saliva were comparable. A physiologically based pharmacokinetic and pharmacodynamic (PBPK/PD) model for CPF incorporated a compartment model to describe the time-course of TCP in blood and saliva. The model adequately simulated the experimental results over the dose ranges evaluated. A rapid and sensitive sequential injection (SI) electrochemical immunoassay was developed to monitor TCP, and the reported detection limit for TCP was 6 ng/L (in water). ...
PMID:17118418
Timchalk C et al; Toxicol Appl Pharmacol 219(2-3):217-25 (2007)

Hazardous Substances Data Bank (HSDB)

For more Metabolism/Metabolites (Complete) data for CHLORPYRIFOS (23 total), please visit the HSDB record page.

Hazardous Substances Data Bank (HSDB)

Chlorpyrifos has known human metabolites that include 3,5,6-Trichloro-2-pyridinol, Chlorpyrifos-oxon, and Diethyl phosphorothioate.
S73 | METXBIODB | Metabolite Reaction Database from BioTransformer | DOI:10.5281/zenodo.4056560

NORMAN Suspect List Exchange

Metabolism of organophosphates occurs principally by oxidation, by hydrolysis via esterases and by reaction with glutathione. Demethylation and glucuronidation may also occur. Oxidation of organophosphorus pesticides may result in moderately toxic products. In general, phosphorothioates are not directly toxic but require oxidative metabolism to the proximal toxin. The glutathione transferase reactions produce products that are, in most cases, of low toxicity. Paraoxonase (PON1) is a key enzyme in the metabolism of organophosphates. PON1 can inactivate some organophosphates through hydrolysis. PON1 hydrolyzes the active metabolites in several organophosphates insecticides as well as, nerve agents such as soman, sarin, and VX. The presence of PON1 polymorphisms causes there to be different enzyme levels and catalytic efficiency of this esterase, which in turn suggests that different individuals may be more susceptible to the toxic effect of organophosphate exposure.

Toxin and Toxin Target Database (T3DB)

9.4 Biological Half-Life

A dose of 50 mg/kg bw [(36)Cl] chlorpyrifos given orally to male Wistar rats by intubation ...The concentrations of residue were highest in liver and kidney 4 hr after dosing, but the half-life in these tissues was < 20 hr. The longest half-time, 62 hr, was recorded in fat.
FAO/WHO; Pesticide Residues in Food, Toxicological Evaluations, Chlorpyrifos (1999). Available from, as of September 17, 2007: https://www.inchem.org/documents/jmpr/jmpmono/v99pr03.htm

Hazardous Substances Data Bank (HSDB)

In persons poisoned with chlorpyrifos formulations, chlorpyrifos was detected in serum samples only and at lower concentration than the diethylphosphorus metabolites, which were excreted mainly in urine. The urinary diethylphosphorus metabolites were excreted by first-order kinetics, with an average elimination half-life of 6.1 + or - 2.2 hr in the fastest phase and 80 + or - 26 hr in the slowest.
FAO/WHO; Pesticide Residues in Food, Toxicological Evaluations, Chlorpyrifos (1999). Available from, as of September 17, 2007: https://www.inchem.org/documents/jmpr/jmpmono/v99pr03.htm

Hazardous Substances Data Bank (HSDB)

... Five volunteers ingested 1 mg (2852 nmol) of chlorpyrifos. Blood samples were taken over 24 hours and total void volumes of urine were collected over 100 hours. Four weeks later 28.59 mg (81567 nmol) of chlorpyrifos was administered dermally to each volunteer for 8 hours. ... The apparent elimination half-life of urinary dialkylphosphates after the oral dose was 15.5 hours and after the dermal dose it was 30 hours. ...
PMID:10341740
Full text: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1757654
Griffin P et al; Occup Environ Med 56(1): 10-3 (1999)

Hazardous Substances Data Bank (HSDB)

Urinary ... biological half-life of chlorpyrifos (O, O-diethyl-O-3,5,6-trichloro-2-pyridinyl phosphorothioate) ... /was/ investigated. Male Wistar rats weighing 200 g were intraperitoneally injected with chlorpyrifos at a level of 0.2 mmol/kg body weight. Both chlorpyrifos and 3,5,6-trichloro-2-pyridinol (TCP) levels in blood showed maximum values at 5 hr post-injection, and then decreased rapidly. Biological half-lives of the blood chlorpyrifos and TCP were estimated to 8.15 and 24.66 hr, respectively. ...
PMID:2473231
Sunaga M et al; Nippon Eiseigaku Zasshi 43(6):1124-9 (1989).

Hazardous Substances Data Bank (HSDB)

For more Biological Half-Life (Complete) data for CHLORPYRIFOS (6 total), please visit the HSDB record page.

Hazardous Substances Data Bank (HSDB)

9.5 Mechanism of Action

The toxicity of chlorpyrifos is probably the result of metabolic conversion to its oxygen analog, chlorpyrifos-oxon, and its subsequent inhibition of various enzymes (eg, cholinesterases, carboxylases, acetylcholinesterases, and mitochondrial oxidative phosphorylases).
USEPA; Ambient Water Quality Criteria Doc: Chlorpyrifos p.2 (1986) EPA 440/5-86-005

Hazardous Substances Data Bank (HSDB)

The organophosphorus insecticides have been known for many years to cause cholinergic crisis in humans as a result of the inhibition of the critical enzyme acetylcholinesterase. The interactions of the activated, toxic insecticide metabolites (termed oxons) with acetylcholinesterase have been studied extensively for decades. However, more recent studies have suggested that the interactions of certain anticholinesterase organophosphates with acetylcholinesterase are more complex than previously thought since their inhibitory capacity has been noted to change as a function of inhibitor concentration. In the present report, chlorpyrifos oxon (O,O-diethyl O-(3,5,6-trichloro-2-pyridyl) phosphate) was incubated with human recombinant acetylcholinesterase in the presence of p-nitrophenyl acetate in order to better characterize kinetically the interactions of this oxon with enzyme. Determination of the dissociation constant, K(d), and the phophorylation rate constant, k(2), for chlorpyrifos oxon with a range of oxon and p-nitrophenyl acetate concentrations revealed that K(d), but not k(2), changed as a function of oxon concentration. Changes in p-nitrophenyl acetate concentrations did not alter these same kinetic parameters. The inhibitory capacity of chlorpyrifos oxon, as measured by k(i) (k(2)/K(d)), was also affected as a result of the concentration-dependent alterations in binding affinity. These results suggest that the concentration-dependent interactions of chlorpyrifos oxon with acetylcholinesterase resulted from a different mechanism than the concentration-dependent interactions of acetylthiocholine. In the latter case, substrate bound to the peripheral anionic site

of acetylcholinesterase has been shown to reduce enzyme activity by blocking the release of the product **thiocholine** from the active site gorge. With **chlorpyrifos oxon**, the rate of release of **3,5,6-trichloro-2-pyridinol** is irrelevant since the active site is not available to interact with other oxon molecules after phosphorylation of Ser-203 has occurred.

PMID:17702992
Sultatos LG; Toxicol Sci 100(1): 128-35 (2007).

▸ Hazardous Substances Data Bank (HSDB)

... Mechanisms contributing to the adverse effects of chlorpyrifos (CPF) on DNA synthesis, cell number and size, and cell signaling mediated by adenylyl cyclase (AC) in PC12 cells, a neuronotypic cell line that recapitulates the essential features of developing mammalian neurons /were concluded/ . ... In undifferentiated cells, cholinergic receptor antagonists had little or no protective effect against the antimitotic actions of CPF; however, when nerve growth factor was used to evoke differentiation, the antagonists showed partial protection against deficits in cell loss and alteration in cell size elicited by CPF, but were ineffective in preventing the deterioration of AC signaling. **Nicotine**, which stimulates nicotinic **acetylcholine** receptors but also possesses a mixture of prooxidant/antioxidant activity, had adverse effects by itself but also protected undifferentiated cells from the actions of CPF and had mixed additive/protective effects on cell number in differentiating cells. The antioxidant vitamin E also protected both undifferentiated and differentiating cells from many of the adverse effects of CPF but worsened the impact on AC signaling. **Theophylline**, which prevents the breakdown of **cyclic AMP**, was the only agent that restored AC signaling to normal or supranormal levels but did so at further cost to cell replication. ... /It was concluded that the/ results show definitive contributions of cholinergic hyperstimulation, oxidative stress, and interference with AC signaling in the developmental neurotoxicity of CPF and point to the potential use of this information to design treatments to ameliorate these adverse effects.

PMID:17805420
*Full text: **https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1964921***
Slotkin TA et al; Environ Health Perspect 115(9): 1306-13 (2007).

▸ Hazardous Substances Data Bank (HSDB)

Organophosphorus derivatives act by combining with and inactivating the enzyme acetylcholinesterase (AChE). ... The inactivation of cholinesterase by cholinesterase inhibitor pesticides allows the accumulation of large amounts of **acetylcholine**, with resultant widespread effects that may be ... separated into 4 categories: (1) Potentiation of postganglionic parasympathetic activity. ... (2) Persistent depolarization of skeletal muscle ... (3) Initial stimulation following depression of cells of central nervous system ... (4) Variable ganglionic stimulation or blockade ... /Cholinesterase inhibitor pesticides/

Dreisbach, R.H. Handbook of Poisoning. 12th ed. Norwalk, CT: Appleton and Lange, 1987., p. 113

▸ Hazardous Substances Data Bank (HSDB)

For more Mechanism of Action (Complete) data for CHLORPYRIFOS (6 total), please visit the **HSDB record page**.

▸ Hazardous Substances Data Bank (HSDB)

9.6 Human Metabolite Information

9.6.1 Cellular Locations

Membrane

▸ Human Metabolome Database (HMDB)

9.7 Transformations

▸ NORMAN Suspect List Exchange

10 Use and Manufacturing

10.1 Uses

EPA CPDat Chemical and Product Categories

The Chemical and Products Database, a resource for exposure-relevant data on chemicals in consumer products, Scientific Data, volume 5, Article number: 180125 (2018), DOI:10.1038/sdata.2018.125

EPA Chemical and Products Database (CPDat)

Sources/Uses

Widely used in homes and on farms for cockroaches, fleas, termites, ticks, and crop pests; [ATSDR ToxFAQs]

Haz-Map, Information on Hazardous Chemicals and Occupational Diseases

Industrial Processes with risk of exposure

Farming (Pesticides) [Category: Industry]

Haz-Map, Information on Hazardous Chemicals and Occupational Diseases

For chlorpyrifos (USEPA/OPP Pesticide Code: 059101) ACTIVE products with label matches. /SRP: Registered for use in the U.S. but approved pesticide uses may change periodically and so federal, state and local authorities must be consulted for currently approved uses./

National Pesticide Information Retrieval System's Database on Chlorpyrifos (2921-88-2). Available from, as of June 4, 2014: https://npirspublic.ceris.purdue.edu/ppis/

Hazardous Substances Data Bank (HSDB)

Chlorpyrifos is an organophosphate insecticide, acaricide, and miticide used to control foliage and soil-borne insect pests on a variety of food and feed crops.

USEPA/Office of Pesticide Programs; Chlorpyrifos Facts EPA-738-F-01-006 (February 2002) Available from, as of September 18, 2007: https://www.epa.gov/pesticides/reregistration/status.htm

Hazardous Substances Data Bank (HSDB)

... Broad-spectrum organophosphate insecticide with wide spread use on food commodities, turf, and ornamental plants. ... commonly used indoors to control structural pests. It is one of the most widely used pesticides in the United States and has been one of the top five insecticides used in residential settings ...

Krieger, R. (ed.). Handbook of Pesticide Toxicology. Volume 1, 2nd ed. 2001. Academic Press, San Diego, California., p. 756

Hazardous Substances Data Bank (HSDB)

Insecticide; Used for control of Coleoptera, Diptera, Homoptera and Lepidoptera in soil or on foliage in over 100 crops, including pome fruit, stone fruit, citrus fruit, nut crops, strawberries, figs, bananas, vines, vegetables, potatoes, beet, tobacco, soya beans, sunflowers, sweet potatoes, peanuts, rice, cotton, alfalfa, cereals, maize, sorghum, asparagus, glasshouse and outdoor ornamentals, turf, and in forestry. Also used for control of household pests, mosquitoes (larvae and adults) and in animal houses.

MacBean C, ed; e-Pesticide Manual. 15th ed., ver. 5.1, Alton, UK; British Crop Protection Council. Chlorpyrifos (2921-88-2) (2008-2010)

Hazardous Substances Data Bank (HSDB)

For more Uses (Complete) data for CHLORPYRIFOS (6 total), please visit the HSDB record page.

Hazardous Substances Data Bank (HSDB)

Chlorpyrifos is used as a pesticide. In the home, it is used to control cockroaches, fleas, and termites; it is also used in some pet flea and tick collars. On the farm, it is used to control ticks on cattle and as a spray to control crop pests. (L268)

Toxin and Toxin Target Database (T3DB)

10.1.1 Use Classification

Chemical Classes -> Organophosphates and carbamates

CDC-ATSDR Toxic Substances Portal

Agrochemicals -> Pesticides

EU Pesticides Database

Insecticides

S69 | LUXPEST | Pesticide Screening List for Luxembourg | DOI:10.5281/zenodo.3862688

NORMAN Suspect List Exchange

Environmental transformation -> Pesticides (parent, predecessor)

Environmental transformation -> Pesticide transformation products (metabolite, successor)

S60 | SWISSPEST19 | Swiss Pesticides and Metabolites from Kiefer et al 2019 | DOI:10.5281/zenodo.3544759

NORMAN Suspect List Exchange

INSECTICIDES

USGS Columbia Environmental Research Center

10.1.2 Household Products

Household & Commercial/Institutional Products

Information on 18 consumer products that contain Chlorpyrifos in the following categories is provided:

• Inside the Home

• Pesticides

• Pet Care

Consumer Product Information Database (CPID)

10.2 Methods of Manufacturing

Chlorpyrifos can be prepared by reaction of 3,5,6-trichloro-2-pyridinol with diethyl phosphorochloridothioate in the presence of sodium carbonate.

Muller F et al; Acaricides. Ullmann's Encyclopedia of Industrial Chemistry 7th ed. (1999-2014). NY, NY: John Wiley & Sons; Online Posting Date: July 15, 2009

Hazardous Substances Data Bank (HSDB)

Preparation: R. H. Rigterink, France 1360901; idem United States of America 3244586 (1964, 1966, both to Dow)

O'Neil, M.J. (ed.). The Merck Index - An Encyclopedia of Chemicals, Drugs, and Biologicals. Cambridge, UK: Royal Society of Chemistry, 2013., p. 389

Hazardous Substances Data Bank (HSDB)

10.3 Impurities

/SRP/: diethyl sulfide & diethyl disulfide are volatile contaminants which are partly responsible for the offensive odor of the technical grade.

Hazardous Substances Data Bank (HSDB)

Impurities /found in the technical product (94.0% active ingredient)/ ... included: some residual solvent, methylene chloride; unreacted O,O-diethyl-phosphorochloridothioate, 3,5,6-trichloro-2-pyridinol; the S-ethyl isomer of chlorpyrifos, and other isomeric and related chloropyridyl phosphorothioates and phosphates; compounds related to 3,5,6-trichloro-2-pyridinol; and trace amounts of sulfotep.

Nat'l Research Council Canada; Ecotoxicology of Chlorpyrifos p.35 (1978) NRCC No. 16079

Hazardous Substances Data Bank (HSDB)

O-Ethyl O,O-bis(3,5,6-trichloro-2-pyridyl) phosphorothioate does not occur as a significant impurity in /technical product (94.0% of active ingredient)/.

Nat'l Research Council Canada; Ecotoxicology of Chlorpyrifos p.35 (1978) NRCC No. 16079

Hazardous Substances Data Bank (HSDB)

10.4 Formulations/Preparations

The National Pesticide Information Retrieval System (NPIRS) identifies 32 companies with active labels for products containing the chemical chlorpyrifos. To view the complete list of companies, product names and percent chlorpyrifos in formulated products click the following url and enter the CAS Registry number in the Active Ingredient field.

National Pesticide Information Retrieval System's Database on Chlorpyrifos (2921-88-2). Available from, as of May 29, 2014: https://npirspublic.ceris.purdue.edu/ppis/

Hazardous Substances Data Bank (HSDB)

Chlorpyrifos SPC 2.32% G Insecticide (Nufarm Americas, Inc.): Active ingredient: chlorpyrifos 2.32%.

National Pesticide Information Retrieval System's Database on Chlorpyrifos (2921-88-2). Available from, as of June 3, 2014: https://npirspublic.ceris.purdue.edu/ppis/

Hazardous Substances Data Bank (HSDB)

Nufarm Chlorpyrifos SPC 1.0% MCB Insecticide (Nufarm Americas, Inc.): Active ingredient: chlorpyrifos 1.0%.

National Pesticide Information Retrieval System's Database on Chlorpyrifos (2921-88-2). Available from, as of June 3, 2014: https://npirspublic.ceris.purdue.edu/ppis/

Hazardous Substances Data Bank (HSDB)

Nufarm Chlorpyrifos SPC 4 Insecticide (Nufarm Americas, Inc.): Active ingredient: chlorpyrifos 44.7%.

National Pesticide Information Retrieval System's Database on Chlorpyrifos (2921-88-2). Available from, as of June 3, 2014: https://npirspublic.ceris.purdue.edu/ppis/

Hazardous Substances Data Bank (HSDB)

For more Formulations/Preparations (Complete) data for CHLORPYRIFOS (43 total), please visit the HSDB record page.

Hazardous Substances Data Bank (HSDB)

10.5 Consumption Patterns

Approximately 10 million pounds are applied annually in agricultural settings. The largest agricultural market for chlorpyrifos in terms of total pounds ai is corn (ca 5.5 million).

USEPA/Office of Pesticide Programs; Chlorpyrifos Facts EPA738-F-01-006 (February 2002) Available from, as of September 18, 2007: https://www.epa.gov/pesticides/reregistration/status.htm

Hazardous Substances Data Bank (HSDB)

Chlorpyrifos use as a termiticide is significant, with a recent estimate of seven million pounds ai applied annually, constituting about 30% of the total annual use.

USEPA/Office of Pesticide Programs; Interim Reregistration Eligibility Decision Document - Chlorpyrifos p.18. Case No. 0100 (September 2001) Available from, as of August 24, 2007: https://www.epa.gov/pesticides/reregistration/status.htm

Hazardous Substances Data Bank (HSDB)

INSECTICIDE USED ON CORN, 39%; ALFALFA, 6%; COTTON, 3%; SORGHUM, 1%; OTHER FIELD CROPS-EG, CITRUS & DECIDUOUS FRUITS/NUTS, 21%; NON-AGRICULTURAL USES, 31% (1982)

SRI

Hazardous Substances Data Bank (HSDB)

(1978) 4.00X10+9 G (CONSUMPTION)

SRI

Hazardous Substances Data Bank (HSDB)

(1982) 3.27X10+9 G (CONSUMPTION)

SRI

Hazardous Substances Data Bank (HSDB)

10.6 General Manufacturing Information

The WHO Recommended Classification of Pesticides by Hazard identifies chlorpyrifos (technical grade) as Class II: moderately hazardous; Main Use: insecticide.

WHO International Programme on Chemical Safety; The WHO Recommended Classification of Pesticides by Hazard and Guidelines to Classification 2009 p.25 (2010)

Hazardous Substances Data Bank (HSDB)

Types and methods of application: Ground and aerial, spray and dust applications.

Purdue University; National Pesticide Information Retrieval System (1987)

Hazardous Substances Data Bank (HSDB)

Application rates: Range from 0.5 lb active ingredient (ai)/acre to 3 lb active ingredient (ai)/acre, and crack and crevice treatment to broadcast treatment for indoor uses.

Purdue University; National Pesticide Information Retrieval System (1987)

Hazardous Substances Data Bank (HSDB)

/Dursban is a/ trademark for insecticides containing O,O-diethyl-O-3,5,6-trichloro-2-pyridyl phosphorothioate.

Lewis, R.J. Sr.; Hawley's Condensed Chemical Dictionary 15th Edition. John Wiley & Sons, Inc. New York, NY 2007., p. 485

Hazardous Substances Data Bank (HSDB)

For more General Manufacturing Information (Complete) data for CHLORPYRIFOS (7 total), please visit the **HSDB record page**.

Hazardous Substances Data Bank (HSDB)

11 Identification

11.1 Analytic Laboratory Methods

AOAC Method 981.03. Chlorpyrifos in Pesticide Formulations. Liquid Chromatographic Method.

Association of Official Analytical Chemists. Official Methods of Analysis. 15th ed. and Supplements. Washington, DC: Association of Analytical Chemists, 1990, p. 199

Hazardous Substances Data Bank (HSDB)

AOAC Method 985.22. Organochlorine and Organophosphorus Pesticide Residues. Gas Chromatographic Method.

Association of Official Analytical Chemists. Official Methods of Analysis. 15th ed. and Supplements. Washington, DC: Association of Analytical Chemists, 1990, p. 282-3

Hazardous Substances Data Bank (HSDB)

Method: OSHA 62; Procedure: gas chromatography using a flame photometric detector; Analyte: chlorpyrifos; Matrix: air; Detection Limit: 0.0033 mg/cu m (0.23 ppb).

U.S. Department of Labor/Occupational Safety and Health Administration's Index of Sampling and Analytical Methods. Chlorpyrifos (2921-88-2). Available from, as of June 4, 2014: https://www.osha.gov/dts/sltc/methods/toc.html

Hazardous Substances Data Bank (HSDB)

Method: NIOSH 5600, Issue 1; Procedure: gas chromatography with flame photometric detector; Analyte: chlorpyrifos; Matrix: air; Detection Limit: 0.04 ug/sample.

CDC; NIOSH Manual of Analytical Methods, 4th ed. Chlorpyrifos (2921-88-2). Available from, as of June 4, 2014: https://www.cdc.gov/niosh/docs/2003-154/

Hazardous Substances Data Bank (HSDB)

For more Analytic Laboratory Methods (Complete) data for CHLORPYRIFOS (21 total), please visit the HSDB record page.

Hazardous Substances Data Bank (HSDB)

11.2 Clinical Laboratory Methods

LC-MS/MS determination in human cord blood.

O'Neil, M.J. (ed.). The Merck Index - An Encyclopedia of Chemicals, Drugs, and Biologicals. Cambridge, UK: Royal Society of Chemistry, 2013., p. 390

Hazardous Substances Data Bank (HSDB)

High-performance liq chromatography with 3 different mobile phases was used to determine chlorpyrifos & its oxygen analog in biological tissues (plasma, brain homogenates, & liver microsomes).

SULTATOS LG ET AL; CHROMATOGRAPHIA 15 (10): 669-71 (1982)

Hazardous Substances Data Bank (HSDB)

11.3 NIOSH Analytical Methods

ORGANOPHOSPHORUS PESTICIDES 5600

NIOSH Manual of Analytical Methods

12 Safety and Hazards

12.1 Hazards Identification

12.1.1 GHS Classification

Showing 1 of 5 View More

Pictogram(s)	 Acute Toxic, Environmental Hazard
Signal	Danger
GHS Hazard Statements	H301: Toxic if swallowed [Danger Acute toxicity, oral] H400: Very toxic to aquatic life [Warning Hazardous to the aquatic environment, acute hazard] H410: Very toxic to aquatic life with long lasting effects [Warning Hazardous to the aquatic environment, long-term hazard]
Precautionary Statement Codes	P264, P270, P273, P301+P316, P321, P330, P391, P405, and P501 (The corresponding statement to each P-code can be found at the GHS Classification page.)

EU REGULATION (EC) No 1272/2008

12.1.2 Hazard Classes and Categories

Showing 2 of 4 View More

Acute Tox. 3 *

Aquatic Acute 1

Aquatic Chronic 1

EU REGULATION (EC) No 1272/2008

Acute Tox. 3 (100%)

Acute Tox. 1 (10.8%)

Aquatic Acute 1 (100%)

Aquatic Chronic 1 (100%)

European Chemicals Agency (ECHA)

12.1.3 Health Hazards

Symptoms of organophosphate insecticide poisoning: cholinesterase inhibition, headache, fatiguedizziness, blurred vision, weakness, nausea, cramps, diarrhea, chest discomfort, sweating, miosis, tearing, salivation, vomiting, cyanosis, papilledema, and muscle twitching. In advanced cases convulsions, coma, loss of reflexes, and loss of sphincter control may occur. EYES: Can produce mild to moderate eye irritation and transient corneal injury. SKIN: Undiluted liquid products can cause skin irritation. Prolonged or repeated exposure may cause superficial burns. (USCG, 1999)

U.S. Coast Guard. 1999. Chemical Hazard Response Information System (CHRIS) - Hazardous Chemical Data. Commandant Instruction 16465.12C. Washington, D.C.: U.S. Government Printing Office.

CAMEO Chemicals

12.1.4 Fire Hazards

Excerpt from ERG Guide 152 [Substances - Toxic (Combustible)]: Combustible material: may burn but does not ignite readily. Containers may explode when heated. Runoff may pollute waterways. Substance may be transported in a molten form. (ERG, 2020)

CAMEO Chemicals

Combustible. Gives off irritating or toxic fumes (or gases) in a fire. Liquid formulations containing organic solvents may be flammable. Risk of fire and explosion if formulations contain flammable/explosive solvents.

ILO International Chemical Safety Cards (ICSC)

12.1.5 Hazards Summary

Chlorpyrifos is an insecticide that is a white crystal-like solid with a strong odor. It does not mix well with water, so it is usually mixed with oily liquids before it is applied to crops or animals. It may also be applied to crops in a capsule form. Chlorpyrifos has been widely used in homes and on farms. In the home, it is used to control cockroaches, fleas, and termites; it is also used in some pet flea and tick collars. On the farm, it is used to control ticks on cattle and as a spray to control crop pests.

CDC-ATSDR Toxic Substances Portal

The EPA reentry interval is 24 hours for emulsifiable concentrate or wettable powder if workers are not wearing protective clothing. Chlorpyrifos is classified as moderately toxic. [EXTOXNET] A small number of the organophosphates (OPs) can Induce Delayed Neuropathy (OPIDN). OPIDN usually occurs after ingestion and is usually nonoccupational. [Levy, p. 431] The average of two baseline respective cholinesterase activity determinations three days apart, with no exposures to enzyme inhibiting pesticides for at least 30 days, is recommended for each worker prior to exposure to cholinesterase inhibitors because of large inter-individual differences in published baseline values. To be established at least once a year. Removal from workplace exposures is recommended until the cholinesterase activity returns to within 20% of baseline. [TLVs and BEIs]

Levy - Levy BS, Wegman DH, Baron SL, Sokas RK (eds). _Occupational and Environmental Health: Recognizing and Preventing Disease and Injury, _6th Ed. Oxford: Oxford University Press, 2011., p. 431
TLVs and BEIs - _Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices. _Cincinnati: ACGIH, 2020.

Haz-Map, Information on Hazardous Chemicals and Occupational Diseases

12.1.6 Skin, Eye, and Respiratory Irritations

/Mild/ dermal irritation, rabbit; ... resolved within 7 days

USEPA/Office of Pesticide Programs; Interim Reregistration Eligibility Decision Document - Chlorpyrifos p.24. Case No. 0100 (September 2001) Available from, as of August 24, 2007: https://www.epa.gov/pesticides/reregistration/status.htm

Hazardous Substances Data Bank (HSDB)

Slight irritation /to rabbit eyes/ resolved within 24 hrs.

USEPA/Office of Pesticide Programs; Interim Reregistration Eligibility Decision Document - Chlorpyrifos p.24. Case No. 0100 (September 2001) Available from, as of August 24, 2007: https://www.epa.gov/pesticides/reregistration/status.htm

Hazardous Substances Data Bank (HSDB)

12.2 Safety and Hazard Properties

12.2.1 Flammable Limits

Flammability

Combustible Solid

The National Institute for Occupational Safety and Health (NIOSH)

12.2.2 NIOSH Recommendations

Recommended Exposure Limit: 10 Hr Time-Weighted Avg: 0.2 mg/cu m. Skin.

NIOSH. NIOSH Pocket Guide to Chemical Hazards. Department of Health & Human Services, Centers for Disease Control & Prevention. National Institute for Occupational Safety & Health. DHHS (NIOSH) Publication No. 2010-168 (2010). Available from: https://www.cdc.gov/niosh/npg

Hazardous Substances Data Bank (HSDB)

Recommended Exposure Limit: 15 Min Short-Term Exposure Limit: 0.6 mg/cu m. Skin.

NIOSH. NIOSH Pocket Guide to Chemical Hazards. Department of Health & Human Services, Centers for Disease Control & Prevention. National Institute for Occupational Safety & Health. DHHS (NIOSH) Publication No. 2010-168 (2010). Available from: https://www.cdc.gov/niosh/npg

Hazardous Substances Data Bank (HSDB)

12.3 First Aid Measures

12.3.1 First Aid

EYES: First check the victim for contact lenses and remove if present. Flush victim's eyes with water or normal saline solution for 20 to 30 minutes while simultaneously calling a hospital or poison control center. Do not put any ointments, oils, or medication in the victim's eyes without specific instructions from a physician. IMMEDIATELY transport the victim after flushing eyes to a hospital even if no symptoms (such as redness or irritation) develop. SKIN: IMMEDIATELY flood affected skin with water while removing and isolating all contaminated clothing. Gently wash all affected skin areas thoroughly with soap and water. If symptoms such as redness or irritation develop, IMMEDIATELY call a physician and be prepared to transport the victim to a hospital for treatment. INHALATION: IMMEDIATELY leave the contaminated area; take deep breaths of fresh air. If symptoms (such as wheezing, coughing, shortness of breath, or burning in the mouth, throat, or chest) develop, call a physician and be prepared to transport the victim to a hospital. Provide proper respiratory protection to rescuers entering an unknown atmosphere. Whenever possible, Self-Contained Breathing Apparatus (SCBA) should be used; if not available, use a level of protection greater than or equal to that advised under Protective Clothing. INGESTION: If the victim is conscious and not convulsing, give 1 or 2 glasses of water to dilute the chemical and IMMEDIATELY call a hospital or poison control center. Be prepared to transport the victim to a hospital if advised by a physician. If the victim is convulsing or unconscious, do not give anything by mouth, ensure that the victim's airway is open and lay the victim on his/her side with the head lower than the body. DO NOT INDUCE VOMITING. IMMEDIATELY transport the victim to a hospital. (NTP, 1992)

National Toxicology Program, Institute of Environmental Health Sciences, National Institutes of Health (NTP). 1992. National Toxicology Program Chemical Repository Database. Research Triangle Park, North Carolina.

CAMEO Chemicals

(See procedures)

Eye: Irrigate immediately - If this chemical contacts the eyes, immediately wash (irrigate) the eyes with large amounts of water, occasionally lifting the lower and upper lids. Get medical attention immediately.

Skin: Soap wash immediately - If this chemical contacts the skin, immediately wash the contaminated skin with soap and water. If this chemical penetrates the clothing, immediately remove the clothing, wash the skin with soap and water, and get medical attention promptly.

Breathing: Respiratory support

Swallow: Medical attention immediately - If this chemical has been swallowed, get medical attention immediately.

The National Institute for Occupational Safety and Health (NIOSH)

12.3.2 Inhalation First Aid

Fresh air, rest. Refer immediately for medical attention.

ILO International Chemical Safety Cards (ICSC)

12.3.3 Skin First Aid

Remove contaminated clothes. Rinse and then wash skin with water and soap. Refer immediately for medical attention.

ILO International Chemical Safety Cards (ICSC)

12.3.4 Eye First Aid

Rinse with plenty of water (remove contact lenses if easily possible). Refer for medical attention.

ILO International Chemical Safety Cards (ICSC)

12.3.5 Ingestion First Aid

Rinse mouth. Do NOT induce vomiting. Refer immediately for medical attention.

▸ ILO International Chemical Safety Cards (ICSC)

12.4 Fire Fighting

Excerpt from ERG Guide 152 [Substances - Toxic (Combustible)]: SMALL FIRE: Dry chemical, CO2 or water spray. LARGE FIRE: Water spray, fog or regular foam. If it can be done safely, move undamaged containers away from the area around the fire. Dike runoff from fire control for later disposal. Avoid aiming straight or solid streams directly onto the product. FIRE INVOLVING TANKS OR CAR/TRAILER LOADS: Fight fire from maximum distance or use unmanned master stream devices or monitor nozzles. Do not get water inside containers. Cool containers with flooding quantities of water until well after fire is out. Withdraw immediately in case of rising sound from venting safety devices or discoloration of tank. ALWAYS stay away from tanks engulfed in fire. For massive fire, use unmanned master stream devices or monitor nozzles; if this is impossible, withdraw from area and let fire burn. (ERG, 2020)

▸ CAMEO Chemicals

Use water spray, foam, powder, carbon dioxide. In case of fire: keep drums, etc., cool by spraying with water.

▸ ILO International Chemical Safety Cards (ICSC)

12.4.1 Fire Fighting Procedures

If material is on fire or involved in a fire: Extinguish fire using agent suitable for type of surrounding fire. (Material itself does not burn, or burns with difficulty.) Keep runoff water out of sewers and water sources. /Other regulated substances, solid, NOS/

Association of American Railroads; Bureau of Explosives. Emergency Handling of Hazardous Materials in Surface Transportation. Association of American Railroads, Pueblo, CO. 2005, p. 223

▸ Hazardous Substances Data Bank (HSDB)

If material on fire or involved in fire: Use water in flooding quantities as fog. Extinguish fire using agent suitable for type of surrounding fire (Material itself does not burn or burns with difficulty.). Use foam, dry chemical, or carbon dioxide. /Organophosphorus pesticides, liquid, NOS/

Association of American Railroads; Bureau of Explosives. Emergency Handling of Hazardous Materials in Surface Transportation. Association of American Railroads, Pueblo, CO. 2005, p. 223

▸ Hazardous Substances Data Bank (HSDB)

If material on fire or involved in fire: Use water in flooding quantities as fog. Extinguish fire using agent suitable for type of surrounding fire (Material itself does not burn or burns with difficulty.). Use foam, dry chemical, or carbon dioxide. /Organophosphorus pesticides, solid, NOS/

Association of American Railroads; Bureau of Explosives. Emergency Handling of Hazardous Materials in Surface Transportation. Association of American Railroads, Pueblo, CO. 2005, p. 223

▸ Hazardous Substances Data Bank (HSDB)

Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

*Sigma-Aldrich Corp; Safety Data Sheet for Chlorpyrrifos (Product Number: 45395) Version 5.3 (June 27, 2014). Available from, as of June 18, 2014: **https://www.sigmaaldrich.com/safety-center.html***

▸ Hazardous Substances Data Bank (HSDB)

12.5 Accidental Release Measures

12.5.1 Isolation and Evacuation

Excerpt from ERG Guide 152 [Substances - Toxic (Combustible)]: IMMEDIATE PRECAUTIONARY MEASURE: Isolate spill or leak area in all directions for at least 50 meters (150 feet) for liquids and at least 25 meters (75 feet) for solids. SPILL: Increase the immediate precautionary measure distance, in the downwind direction, as necessary. FIRE: If tank, rail car or tank truck is involved in a fire, ISOLATE for 800 meters (1/2 mile) in all directions; also, consider initial evacuation for 800 meters (1/2 mile) in all directions. (ERG, 2020)

▸ CAMEO Chemicals

12.5.2 Spillage Disposal

Evacuate danger area! Consult an expert! Personal protection: chemical protection suit including self-contained breathing apparatus. Do NOT let this chemical enter the environment. Do NOT wash away into sewer. Sweep spilled substance into covered containers. If appropriate, moisten first to prevent dusting. Carefully collect remainder. Then store and dispose of according to local regulations.

▸ ILO International Chemical Safety Cards (ICSC)

12.5.3 Cleanup Methods

Environmental considerations: land spill: Dig a pit, pond, lagoon, or holding area to contain liquid or solid material. /SRP: If time permits, pits, ponds, lagoons, soak holes, or holding areas should be sealed with an impermeable flexible membrane liner./ Cover solids with a plastic sheet to prevent dissolving in rain or fire fighting water. Dike surface flow using soil, sand bags, foamed polyurethane, or foamed concrete. /Organophosphorus pesticides, solid, NOS/

Association of American Railroads; Bureau of Explosives. Emergency Handling of Hazardous Materials in Surface Transportation. Association of American Railroads, Pueblo, CO. 2005, p. 223

▸ Hazardous Substances Data Bank (HSDB)

Environmental considerations: land spill: Dig a pit, pond, lagoon, or holding area to contain liquid or solid material. /SRP: If time permits, pits, ponds, lagoons, soak holes, or holding areas should be sealed with an impermeable flexible membrane liner./. Dike surface flow using soil, sand bags, foamed polyurethane, or foamed concrete. /Organophosphorus pesticides, liquid, NOS/

Association of American Railroads; Bureau of Explosives. Emergency Handling of Hazardous Materials in Surface Transportation. Association of American Railroads, Pueblo, CO. 2005, p. 223

▸ Hazardous Substances Data Bank (HSDB)

Environmental considerations: water spill: Use natural deep water pockets, excavated lagoons, or sand bag barriers to trap material at bottom. Remove trapped material with suction hoses. Use mechanical dredges or lifts to remove immobilized masses of pollutants and precipitates. /Other regulated substances, solid, NOS/

Association of American Railroads; Bureau of Explosives. Emergency Handling of Hazardous Materials in Surface Transportation. Association of American Railroads, Pueblo, CO. 2005, p. 223

▸ Hazardous Substances Data Bank (HSDB)

Environmental considerations: water spill: Use natural barriers or oil spill control booms to limit spill travel. Use natural deep water pockets, excavated lagoons, or sand bag barriers to trap material at bottom. Remove trapped material with suction hoses. /Organophosphorus pesticides, liquid and solid, NOS/

Association of American Railroads; Bureau of Explosives. Emergency Handling of Hazardous Materials in Surface Transportation. Association of American Railroads, Pueblo, CO. 2005, p. 223

Hazardous Substances Data Bank (HSDB)

For more Cleanup Methods (Complete) data for CHLORPYRIFOS (6 total), please visit the HSDB record page.

Hazardous Substances Data Bank (HSDB)

12.5.4 Disposal Methods

SRP: The most favorable course of action is to use an alternative chemical product with less inherent propensity for occupational harm/injury/toxicity or environmental contamination. Recycle any unused portion of the material for its approved use or return it to the manufacturer or supplier. Ultimate disposal of the chemical must consider: the material's impact on air quality; potential migration in soil or water; effects on animal and plant life; and conformance with environmental and public health regulations.

Hazardous Substances Data Bank (HSDB)

SRP: Wastewater from contaminant suppression, cleaning of protective clothing/equipment, or contaminated sites should be contained and evaluated for subject chemical or decomposition product concentrations. Concentrations shall be lower than applicable environmental discharge or disposal criteria. Alternatively, pretreatment and/or discharge to a permitted wastewater treatment facility is acceptable only after review by the governing authority and assurance that "pass through" violations will not occur. Due consideration shall be given to remediation worker exposure (inhalation, dermal and ingestion) as well as fate during treatment, transfer and disposal. If it is not practicable to manage the chemical in this fashion, it must be evaluated in accordance with EPA 40 CFR Part 261, specifically Subpart B, in order to determine the appropriate local, state and federal requirements for disposal.

Hazardous Substances Data Bank (HSDB)

This pesticide is toxic to birds and /other/ wildlife, and extremely toxic to fish and aquatic organisms. Do not discharge effluent containing this product into lakes, streams, ponds, estuaries, oceans, or other waters unless in accordance with the requirements of a National Pollutant Discharge Elimination System (NPDES) permit and the permitting authority has been notified in writing prior to discharge. Do not discharge effluent containing this product to sewer systems without previously notifying the local sewage treatment plant authority. For guidance, contact your State Water Board or Regional Office of the EPA. /Dursban W/

*USEPA; Pesticide Product Label System. Product Label for Dursban W dated September 8, 2000. Available from, as of November 19, 2007: **https://oaspub.epa.gov/pestlabl/ppls.home***

Hazardous Substances Data Bank (HSDB)

Pesticide Disposal: Wastes resulting from the use of this product may be disposed of on site or at an approved waste disposal facility. Container Disposal: Completely empty liner by shaking or tapping sides and bottom to loosen clinging particles. Empty residues into manufacturing equipment. Then dispose of liner in a sanitary landfill or by incineration, or, if allowed by state and local authorities, by burning. If container is contaminated and cannot be reused, dispose of in the same manner. /Dursban W/

*USEPA; Pesticide Product Label System. Product Label for Dursban W dated September 8, 2000. Available from, as of November 19, 2007: **https://oaspub.epa.gov/pestlabl/ppls.home***

Hazardous Substances Data Bank (HSDB)

For more Disposal Methods (Complete) data for CHLORPYRIFOS (6 total), please visit the HSDB record page.

Hazardous Substances Data Bank (HSDB)

12.5.5 Preventive Measures

Do not get in eyes or on clothing. Avoid contact with skin. Avoid breathing dust and spray mist. Wear protective clothing (long-sleeved shirt and long pants, waterproof gloves, and shoes plus socks). Wear protective eyewear and a respiratory protection device (MSHA/INIOSH approved number TC-21C) when mixing and loading or working in a non-ventilated space. Wash thoroughly with soap and water after handling and before eating, drinking, or using tobacco. Remove contamInated clothing and wash before reuse. Keep away from food, feedstuffs and water supplies. /Dursban W/

*USEPA; Pesticide Product Label System. Product Label for Dursban W dated September 8, 2000. Available from, as of November 19, 2007: **https://oaspub.epa.gov/pestlabl/ppls.home***

Hazardous Substances Data Bank (HSDB)

Avoid contact with skin, eyes, and clothing. Wash contaminated clothing before re-use. Avoid breathing dust, spray, or mist. Do not contaminate food or feed. /Data from table/

Nat'l Research Council Canada; Ecotoxicology of Chlorpyrifos p.204 (1978) NRCC No. 10679

Hazardous Substances Data Bank (HSDB)

If material is not on fire and not involved in fire: Keep material out of water sources and sewers.

Association of American Railroads; Bureau of Explosives. Emergency Handling of Hazardous Materials in Surface Transportation. Association of American Railroads, Pueblo, CO. 2005, p. 223

Hazardous Substances Data Bank (HSDB)

The worker should immediately wash the skin when it becomes contaminated.

*NIOSH. NIOSH Pocket Guide to Chemical Hazards. Department of Health & Human Services, Centers for Disease Control & Prevention. National Institute for Occupational Safety & Health. DHHS (NIOSH) Publication No. 2010-168 (2010). Available from: **https://www.cdc.gov/niosh/npg***

Hazardous Substances Data Bank (HSDB)

For more Preventive Measures (Complete) data for CHLORPYRIFOS (11 total), please visit the HSDB record page.

Hazardous Substances Data Bank (HSDB)

12.6 Handling and Storage

12.6.1 Nonfire Spill Response

Excerpt from ERG Guide 152 [Substances - Toxic (Combustible)]: ELIMINATE all ignition sources (no smoking, flares, sparks or flames) from immediate area. Do not touch damaged containers or spilled material unless wearing appropriate protective clothing. Stop leak if you can do it without risk. Prevent entry into waterways, sewers, basements or confined areas. Cover with plastic sheet to prevent spreading. Absorb or cover with dry earth, sand or other non-combustible material and transfer to containers. DO NOT GET WATER INSIDE CONTAINERS. (ERG, 2020)

CAMEO Chemicals

12.6.2 Safe Storage

Store only in original container. Keep in a well-ventilated room. Separated from food and feedstuffs. Provision to contain effluent from fire extinguishing. Store in an area without drain or sewer access.

ILO International Chemical Safety Cards (ICSC)

12.6.3 Storage Conditions

Do not contaminate water, food or feed by storage or disposal. Open dumping is prohibited. ... Store in original container in secured dry storage area. Prevent cross-contamination with other pesticides and fertilizers. Do not store above 1002F for extended periods of time. If container is damaged or spills occurs, use product immediately or dispose of product ... . /Dursban W/

USEPA; Pesticide Product Label System. Product Label for Dursban W dated September 8, 2000. Available from, as of November 19, 2007: https://oaspub.epa.gov/pestlabl/ppls.home

Hazardous Substances Data Bank (HSDB)

... Chlorpyrifos must be stored to avoid contact with strong bases, or acids, or acid fumes since violent reaction can occur. Store in tightly closed containers in a cool, well ventilated area away from sources of heat.

Sittig, M. Handbook of Toxic and Hazardous Chemicals and Carcinogens, 2002. 4th ed.Vol 1 A-H Norwich, NY: Noyes Publications, 2002., p. 604

Hazardous Substances Data Bank (HSDB)

Keep locked up. Keep away from food, drink and animal feeding stuffs.

Commission of the European Communities. Legislation on Dangerous Substances - Classification and Labelling in the European Communities. Vol. II. London and Trotman Ltd., 1989., p. I-121

Hazardous Substances Data Bank (HSDB)

Keep container tightly closed in a dry and well-ventilated place. Recommended storage temperature: 2 - 8 °C

Sigma-Aldrich Corp; Safety Data Sheet for Chlorpyrrifos (Product Number: 45395) Version 5.3 (June 27, 2014). Available from, as of June 18, 2014: https://www.sigmaaldrich.com/safety-center.html

Hazardous Substances Data Bank (HSDB)

12.7 Exposure Control and Personal Protection

Exposure Summary

Biological Exposure Indices (BEI) [ACGIH] - Acetylcholinesterase activity in red blood cells = 70% of individual's baseline; Butylcholinesterase activity in serum or plasma = 60% of individual's baseline; Sample at end of shift; [TLVs and BEIs]

ACGIH - Documentation of the TLVs and BEIs, 7th Ed. Cincinnati: ACGIH Worldwide, 2020.
TLVs and BEIs - _Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices. _Cincinnati: ACGIH, 2020.

Haz-Map, Information on Hazardous Chemicals and Occupational Diseases

12.7.1 Recommended Exposure Limit (REL)

REL-TWA (Time Weighted Average)

0.2 mg/m^3

Occupational Safety and Health Administration (OSHA)

TWA 0.2 mg/m^3 ST 0.6 mg/m^3 [skin]

The National Institute for Occupational Safety and Health (NIOSH)

12.7.2 Permissible Exposure Limit (PEL)

none See Appendix G

The National Institute for Occupational Safety and Health (NIOSH)

12.7.3 Immediately Dangerous to Life or Health (IDLH)

N.D.

See: IDLH INDEX

The National Institute for Occupational Safety and Health (NIOSH)

12.7.4 Threshold Limit Values (TLV)

0.1 [mg/m3], inhalable fraction and vapor

Haz-Map, Information on Hazardous Chemicals and Occupational Diseases

8 hr Time Weighted Avg (TWA): 0.1 mg/cu m (inhalable fraction and vapor), skin.

American Conference of Governmental Industrial Hygienists. Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices. ACGIH, Cincinnati, OH 2014, p. 20

Hazardous Substances Data Bank (HSDB)

Excursion Limit Recommendation: Excursions in worker exposure levels may exceed 3 times the TLV-TWA for no more than a total of 30 minutes during a work day, and under no circumstances should they exceed 5 times the TLV-TWA, provided that the TLV-TWA is not exceeded.

American Conference of Governmental Industrial Hygienists. Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices. ACGIH, Cincinnati, OH 2014, p. 5

Hazardous Substances Data Bank (HSDB)

A4; Not classifiable as a human carcinogen.

American Conference of Governmental Industrial Hygienists. Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices. ACGIH, Cincinnati, OH 2014, p. 20

Hazardous Substances Data Bank (HSDB)

Biological Exposure Index (BEI): Determinant: cholinesterase activity in red blood cells; Sampling Time: discretionary; BEI: 70% of individual's baseline. The determinant is nonspecific, since it is also observed after exposure to other chemicals. /Acetylcholinesterase inhibiting pesticides/

American Conference of Governmental Industrial Hygienists. Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices. ACGIH, Cincinnati, OH 2014, p. 112

- Hazardous Substances Data Bank (HSDB)

0.1 mg/m3, as TWA; (skin); A4 (not classifiable as a human carcinogen); BEI issued

- ILO International Chemical Safety Cards (ICSC)

TLV-TWA (Time Weighted Average)

0.1 mg/m^3 (inhalable fraction and vapor) [2000]

- Occupational Safety and Health Administration (OSHA)

12.7.5 Other Standards Regulations and Guidelines

Australia: 0.2 mg/cu m, 0.6 mg/cu m STEL (deletion proposed), skin (1990); United Kingdom: 0.2 mg/cu m, 10-min STEL 0.6 mg/cu m (1991).

American Conference of Governmental Industrial Hygienists, Inc. Documentation of the Threshold Limit Values and Biological Exposure Indices. 6th ed. Volumes I, II, III. Cincinnati, OH: ACGIH, 1991., p. 311

- Hazardous Substances Data Bank (HSDB)

12.7.6 Inhalation Risk

A harmful concentration of airborne particles can be reached quickly on spraying or when dispersed, especially if powdered.

- ILO International Chemical Safety Cards (ICSC)

12.7.7 Effects of Short Term Exposure

The substance may cause effects on the nervous system by a cholinesterase inhibiting effect. Exposure far above the OEL could cause death. The effects may be delayed. Medical observation is indicated.

- ILO International Chemical Safety Cards (ICSC)

12.7.8 Effects of Long Term Exposure

Cholinesterase inhibition. Cumulative effects are possible. See Acute Hazards/Symptoms.

- ILO International Chemical Safety Cards (ICSC)

12.7.9 Allowable Tolerances

Tolerances are established for residues of the pesticide chlorpyrifos per se (O,O-diethyl-O-(3,5,6-trichloro-2-pyridyl) phosphorothioate) in or on the following food commodities:

Commodity	Parts per million
Alfalfa, forage	3.0
Alfalfa, hay	13
Almond	0.2
Almond, hulls	12
Apple	0.01
Apple, wet pomace	0.02
Banana	0.1
Beet, sugar, dried pulp	5.0
Beet, sugar, molasses	15
Beet, sugar, roots	1.0
Beet, sugar, tops	8.0
Cattle, fat	0.3
Cattle, meat	0.05
Cattle, meat byproducts	0.05
Cherry, sweet	1.0
Cherry, tart	1.0
Citrus, dried pulp	5.0
Citrus, oil	2.0
Corn, field, forage	8.0
Corn, field, grain	0.05
Corn, field, refined oil	0.25
Corn, field, stover	8.0
Corn, sweet, forage	8.0
Corn, sweet, kernel plus cob with husk removed	0.05
Corn, sweet, stover	8.0
Cotton, undelinted seed	0.2
Cranberry	1.0
Cucumber	0.05
Egg	0.01
Fig	0.01
Fruit, citrus, group 10	1.0

Commodity	Parts per million
Goat, fat	0.2
Goat, meat	0.05
Goat, meat byproducts	0.05
Hazelnut	0.2
Hog, fat	0.2
Hog, meat	0.05
Hog, meat byproducts	0.05
Horse, fat	0.25
Horse, meat	0.25
Horse, meat byproducts	0.25
Kiwifruit	2.0
Milk, fat (Reflecting 0.01 ppm in whole milk)	0.25
Nectarine	0.05
Onion, bulb	0.5
Peach	0.05
Peanut	0.2
Peanut, refined oil	0.2
Pear	0.05
Pecan	0.2
Pepper	1.0
Peppermint, tops	0.8
Peppermint, oil	8.0
Plum, prune, fresh	0.05
Poultry, fat	0.1
Poultry, meat	0.1
Poultry, meat byproducts	0.1
Pumpkin	0.05
Radish	2.0
Rutabaga	0.5
Sheep, fat	0.2
Sheep, meat	0.05
Sheep, meat byproducts	0.05
Spearmint, tops	0.8
Spearmint, oil	8.0
Sorghum, grain, forage	0.5
Sorghum, grain, grain	0.5
Sorghum, grain, stover	2.0
Soybean, seed	0.3
Strawberry	0.2
Sunflower, seed	0.1
Sweet potato, roots	0.05
Turnip, roots	1.0
Turnip, tops	0.3
Vegetable, brassica, leafy, group 5	1.0
Vegetable, legume, group 6, except soybean	0.05
Walnut	0.2
Wheat, forage	3.0
Wheat, grain	0.5
Wheat, straw	6.0

*40 CFR 180.342(a)(1) (USEPA); U.S. National Archives and Records Administration's Electronic Code of Federal Regulations. Available from, as of May 2, 2014: **https://www.ecfr.gov/cgi-bin/ECFR?page=browse***

▸ Hazardous Substances Data Bank (HSDB)

A tolerance of 0.1 part per million is established for residues of chlorpyrifos, per se, in or on food commodities (other than those already covered by a higher tolerance as a result of use on growing crops) in food service establishments where food and food products are prepared and served, as a result of the application of chlorpyrifos in microencapsulated form.

*40 CFR 180.342(a)(3) (USEPA); U.S. National Archives and Records Administration's Electronic Code of Federal Regulations. Available from, as of May 2, 2014: **https://www.ecfr.gov***

▸ Hazardous Substances Data Bank (HSDB)

Tolerances with regional registration, as defined in 180.1(l), are established for residues of the pesticide chlorpyrifos per se (O,O-diethyl-O-(3,5,6-trichloro-2-pyridyl) phosphorothioate) in or on the following food commodities:

Commodity	Parts per million
Asparagus	5.0
Grape	0.01

*40 CFR 180.342(c) (USEPA); U.S. National Archives and Records Administration's Electronic Code of Federal Regulations. Available from, as of May 2, 2014: **https://www.ecfr.gov/cgi-bin/ECFR?page=browse***

▸ Hazardous Substances Data Bank (HSDB)

12.7.10 Personal Protective Equipment (PPE)

Excerpt from NIOSH Pocket Guide for Chlorpyrifos: Skin: PREVENT SKIN CONTACT - Wear appropriate personal protective clothing to prevent skin contact. Eyes: PREVENT EYE CONTACT - Wear appropriate eye protection to prevent eye contact. Wash skin: WHEN CONTAMINATED - The worker should immediately wash the skin when it becomes contaminated. Remove: WHEN WET OR CONTAMINATED - Work clothing that becomes wet or significantly contaminated should be removed and replaced. Change: DAILY - Workers whose clothing may have become contaminated should change into uncontaminated clothing before leaving the work premises. (NIOSH, 2022)

- CAMEO Chemicals

Personnel protection: ... Wear positive pressure self-contained breathing apparatus. ... Wear appropriate chemical protective clothing. /Organophosphorus pesticides, liquid and solid, NOS/

Association of American Railroads; Bureau of Explosives. Emergency Handling of Hazardous Materials in Surface Transportation. Association of American Railroads, Pueblo, CO. 2005, p. 223

- Hazardous Substances Data Bank (HSDB)

Wear appropriate personal protective clothing to prevent skin contact.

*NIOSH. NIOSH Pocket Guide to Chemical Hazards. Department of Health & Human Services, Centers for Disease Control & Prevention. National Institute for Occupational Safety & Health. DHHS (NIOSH) Publication No. 2010-168 (2010). Available from: **https://www.cdc.gov/niosh/npg***

- Hazardous Substances Data Bank (HSDB)

Wear appropriate eye protection to prevent eye contact.

*NIOSH. NIOSH Pocket Guide to Chemical Hazards. Department of Health & Human Services, Centers for Disease Control & Prevention. National Institute for Occupational Safety & Health. DHHS (NIOSH) Publication No. 2010-168 (2010). Available from: **https://www.cdc.gov/niosh/npg***

- Hazardous Substances Data Bank (HSDB)

Personnel protection: ... Wear appropriate chemical protective gloves, boots and goggles. /Other regulated substances, solid, NOS/

Association of American Railroads; Bureau of Explosives. Emergency Handling of Hazardous Materials in Surface Transportation. Association of American Railroads, Pueblo, CO. 2005, p. 223

- Hazardous Substances Data Bank (HSDB)

(See protection codes)

Skin: Prevent skin contact - Wear appropriate personal protective clothing to prevent skin contact.

Eyes: Prevent eye contact - Wear appropriate eye protection to prevent eye contact.

Wash skin: When contaminated

Remove: When wet or contaminated

Change: Daily - Workers whose clothing may have become contaminated should change into uncontaminated clothing before leaving the work premises.

- The National Institute for Occupational Safety and Health (NIOSH)

12.7.11 Respirator Recommendations

Important additional information about respirator selection

- The National Institute for Occupational Safety and Health (NIOSH)

12.7.12 Fire Prevention

NO open flames.

- ILO International Chemical Safety Cards (ICSC)

12.7.13 Exposure Prevention

STRICT HYGIENE! AVOID EXPOSURE OF ADOLESCENTS AND CHILDREN! IN ALL CASES CONSULT A DOCTOR! FIRST AID: USE PERSONAL PROTECTION.

- ILO International Chemical Safety Cards (ICSC)

12.7.14 Inhalation Prevention

Use local exhaust or breathing protection.

- ILO International Chemical Safety Cards (ICSC)

12.7.15 Skin Prevention

Protective gloves. Protective clothing.

- ILO International Chemical Safety Cards (ICSC)

12.7.16 Eye Prevention

Wear face shield or eye protection in combination with breathing protection if powder.

- ILO International Chemical Safety Cards (ICSC)

12.7.17 Ingestion Prevention

Do not eat, drink, or smoke during work. Wash hands before eating.

- ILO International Chemical Safety Cards (ICSC)

12.8 Stability and Reactivity

12.8.1 Air and Water Reactions

Insoluble in water. It reacts with water and most reactive hydrogen compounds. The rate of hydrolysis in water increases with pH, with temperature and with the presence of copper and possibly other metals that can form chelates. (NTP, 1992)

National Toxicology Program, Institute of Environmental Health Sciences, National Institutes of Health (NTP). 1992. National Toxicology Program Chemical Repository Database. Research Triangle Park, North Carolina.

CAMEO Chemicals

12.8.2 Reactive Group

Amines, Phosphines, and Pyridines

Esters, Sulfate Esters, Phosphate Esters, Thiophosphate Esters, and Borate Esters

Aryl Halides

CAMEO Chemicals

12.8.3 Reactivity Profile

CHLORPYRIFOS is sensitive to heat and is decomposed by moisture. This chemical is hydrolyzed by strong alkalis. It is corrosive to copper and brass. It is also corrosive to copper alloys. It reacts with water and most reactive hydrogen compounds. The rate of hydrolysis in water increases with pH, with temperature and with the presence of copper and possibly other metals that can form chelates. (NTP, 1992)

National Toxicology Program, Institute of Environmental Health Sciences, National Institutes of Health (NTP). 1992. National Toxicology Program Chemical Repository Database. Research Triangle Park, North Carolina.

CAMEO Chemicals

12.8.4 Hazardous Reactivities and Incompatibilities

Incompartible Materials: Brass

*Sigma-Aldrich Corp; Safety Data Sheet for Chlorpyrrifos (Product Number: 45395) Version 5.3 (June 27, 2014). Available from, as of June 18, 2014: **https://www.sigmaaldrich.com/safety-center.html***

Hazardous Substances Data Bank (HSDB)

Strong acids, caustics, amines [Note: Corrosive to copper & brass].

*NIOSH. NIOSH Pocket Guide to Chemical Hazards. Department of Health & Human Services, Centers for Disease Control & Prevention. National Institute for Occupational Safety & Health. DHHS (NIOSH) Publication No. 2010-168 (2010). Available from: **https://www.cdc.gov/niosh/npg***

Hazardous Substances Data Bank (HSDB)

12.9 Transport Information

12.9.1 DOT Emergency Guidelines

/GUIDE 131 FLAMMABLE LIQUIDS - TOXIC/ Fire or Explosion: HIGHLY FLAMMABLE: Will be easily ignited by heat, sparks or flames. Vapors may form explosive mixtures with air. Vapors may travel to source of ignition and flash back. Most vapors are heavier than air. They will spread along ground and collect in low or confined areas (sewers, basements, tanks). Vapor explosion and poison hazard indoors, outdoors or in sewers. Those substances designated with a (P) may polymerize explosively when heated or involved in a fire. Runoff to sewer may create fire or explosion hazard. Containers may explode when heated. Many liquids are lighter than water. /Organophosphorus pesticide, liquid, flammable, toxic; Organophosphorus pesticide, liquid, flammable, poisonous; Organophosphorus pesticide, liquid, toxic, flammable; Organophosphorus pesticide, liquid, poisonous, flammable; ID: 2784, 3017/

U.S. Department of Transportation. 2012 Emergency Response Guidebook. Washington, D.C. 2012

Hazardous Substances Data Bank (HSDB)

/GUIDE 131 FLAMMABLE LIQUIDS - TOXIC/ Health: TOXIC; may be fatal if inhaled, ingested or absorbed through skin. Inhalation or contact with some of these materials will irritate or burn skin and eyes. Fire will produce irritating, corrosive and/or toxic gases. Vapors may cause dizziness or suffocation. Runoff from fire control or dilution water may cause pollution. /Organophosphorus pesticide, liquid, flammable, toxic; Organophosphorus pesticide, liquid, flammable, poisonous; Organophosphorus pesticide, liquid, toxic, flammable; Organophosphorus pesticide, liquid, poisonous, flammable; ID: 2784, 3017/

U.S. Department of Transportation. 2012 Emergency Response Guidebook. Washington, D.C. 2012

Hazardous Substances Data Bank (HSDB)

/GUIDE 131 FLAMMABLE LIQUIDS - TOXIC/ Public Safety: CALL Emergency Response Telephone Number on Shipping Paper first. If Shipping Paper not available or no answer, refer to appropriate telephone number listed on the inside back cover. As an immediate precautionary measure, isolate spill or leak area for at least 50 meters (150 feet) in all directions. Keep unauthorized personnel away. Stay upwind. Keep out of low areas. Ventilate closed spaces before entering. /Organophosphorus pesticide, liquid, flammable, toxic; Organophosphorus pesticide, liquid, flammable, poisonous; Organophosphorus pesticide, liquid, toxic, flammable; Organophosphorus pesticide, liquid, poisonous, flammable; ID: 2784, 3017/

U.S. Department of Transportation. 2012 Emergency Response Guidebook. Washington, D.C. 2012

Hazardous Substances Data Bank (HSDB)

/GUIDE 131 FLAMMABLE LIQUIDS - TOXIC/ Protective Clothing: Wear positive pressure self-contained breathing apparatus (SCBA). Wear chemical protective clothing that is specifically recommended by the manufacturer. It may provide little or no thermal protection. Structural firefighters' protective clothing provides limited protection in fire situations ONLY; it is not effective in spill situations where direct contact with the substance is possible. /Organophosphorus pesticide, liquid, flammable, toxic; Organophosphorus pesticide, liquid, flammable, poisonous; Organophosphorus pesticide, liquid, toxic, flammable; Organophosphorus pesticide, liquid, poisonous, flammable; ID: 2784, 3017/

U.S. Department of Transportation. 2012 Emergency Response Guidebook. Washington, D.C. 2012

Hazardous Substances Data Bank (HSDB)

For more DOT Emergency Guidelines (Complete) data for CHLORPYRIFOS (16 total), please visit the HSDB record page.

Hazardous Substances Data Bank (HSDB)

12.9.2 DOT ID and Guide

2783 152

- The National Institute for Occupational Safety and Health (NIOSH)

12.9.3 Shipping Name/ Number DOT/UN/NA/IMO

UN 2783; Organophosphorus pesticides, solid, toxic

- Hazardous Substances Data Bank (HSDB)

UN 2784; Organophosphorus pesticides, liquid, flammable, toxic, flash point less than 23 °C

- Hazardous Substances Data Bank (HSDB)

UN 3017; Organophosphorus pesticides, liquid, toxic, flammable, flash point not less than 23 °C

- Hazardous Substances Data Bank (HSDB)

UN 3018; Organophosphorus pesticides, liquid, toxic

- Hazardous Substances Data Bank (HSDB)

For more Shipping Name/ Number DOT/UN/NA/IMO (Complete) data for CHLORPYRIFOS (6 total), please visit the HSDB record page.

- Hazardous Substances Data Bank (HSDB)

12.9.4 Standard Transportation Number

49 411 23; Chlorpyrifos (agricultural insecticides, not elsewhere classified, liquid)

- Hazardous Substances Data Bank (HSDB)

49 411 24; Chlorpyrifos (agricultural insecticides, not elsewhere classified, other than liquid)

- Hazardous Substances Data Bank (HSDB)

49 411 25; Chlorpyrifos (insecticides, other than agricultural not elsewhere classified)

- Hazardous Substances Data Bank (HSDB)

12.9.5 Shipment Methods and Regulations

No person may /transport,/ offer or accept a hazardous material for transportation in commerce unless that person is registered in conformance ... and the hazardous material is properly classed, described, packaged, marked, labeled, and in condition for shipment as required or authorized by ... /the hazardous materials regulations (49 CFR 171-177)./

49 CFR 171.2 (USDOT); U.S. National Archives and Records Administration's Electronic Code of Federal Regulations. Available from, as of June 5, 2014: https://www.ecfr.gov

- Hazardous Substances Data Bank (HSDB)

The International Air Transport Association (IATA) Dangerous Goods Regulations are published by the IATA Dangerous Goods Board pursuant to IATA Resolutions 618 and 619 and constitute a manual of industry carrier regulations to be followed by all IATA Member airlines when transporting hazardous materials.

International Air Transport Association. Dangerous Goods Regulations. 55th Edition. Montreal, Quebec Canada. 2014., p. 282, 283

- Hazardous Substances Data Bank (HSDB)

The International Maritime Dangerous Goods Code lays down basic principles for transporting hazardous chemicals. Detailed recommendations for individual substances and a number of recommendations for good practice are included in the classes dealing with such substances. A general index of technical names has also been compiled. This index should always be consulted when attempting to locate the appropriate procedures to be used when shipping any substance or article.

International Maritime Organization. IMDG Code. International Maritime Dangerous Goods Code Volume 2 2012, p. 152, 153, 183

- Hazardous Substances Data Bank (HSDB)

12.9.6 DOT Label

Poison

- CAMEO Chemicals

12.9.7 Packaging and Labelling

Do not transport with food and feedstuffs. Marine pollutant.

- ILO International Chemical Safety Cards (ICSC)

12.9.8 EC Classification

Symbol: T, N; R: 25-50/53; S: (1/2)-45-60-61

- ILO International Chemical Safety Cards (ICSC)

12.9.9 UN Classification

UN Hazard Class: 6.1; UN Pack Group: III

- ILO International Chemical Safety Cards (ICSC)

12.10 Regulatory Information

12.10.1 Federal Drinking Water Guidelines

EPA 2 ug/L

USEPA/Office of Water; Federal-State Toxicology and Risk Analysis Committee (FSTRAC). Summary of State and Federal Drinking Water Standards and Guidelines (11/93) To Present

Hazardous Substances Data Bank (HSDB)

12.10.2 State Drinking Water Guidelines

(FL) FLORIDA 21 ug/L

USEPA/Office of Water; Federal-State Toxicology and Risk Analysis Committee (FSTRAC). Summary of State and Federal Drinking Water Standards and Guidelines (11/93) To Present

Hazardous Substances Data Bank (HSDB)

12.10.3 Clean Water Act Requirements

Chlorpyrifos is designated as a hazardous substance under section 311(b)(2)(A) of the Federal Water Pollution Control Act and further regulated by the Clean Water Act Amendments of 1977 and 1978. These regulations apply to discharges of this substance. This designation includes any isomers and hydrates, as well as any solutions and mixtures containing this substance.

40 CFR 116.4 (USEPA); U.S. National Archives and Records Administration's Electronic Code of Federal Regulations. Available from, as of May 2, 2014: https://www.ecfr.gov

Hazardous Substances Data Bank (HSDB)

12.10.4 CERCLA Reportable Quantities

Persons in charge of vessels or facilities are required to notify the National Response Center (NRC) immediately, when there is a release of this designated hazardous substance, in an amount equal to or greater than its reportable quantity of 1 lb or 0.454 kg. The toll free number of the NRC is (800) 424-8802. The rule for determining when notification is required is stated in 40 CFR 302.4 (section IV. D.3.b).

40 CFR 302.4 (USEPA); U.S. National Archives and Records Administration's Electronic Code of Federal Regulations. Available from, as of May 2, 2014: https://www.ecfr.gov

Hazardous Substances Data Bank (HSDB)

12.10.5 FIFRA Requirements

Tolerances are established for residues of the pesticide chlorpyrifos per se (O,O-diethyl-O-(3,5,6-trichloro-2-pyridyl) phosphorothioate) in or on the following food commodities:

Commodity
Alfalfa, forage
Alfalfa, hay
Almond
Almond, hulls
Apple
Apple, wet pomace
Banana
Beet, sugar, dried pulp
Beet, sugar, molasses
Beet, sugar, roots
Beet, sugar, tops
Cattle, fat
Cattle, meat
Cattle, meat byproducts
Cherry, sweet
Cherry, tart
Citrus, dried pulp
Citrus, oil
Corn, field, forage
Corn, field, grain
Corn, field, refined oil
Corn, field, stover
Corn, sweet, forage
Corn, sweet, kernel plus cob with husk removed
Corn, sweet, stover
Cotton, undelinted seed
Cranberry
Cucumber
Egg
Fig
Fruit, citrus, group 10
Goat, fat
Goat, meat
Goat, meat byproducts
Hazelnut

Commodity
Hog, fat
Hog, meat
Hog, meat byproducts
Horse, fat
Horse, meat
Horse, meat byproducts
Kiwifruit
Milk, fat (Reflecting 0.01 ppm in whole milk)
Nectarine
Onion, bulb
Peach
Peanut
Peanut, refined oil
Pear
Pecan
Pepper
Peppermint, tops
Peppermint, oil
Plum, prune, fresh
Poultry, fat
Poultry, meat
Poultry, meat byproducts
Pumpkin
Radish
Rutabaga
Sheep, fat
Sheep, meat
Sheep, meat byproducts
Spearmint, tops
Spearmint, oil
Sorghum, grain, forage
Sorghum, grain, grain
Sorghum, grain, stover
Soybean, seed
Strawberry
Sunflower, seed
Sweet potato, roots
Turnip, roots
Turnip, tops
Vegetable, brassica, leafy, group 5
Vegetable, legume, group 6, except soybean
Walnut
Wheat, forage
Wheat, grain
Wheat, straw

40 CFR 180.342(a)(1) (USEPA); U.S. National Archives and Records Administration's Electronic Code of Federal Regulations. Available from, as of May 2, 2014: ***https://www.ecfr.gov/cgi-bin/ECFR?page=browse***

▸ **Hazardous Substances Data Bank (HSDB)**

A tolerance of 0.1 part per million is established for residues of chlorpyrifos, per se, in or on food commodities (other than those already covered by a higher tolerance as a result of use on growing crops) in food service establishments where food and food products are prepared and served, as a result of the application of chlorpyrifos in microencapsulated form.

40 CFR 180.342(a)(3) (USEPA); U.S. National Archives and Records Administration's Electronic Code of Federal Regulations. Available from, as of May 2, 2014: ***https://www.ecfr.gov***

▸ **Hazardous Substances Data Bank (HSDB)**

Tolerances with regional registration, as defined in 180.1(l), are established for residues of the pesticide chlorpyrifos per se (O,O-diethyl-O-(3,5,6-trichloro-2-pyridyl) phosphorothioate) in or on the following food commodities:

Commodity
Asparagus
Grape

40 CFR 180.342(c) (USEPA); U.S. National Archives and Records Administration's Electronic Code of Federal Regulations. Available from, as of May 2, 2014: ***https://www.ecfr.gov/cgi-bin/ECFR?page=browse***

▸ **Hazardous Substances Data Bank (HSDB)**

EPA has concluded, after completing its assessment of the cumulative risks associated with exposures to all of the OPs /including chlorpyrifos/, that: (1) the pesticides covered by the IREDs that were pending the results of the OP cumulative assessment (listed in Attachment A) are indeed eligible for reregistration; and (2) the pesticide tolerances covered by the IREDs and TREDs that were pending the results of the OP cumulative assessment (listed in Attachment A) meet the safety standard under Section 408(b)(2) of the FFDCA. Thus, with regard to the OPs, EPA has fulfilled its obligations as to FFDCA tolerance reassessment and FIFRA reregistration, other than product-specific reregistration.

USEPA/Office of Prevention, Pesticides and Toxic Substances; Reregistration Eligibility Decision Document - Chlorpyrifos p.1 (July 2006). Available from, as of June 5, 2014: ***https://www.epa.gov/pesticides/reregistration/status.htm***

Hazardous Substances Data Bank (HSDB)

For more FIFRA Requirements (Complete) data for CHLORPYRIFOS (7 total), please visit the **HSDB record page**.

Hazardous Substances Data Bank (HSDB)

12.11 Other Safety Information

12.11.1 Toxic Combustion Products

Phosphorous oxides Carbon oxides, nitrogen oxides (NOx), Sulphur oxides, Oxides of phosphorus, **Hydrogen chloride** gas

*Sigma-Aldrich Corp; Safety Data Sheet for Chlorpyrrifos (Product Number: 45395) Version 5.3 (June 27, 2014). Available from, as of June 18, 2014: **https://www.sigmaaldrich.com/safety-center.html***

Hazardous Substances Data Bank (HSDB)

12.11.2 History and Incidents

A major spillage of the insecticide Dursban (500 L) occurred along 19 km of the River Roding, Essex, UK on 2 Apr 1985. Within 30 to 40 hr, Dursban had entered tidal reaches of the river, 26 km downstream from the spillage point. 90% of the previous biomass of fish (4740 kg) and all aquatic arthropods were killed over a 23 km stretch of the River Roding. Initial concentration in **water** reached 14 mg/L in Brookhouse Brook (spill site) and 2.5 mg/L in the Roding, 15.7 km from the spillage point. The entire affected 23 km of the freshwater Roding was subject to >0.3 mg/L of the active ingredient chlorpyrifos, but concentrations were considerably less (<30 ug/L) in tidal water. River sediment was contaminated with up to 818 mg/kg (fresh weight) chlorpyrifos at Brookhouse Brook and 21 mg/kg 5 km from the spillage point. Concentration in water had declined to below 10 ug/L within 3 wk of the spill, and by 64 wk was not detectable in the Roding. Five affected macroinvertebrate riffles and an upstream control were kick-sampled at approx 10 wk intervals for 2 yr following the spill; results are compared with species composition and relative abundance data collected from the same sites during the previous 6 yr. Initial concentration of chlorpyrifos in river water (up to 2.5 mg/L) exceeded the level lethal to all the aquatic arthropods present by at least 10 fold, and this group of macroinvertebrates was eliminated. Mollusks and annelids, which are relatively tolerant of chlorpyrifos, survived. Since these groups already dominated the lower-most urban reaches, the impact of the spill was greatest further upstream, where reaches with a better quality previously supported a more diverse and abundant arthropod fauna. Chlorpyrifos residues in water declined below 1 ug/L within 11 wk, but sediment within 5 km of the spillage site remained highly contaminated for considerably longer. Of 10 arthropod taxa previously common to all sites, chironomid larvae were first to recolonize affected reaches, 13 wk after the spill. The isopod Asellus aquaticus, was also quick to recover. Although other arthropods had recolonized most sites within 79 wk, the coleopteran Oulimnius tuberculatus and the ephemeropteran Caenis moesta had failed to return to the lower-most reaches after 108 wk.

PMID:15092415
Raven PJ, George JJ; Environ Pollut 59 (1): 55-70 (1989)

Hazardous Substances Data Bank (HSDB)

12.11.3 Special Reports

DHHS/ATSDR; Toxicological Profile for Chlorpyrifos (September 1997). The ATSDR toxicological profile characterizes the toxicologic and adverse health effects information for the hazardous substance. Each peer-reviewed profile identifies and reviews the key literature that describes a hazardous substance's toxicologic properties. Other pertinent literature is also presented, but is described in less detail than the key studies.[Available from, as of November 19, 2007: http://www.atsdr.cdc.gov/toxprofiles/tp84.html]

Hazardous Substances Data Bank (HSDB)

FAO/WHO; Pesticide Residues in Food, Toxicological Evaluations, Chlorpyrifos (1999). Chlorpyrifos was reviewed at the Joint meeting of the FAO Panel of Experts on Pesticide Residues in Food and the Environment and the WHO Core Assessment Group in Rome, 20-29 September 1999, within the periodic review programme of the Codex Committee on Pesticide Residues.

Hazardous Substances Data Bank (HSDB)

USEPA; Ambient **Water** Quality Criteria Doc: Chlorpyrifos (1986) EPA 440/5-86-005

Hazardous Substances Data Bank (HSDB)

Nat'l Research Council Canada; Ecotoxicology of Chlorpyrifos (1978) NRCC No. 16079

Hazardous Substances Data Bank (HSDB)

USEPA/Office of Prevention, Pesticides and Toxic Substances; Interim Reregistration Eligibility Decision Document - Chlorpyrifos Case No. 0100 (September 2001)[Available from, as of June 5, 2014: http://www.epa.gov/pesticides/reregistration/status.htm]

Hazardous Substances Data Bank (HSDB)

13 Toxicity

13.1 Toxicological Information

CDC-ATSDR Toxicological Profile

- CDC-ATSDR Toxic Substances Portal

13.1.1 Toxicity Summary

IDENTIFICATION AND USE: Chlorpyrifos (CPF) is a colorless to white crystalline solid with a mild mercaptan odor. CPF is an organophosphate insecticide, acaricide, and miticide used to control foliage and soil-borne insect pests on a variety of food and feed crops. It is registered for use in the U.S. but approved pesticide uses may change periodically and so federal, state and local authorities must be consulted for currently approved uses. HUMAN EXPOSURE AND TOXICITY: CPF can cause cholinesterase inhibition in humans leading to an overstimulated nervous system causing nausea, dizziness, confusion, and respiratory paralysis and death at very high exposures. Significant changes in plasma cholinesterase inhibition were seen in repeated doses of 0.1 mg/kg of CPF but not in single doses. Organophosphate poisoning may mimic acute complications in pregnancy, such as eclampsia and seizures. Poisoning during pregnancy may result in serious adverse effects for both mother and the fetus or neonate. Prompt diagnosis and treatment including general supportive measures and use of specific pharmacological agents such as **atropine** and oximes are necessary to avoid adverse outcomes. ANIMAL STUDIES: CPF affects cardiac cholinesterase (ChE) activity and muscarinic receptor binding in neonatal and adult rats. Dose- and time-related changes in body weight and cholinergic signs of toxicity (involuntary movements) were noted in both age groups. With 1x LD(10), relatively similar maximal reductions in ChE activity and muscarinic receptor binding were noted, but receptor binding reductions appeared earlier in adults and were more prolonged in neonates. Studies were performed in dogs to find out whether exposure limits that protect brain acetylcholinesterase (AChE) will protect peripheral tissue AChE after exposure to CPF. The results show that red blood cells AChE is more sensitive than brain or peripheral tissue AChE to inhibition by CPF, and that protection of brain AChE would protect peripheral tissue AChE. Fetal or neonatal exposure to CPF or related organophosphate pesticides leads to abnormalities of brain cell development, synaptic function, and behavior. Studies in rats indicate profound effects on **serotonin** (5HT) systems that originate during CPF exposure and that are still present at 2 months posttreatment in the young adult. Findings at 5 months of age replicate those seen in young adulthood and strongly suggest that the effects of neonatal CPF exposure on 5HT systems are permanent. Developmental exposure to CPF alters cell signaling both in the brain and in peripheral tissues, affecting the responses to a variety of neurotransmitters and hormones. When tested in adulthood, CPF-exposed male animals displayed elevations in plasma **cholesterol** and triglycerides, without underlying alterations in nonesterified free fatty acids and **glycerol**. Similarly, in the postprandial state, male rats showed hyperinsulinemia in the face of normal circulating **glucose** levels but demonstrated appropriate reduction of circulating insulin concentrations after fasting. Apparently subtoxic neonatal chlorpyrifos exposure, devoid of effects on viability or growth, produce a metabolic pattern for plasma lipids and insulin that resembles the major adult risk factors for atherosclerosis and type 2 diabetes mellitus. CPF was evaluated for clastogenic potential using rat lymphocytes treated for 4 hours with concentrations of up to 5000 mg/mL with and without metabolic activation. No increase in chromosomal aberrations was detected. ECOTOXICITY STUDIES: Intoxication in the bobwhite was characterized by reduced food consumption and diarrhea in 48 hr, followed by lethargy, wing droop, muscular incoordination, tremors and tetany immediately preceding death. There was a significant correlation between ChE activity and total food consumption. A major spillage of the insecticide Dursban (500 L) occurred along the River Roding, Essex, UK on 2 Apr 1985. Within 30 to 40 hr, Dursban had entered tidal reaches of the river, 26 km downstream from the spillage point. 90% of the previous biomass of fish (4740 kg) and all aquatic arthropods were killed over a 23 km stretch of the River Roding. Mollusks and annelids, which are relatively tolerant of chlorpyrifos, survived.

- Hazardous Substances Data Bank (HSDB)

Chlorpyrifos is a cholinesterase or acetylcholinesterase (AChE) inhibitor. A cholinesterase inhibitor (or 'anticholinesterase') suppresses the action of acetylcholinesterase. Because of its essential function, chemicals that interfere with the action of acetylcholinesterase are potent neurotoxins, causing excessive salivation and eye-watering in low doses, followed by muscle spasms and ultimately death. Nerve gases and many substances used in insecticides have been shown to act by binding a **serine** in the active site of **acetylcholine** esterase, inhibiting the enzyme completely. **Acetylcholine** esterase breaks down the neurotransmitter **acetylcholine**, which is released at nerve and muscle junctions, in order to allow the muscle or organ to relax. The result of **acetylcholine** esterase inhibition is that **acetylcholine** builds up and continues to act so that any nerve impulses are continually transmitted and muscle contractions do not stop. Among the most common acetylcholinesterase inhibitors are **phosphorus**-based compounds, which are designed to bind to the active site of the enzyme. The structural requirements are a **phosphorus** atom bearing two lipophilic groups, a leaving group (such as a halide or **thiocyanate**), and a terminal **oxygen**.

- Toxin and Toxin Target Database (T3DB)

13.1.2 NIOSH Toxicity Data

- The National Institute for Occupational Safety and Health (NIOSH)

13.1.3 Evidence for Carcinogenicity

Cancer Classification: Group E Evidence of Non-carcinogenicity for Humans

USEPA Office of Pesticide Programs, Health Effects Division, Science Information Management Branch: "Chemicals Evaluated for Carcinogenic Potential" (April 2006)

- Hazardous Substances Data Bank (HSDB)

A4; Not classifiable as a human carcinogen.

American Conference of Governmental Industrial Hygienists. Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices. ACGIH, Cincinnati, OH 2014, p. 20

- Hazardous Substances Data Bank (HSDB)

13.1.4 Carcinogen Classification

Carcinogen Classification	Spraying and application of nonarsenical insecticides entail exposures that are probably carcinogenic to humans (Group 2A). (L135)

Toxin and Toxin Target Database (T3DB)

13.1.5 Health Effects

Acute exposure to cholinesterase inhibitors can cause a cholinergic crisis characterized by severe nausea/vomiting, salivation, sweating, bradycardia, hypotension, collapse, and convulsions. Increasing muscle weakness is a possibility and may result in death if respiratory muscles are involved. Accumulation of ACh at motor nerves causes overstimulation of nicotinic expression at the neuromuscular junction. When this occurs symptoms such as muscle weakness, fatigue, muscle cramps, fasciculation, and paralysis can be seen. When there is an accumulation of ACh at autonomic ganglia this causes overstimulation of nicotinic expression in the sympathetic system. Symptoms associated with this are hypertension, and hypoglycemia. Overstimulation of nicotinic **acetylcholine** receptors in the central nervous system, due to accumulation of ACh, results in anxiety, headache, convulsions, ataxia, depression of respiration and circulation, tremor, general weakness, and potentially coma. When there is expression of muscarinic overstimulation due to excess **acetylcholine** at muscarinic **acetylcholine** receptors symptoms of visual disturbances, tightness in chest, wheezing due to bronchoconstriction, increased bronchial secretions, increased salivation, lacrimation, sweating, peristalsis, and urination can occur. Certain reproductive effects in fertility, growth, and development for males and females have been linked specifically to organophosphate pesticide exposure. Most of the research on reproductive effects has been conducted on farmers working with pesticides and insecticdes in rural areas. In females menstrual cycle disturbances, longer pregnancies, spontaneous abortions, stillbirths, and some developmental effects in offspring have been linked to organophosphate pesticide exposure. Prenatal exposure has been linked to impaired fetal growth and development. Neurotoxic effects have also been linked to poisoning with OP pesticides causing four neurotoxic effects in humans: cholinergic syndrome, intermediate syndrome, organophosphate-induced delayed polyneuropathy (OPIDP), and chronic organophosphate-induced neuropsychiatric disorder (COPIND). These syndromes result after acute and chronic exposure to OP pesticides.

Toxin and Toxin Target Database (T3DB)

13.1.6 Exposure Routes

The substance can be absorbed into the body by inhalation, through the skin and by ingestion.

ILO International Chemical Safety Cards (ICSC)

inhalation, skin absorption, ingestion, skin and/or eye contact

The National Institute for Occupational Safety and Health (NIOSH)

Oral (L268) ; inhalation (L268) ; dermal (L268)

Toxin and Toxin Target Database (T3DB)

13.1.7 Symptoms

wheezing, laryngeal spasms, salivation; bluish lips, skin; miosis, blurred vision; nausea, vomiting, abdominal cramps, diarrhea

The National Institute for Occupational Safety and Health (NIOSH)

Chlorpyrifos exposure may produce a variety of effects on the nervous system including headaches, blurred vision, lacrimation, excessive salivation, runny nose, dizziness, confusion, muscle weakness or tremors, nausea, diarrhea, and sudden changes in heart rate. High levels may result in severe sweating, loss of bowel control, severe muscle tremors, seizures, loss of consciousness, coma, or death. (L268)

Toxin and Toxin Target Database (T3DB)

13.1.8 Inhalation Symptoms

Pupillary constriction, muscle cramp, excessive salivation. Muscle twitching. Convulsions. Dizziness. Sweating. Wheezing. Laboured breathing. Unconsciousness.

ILO International Chemical Safety Cards (ICSC)

13.1.9 Skin Symptoms

MAY BE ABSORBED! See Inhalation.

ILO International Chemical Safety Cards (ICSC)

13.1.10 Eye Symptoms

Redness. Pain. Pupillary constriction. Blurred vision.

ILO International Chemical Safety Cards (ICSC)

13.1.11 Ingestion Symptoms

Excessive salivation. Nausea. Vomiting. Abdominal cramps. Diarrhoea. Further see Inhalation.

ILO International Chemical Safety Cards (ICSC)

13.1.12 Target Organs

Neurological (Nervous System)

CDC-ATSDR Toxic Substances Portal

respiratory system, central nervous system, peripheral nervous system, plasma cholinesterase

The National Institute for Occupational Safety and Health (NIOSH)

13.1.13 Acute Toxicity Link

Chemical: CHLORPYRIFOS

USGS Columbia Environmental Research Center

13.1.14 Adverse Effects

Neurotoxin - Predominantly motor

Other Poison - Organophosphate

ACGIH Carcinogen - Not Classifiable.

Haz-Map, Information on Hazardous Chemicals and Occupational Diseases

13.1.15 Acute Effects

ChemIDplus

13.1.16 Toxicity Data

LD50: 102 mg/kg (Oral, Rat) (T42) LD50: 1233 mg/kg (Dermal, Rabbit) (T42) LD50: 192 mg/kg (Intraperitoneal, Mouse) (T14) LC50: 560 mg/m3 over 4 hours (Inhalation, Rat) (T42)

Toxin and Toxin Target Database (T3DB)

13.1.17 Minimum Risk Level

Acute Oral: 0.003 mg/kg/day (L134) Intermediate Oral: 0.003 mg/kg/day (L134) Chronic Oral: 0.001 mg/kg/day (L134)

Toxin and Toxin Target Database (T3DB)

13.1.18 Treatment

If the compound has been ingested, rapid gastric lavage should be performed using 5% **sodium bicarbonate**. For skin contact, the skin should be washed with soap and **water**. If the compound has entered the eyes, they should be washed with large quantities of isotonic saline or **water**. In serious cases, **atropine** and/or **pralidoxime** should be administered. Anti-cholinergic drugs work to counteract the effects of excess **acetylcholine** and reactivate AChE. **Atropine** can be used as an antidote in conjunction with **pralidoxime** or other pyridinium oximes (such as **trimedoxime** or **obidoxime**), though the use of '-oximes' has been found to be of no benefit, or possibly harmful, in at least two meta-analyses. **Atropine** is a muscarinic antagonist, and thus blocks the action of **acetylcholine** peripherally.

Toxin and Toxin Target Database (T3DB)

13.1.19 Interactions

Chlorpyrifos (CPF) is one of the most widely used organophosphorous insecticides in agriculture with its attendant adverse health outcomes. This study aimed at evaluating the effect of subchronic oral CPF administration on hematological and serum biochemical indices, and the possible ameliorating effect of **vitamin C** on the indices in mice. Thirty mice divided into 3 groups of 10 mice each were used for this study. Mice in group I (control) were dosed with vegetable oil, while those in group II were given CPF (21.3 mg/kg~ 1/5(th) LD50) only. Mice in group III were pretreated with **vitamin C** (100 mg/kg) prior to dosing with CPF 30 min later (**Vitamin C** + CPF-treated group). This regime was given to each group of mice three times a week for a period of ten weeks. During the study period, mice were examined for signs of toxicity, and weight of each mouse was measured every week. At the end of the study period, blood samples were collected from the mice and analyzed for packed cell volume (PCV), total red blood cell (RBC), white blood cell (WBC) and total protein (TP). Serum obtained from the blood was analyzed for Na(+, K+ and Cl-), **urea**, **creatinine**, **alanine** aminotransferase (ALT), **aspartate** aminotransferase (AST), and alkaline phosphatase (ALP). The results showed that mice in the **vitamin C** + CPF-treated group exhibited milder signs of toxicity and significant increase in weight gain ($p<0.01$) compared to the CPF-treated group. No significant increase in weight in the CPF-treated group was observed compared to the control. There was a significant increase in PCV, RBC, Hb, TP and creatinine, but a significant decrease was obtained in WBC, ALT and AST in the CPF-treated group compared to the control. All the parameters with the exception of WBC, ALT and AST (which increased significantly), were significantly decreased in the vitamin C + CPF-treated group compared to CPF-treated group. ALP was significantly elevated in the CPF-treated group compared to both the control and vitamin C + CPF-treated group. No significant changes in urea and the measured electrolytes in all three groups, except a significant decrease in the concentration of Na(+) was observed in the CPF-treated group compared to the control. The study demonstrated that pretreatment of CPF-administered mice with vitamin C significantly altered some important hematological and serum biochemical parameters, revealing the protective action of the vitamin against some organ damage induced by CPF.

PMID:17538235
Ambali S et al; J Toxicol Sci 32(2): 111-20 (2007).

Hazardous Substances Data Bank (HSDB)

... Interestingly, clinical evidence suggests that exposure to organophosphates might be linked to increased **ethanol** sensitivity and reduced voluntary consumption of **ethanol**-containing beverages in humans. ... Present study specifically evaluated neurobiological and behavioral responses to **ethanol** in Wistar rats that were previously exposed to the pesticide organophosphate chlorpyrifos (CPF). In agreement with clinical data, animals pretreated with a single injection of CPF showed long-lasting **ethanol** avoidance that was not secondary to altered gustatory processing or enhancement of the aversive properties of **ethanol**. Furthermore, CPF pretreatment increased **ethanol**-induced sedation without altering blood **ethanol** levels. An immunocytochemical assay revealed reduced c-fos expression in the Edinger-Westphal nucleus following CPF treatment, a critical brain area that has been implicated in **ethanol** intake and sedation. /It was hypothesized/ ... that CPF might modulate cellular mechanisms (decreased intracellular **cAMP** signaling, alpha-7-nicotinic receptors, and/or cerebral acetylcholinesterase inhibition) in neuronal pathways critically involved in neurobiological responses to **ethanol**.

PMID:17190973
Carvajal F et al; Toxicol Sci 96(2): 310-20 (2007)

Hazardous Substances Data Bank (HSDB)

... The effects of developmental exposure to terbutaline, a beta2-adrenergic receptor agonist used to arrest preterm labor, and chlorpyrifos, a widely used organophosphate pesticide, on serotonin (5HT) systems /were examined/. Treatments were chosen to parallel periods typical of human developmental exposures, terbutaline (10 mg/kg) on postnatal days (PN) 2-5 and chlorpyrifos (5 mg/kg) on PN11-14, with assessments conducted in juvenile and adolescent stages (PN21, PN30 and PN45), comparing each agent alone as well as sequential administration of both. By itself, terbutaline produced persistent 5HT presynaptic hyperactivity as evidenced by increased 5HT turnover in brain regions containing 5HT terminal zones; this effect was similar to that seen in earlier studies with chlorpyrifos administration during the same early postnatal period. Later administration of chlorpyrifos (PN11-14) produced a transient increase in 5HT turnover during the juvenile stage, and the sequential exposure paradigm, terbutaline followed by chlorpyrifos, showed a corresponding increase in effect over either agent alone. ... the interaction between terbutaline and chlorpyrifos suggests that tocolytic therapy may alter the subsequent susceptibility to common environmental toxicants.

PMID:17562396
Full text: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1986775
Slotkin TA, Seidler FJ; Brain Res Bull 73(4-6): 301-9 (2007).

Hazardous Substances Data Bank (HSDB)

Addition of ascorbic acid to the diet (0.5%) enhanced the acute toxicity of leptophos, chlorpyrifos and diazinon and protected a number of the monitored serum enzymes from being decreased except for leptophos.

PMID:6184393
Enan EE et al; J Environ Sci Health (B) 17 (5): 549-70 (1982)

Hazardous Substances Data Bank (HSDB)

For more Interactions (Complete) data for CHLORPYRIFOS (15 total), please visit the HSDB record page.

Hazardous Substances Data Bank (HSDB)

13.1.20 Antidote and Emergency Treatment

Immediate first aid: Ensure that adequate decontamination has been carried out. If patient is not breathing, start artificial respiration, preferably with a demand-valve resuscitator, bag-valve-mask device, or pocket mask, as trained. Perform CPR as necessary. Immediately flush contaminated eyes with gently flowing water. Do not induce vomiting. If vomiting occurs, lean patient forward or place on left side (head-down position, if possible) to maintain an open airway and prevent aspiration. Keep patient quiet and maintain normal body temperature. Obtain medical attention. /Organophosphates and related compounds/

Currance, P.L. Clements, B., Bronstein, A.C. (Eds).; Emergency Care For Hazardous Materials Exposure. 3rd revised edition, Elsevier Mosby, St. Louis, MO 2007, p. 294

Hazardous Substances Data Bank (HSDB)

Basic treatment: Establish a patent airway (oropharyngeal or nasopharyngeal airway, if needed). Suction if necessary. Aggressive airway control may be needed. Watch for signs of respiratory insufficiency and assist ventilations if necessary. Administer oxygen by nonrebreather mask at 10 to 15 L/min. Monitor for pulmonary edema and treat if necessary ... . Monitor for shock and treat if necessary ... . Anticipate seizures and treat if necessary ... . For eye contamination, flush eyes immediately with water. Irrigate each eye continuously with 0.9% saline (NS) during transport ... . Do not use emetics. For ingestion, rinse mouth and administer 5 mL/kg up to 200 mL of water for dilution if the patient can swallow, has a strong gag reflex, and does not drool. Administer activated charcoal ... . /Organophosphates and related compounds/

Currance, P.L. Clements, B., Bronstein, A.C. (Eds).; Emergency Care For Hazardous Materials Exposure. 3rd revised edition, Elsevier Mosby, St. Louis, MO 2007, p. 294

Hazardous Substances Data Bank (HSDB)

Advanced treatment: Consider orotracheal or nasotracheal intubation for airway control in the patient who is unconscious, has severe pulmonary edema, or is in severe respiratory distress. Positive-pressure ventilation techniques with a bag valve mask device may be beneficial. Monitor cardiac rhythm and treat arrhythmias if necessary ... . Start IV administration of D5W /SRP: "To keep open", minimal flow rate/. Use 0.9% saline (NS) or lactated Ringer's (LR) if signs of hypovolemia are present. For hypotension with signs of hypovolemia, administer fluid cautiously and consider vasopressors if patient is hypotensive with a normal fluid volume. Watch for signs of fluid overload ... . Administer atropine. Correct hypoxia before giving atropine ... . Administer pralidoxime chloride (2 PAM). ... . Treat seizures with adequate atropinization and correction of hypoxia. In rare cases diazepam or lorazepam may be necessary ... . Use proparacaine hydrochloride to assist eye irrigation ... . /Organophosphates and related compounds/

Currance, P.L. Clements, B., Bronstein, A.C. (Eds).; Emergency Care For Hazardous Materials Exposure. 3rd revised edition, Elsevier Mosby, St. Louis, MO 2007, p. 294-5

Hazardous Substances Data Bank (HSDB)

Emergency and supportive measures. Caution: Rescuers and health care providers must take measures to prevent direct contact with the skin or clothing of contaminated victims because secondary contamination and serious illness may result, especially with neve agents or potent pesticides. ... 1. Maintain an open airway and assist ventilation if necessary. Pay careful attention to respiratory muscle weakness and the presence of bronchial secretions. Respiratory arrest is often preceded by increasing weakness of neck flexion muscles. If intubation is required, a nondepolarizing agent should be used because the effect of succinylcholine will be markedly prolonged secondary to the inhibition of PChE. 2. Anticipate and treat hydrocarbon pneumonitis, hypotension,seizures, and coma if they occur. Seizures should be treated with a benzodiazepine such as diazepam. 3. Observe asymptomatic patients for at least 8-12 hours to rule out delayed-onset symptoms, especially after extensive skin exposure or ingestion of a highly fat-soluble agent. /Organophosphorus and carbamate insecticides/

OLSON, K.R. (Ed). Poisoning and Drug Overdose, Sixth Edition. McGraw-Hill, New York, NY 2012, p. 319

Hazardous Substances Data Bank (HSDB)

For more Antidote and Emergency Treatment (Complete) data for CHLORPYRIFOS (22 total), please visit the HSDB record page.

Hazardous Substances Data Bank (HSDB)

13.1.21 Medical Surveillance

Whole Blood reference Ranges: Normal - not established; Exposed - not established; Toxic - not established. Serum or Plasma Reference Ranges: Normal - not established; Exposed - not established; Toxic - not established. urine Reference Ranges: Normal - not established; Exposed - not established; Toxic - not established.

Ryan, R.P., C.E. Terry (eds.). Toxicology Desk Reference 4th ed. Volumes 1-3. Taylor & Francis, Washington, D.C. 1997., p. 737

Hazardous Substances Data Bank (HSDB)

Respiratory Symptom Questionnaires: Questionnaires have been published by the American Thoracic Society (ATS) and the British Medical Research Council. These questionnaires have been found to be useful in identification of people with chronic bronchitis, however certain pulmonary function tests such as FEV1 (see pulmonary function test section) have been found to be better predictors of chronic airflow obstruction.

Ryan, R.P., C.E. Terry (eds.). Toxicology Desk Reference 4th ed. Volumes 1-3. Taylor & Francis, Washington, D.C. 1997., p. 739

Hazardous Substances Data Bank (HSDB)

Chest Radiography: This test is widely used for assessing pulmonary disease. Chest radiographs have been found to be useful for detection of early lung cancer in asymptomatic people, especially for detection of peripheral tumors such as adenocarcinomas. However, even though OSHA mandates this test for exposure to some toxicants such as asbestos, there are conflicting views on its efficacy in detection of pulmonary disease.

Ryan, R.P, C.E. Terry (eds.). Toxicology Desk Reference 4th ed. Volumes 1-3. Taylor & Francis, Washington, D.C. 1997., p. 739

Hazardous Substances Data Bank (HSDB)

Pulmonary Function Tests: The tests that have been found to be practical for population monitoring include: Spirometry and expiratory flow-volume curves; Determination of lung volumes; Diffusing capacity for **carbon monoxide**; Single-breath **nitrogen** washout; Inhalation challenge tests; Serial measurements of peak expiratory-flow; Exercise testing.

Ryan, R.P, C.E. Terry (eds.). Toxicology Desk Reference 4th ed. Volumes 1-3. Taylor & Francis, Washington, D.C. 1997., p. 739

Hazardous Substances Data Bank (HSDB)

For more Medical Surveillance (Complete) data for CHLORPYRIFOS (10 total), please visit the **HSDB record page**.

Hazardous Substances Data Bank (HSDB)

13.1.22 Human Toxicity Excerpts

/HUMAN EXPOSURE STUDIES/ ... Five volunteers ingested 1 mg (2852 nmol) of chlorpyrifos. Blood samples were taken over 24 hours and total void volumes of urine were collected over 100 hours. Four weeks later 28.59 mg (81567 nmol) of chlorpyrifos was administered dermally to each volunteer for 8 hours. Unabsorbed chlorpyrifos was washed from the skin and retained for subsequent measurement. The same blood and urine sampling regime was followed as for the oral administration. Plasma and erythrocyte cholinesterase concentrations were determined for each blood sample. The concentration of two urinary metabolites of chlorpyrifos, **diethylphosphate** and diethyl-thiophosphate was determined for each urine sample. ... The apparent elimination half life of urinary dialkylphosphates after the oral dose was 15.5 hours and after the dermal dose it was 30 hours. Most of the oral dose (mean (range) 93% (55-115%)) and 1% of the applied dermal dose was recovered as urinary metabolites. About half (53%) of the dermal dose was recovered from the skin surface. The absorption rate through the skin, as measured by urinary metabolites was 456 ng/sq cm/hr. Blood plasma and erythrocyte cholinesterase activity did not fall significantly during either dosing regime. ... The amounts of chlorpyrifos used did not depress acetyl cholinesterase activity but could be readily detected as urinary dialkylphosphate metabolites indicating that the urinary assay is a more sensitive indicator of exposure.

PMID:10341740
*Full text: **https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1757654***
Griffin P et al; Occup Environ Med 56(1): 10-3 (1999)

Hazardous Substances Data Bank (HSDB)

/HUMAN EXPOSURE STUDIES/ Four volunteers were exposed for 5 min to a formulation containing 61.5% chlorpyrifos and 34.5% **xylene** from an ultra-low volume cold aerosol fog generator delivering 3.8 L/hr. Air sampling showed a concentration of chlorpyrifos in the breathing space of about 108 mg/L (range, 83-133 mg/L). The subjects were exposed at a distance of 8 m and wore plastic coveralls allowing exposure of the heads and hands of two subjects and the heads, hands, and arms of the other two. Exposure was terminated after 5 min because of the ocular and pulmonary irritation induced. Plasma and erythrocyte cholinesterase activity was not depressed 24 hr after exposure.

*FAO/WHO; Pesticide Residues in Food, Toxicological Evaluations, Chlorpyrifos (1999). Available from, as of September 17, 2007: **https://www.inchem.org/documents/jmpr/jmpmono/v99pr03.htm***

Hazardous Substances Data Bank (HSDB)

/HUMAN EXPOSURE STUDIES/ ... The methods and results are described of a study on the dermal absorption of chlorpyrifos (CPF) in humans established via urinary excretion of the metabolite **3,5,6-trichloro-2-pyridinol** (TCP). ... Two dermal, single, doses of CPF were applied in two study groups (A and B) each comprising three apparently healthy male volunteers who gave their written informed consent. The clinical part of the study was conducted in compliance with the ICH Guideline and the EC principles of good clinical practice (GCP). An approximately 0.5 mL dilution of CPF in **ethanol** was applied to an area of approximately 100 sq cm of the volar aspect of the forearm, resulting in doses of either 5 mg (A) or 15 mg (B) of CPF per study subject. Duration of dermal exposure was 4 hr, after which the non-absorbed fraction was washed off. The following samples were collected at pre-determined intervals for the determination of either CPF or its metabolite TCP: dosing solutions, wash-off fractions and urine samples collected up to 120 hr after dosing. A relatively large fraction of CPF (42%-67% of the applied dose) was washed off from the exposed skin area. Application of either 5 mg (A) or 15 mg CPF (B) resulted in the total urinary excretion of 131.8 ug (A) or 115.6 ug (B) of TCP 120 hr after dosing. This indicated that 4.3% of the applied dose has been absorbed (A), while in group (B) no significant increase in urinary TCP (115.6 ug) was established. The latter indicates that an increase in the dermal dose at a fixed area does not increase absorption, which suggests that the percutaneous penetration rate was constant. Further, it was observed that the clearance of CPF by the body was not completed within 120 hr, suggesting that CPF or TCP was retained by the skin and/or accumulated in the body. A mean elimination half-life of 41 hr was established. The results show that daily occupational exposure to CPF may result in accumulation of CPF and/or its metabolites, ...

PMID:15627216
Meuling WJ et al; Int Arch Occup Environ Health 78(1): 44-50 (2005).

Hazardous Substances Data Bank (HSDB)

/HUMAN EXPOSURE STUDIES/ In a double-blind, randomized, placebo controlled study of the effects of single oral doses of chlorpyrifos (purity, 99.8%), groups of six fasted men and women aged 18-55 received doses of 0, 0.5, 1, or 2 mg/kg bw in **lactose** powder. The study was conducted in two phases separated by 14 days. The volunteers were dosed with 0, 0.5, or 1 mg/kg bw in the first phase and the results were assessed before administration of 0 or 2 mg/kg bw in the second phase. Blood samples were collected 10 and 0 hr before treatment and 2, 4, 8, 12, 24, 36, 48, 72, 96, 120, 144, and 168 hr after treatment and analyzed for erythrocyte cholinesterase activity and chlorpyrifos and its metabolites. In addition, all urine voided from 48 hr before dosing to 168 hr after dosing was collected at 12- or 6-hr intervals and analyzed for chlorpyifos and metabolites. Hematology, clinical chemistry, urinary analysis and a brief physical examination were performed at completion of the study. ... The doses were taken by capsule after an overnight fast. The health status of subjects was monitored closely; vital signs (blood pressure, pulse, respiration, and temperature) were assessed before dosing and 1, 2, 4, 8, 12, 24, 48, and 168 hr after treatment. ... Treatment had no effect on general health or on clinical chemical parameters measured 7 days after dosing. The only treatment-related effect was found in the woman who withdrew from the study, who had decreased erythrocyte cholinesterase activity when compared with her pre-treatment values at most sampling times, with 98.4% of the pretreatment value at 4 hr after dosing, 77% at 8 hr, 72% at 12 hr, 74% at 24 hr, 81% at 36 hr, and 80% at 48 hr. When the data for this subject are removed from the analysis, the mean for women receiving 2 mg/kg bw is indistinguishable from the value for concurrent controls. The NOAEL for clinical signs or symptoms was thus the highest dose tested, and the NOAEL for inhibition of erythrocyte cholinesterase activity was 1 mg/kg bw on the basis of significant inhibition in one of 12 subjects.

*FAO/WHO; Pesticide Residues in Food, Toxicological Evaluations, Chlorpyrifos (1999). Available from, as of September 17, 2007: **https://www.inchem.org/documents/jmpr/jmpmono/v99pr03.htm***

Hazardous Substances Data Bank (HSDB)

For more Human Toxicity Excerpts (Complete) data for CHLORPYRIFOS (35 total), please visit the **HSDB record page**.

Hazardous Substances Data Bank (HSDB)

13.1.23 Non-Human Toxicity Excerpts

/LABORATORY ANIMALS: Acute Exposure/ ... Organophosphorus (OP) insecticides can potentially influence cardiac function in a receptor-mediated manner indirectly by inhibiting acetylcholinesterase and directly by binding to muscarinic M(2) receptors. Young animals are generally more sensitive than adults to the acute toxicity of OP insecticides and age-related differences in potency of direct binding to muscarinic receptors by some OP toxicants have been reported. ... /The study/ compared the effects of the common OP insecticide chlorpyrifos (CPF) on functional signs of toxicity and cardiac cholinesterase (ChE) activity and muscarinic receptor binding in neonatal and adult rats. Dosages were based on acute lethality (i.e., 0.5 and 1x LD(10): neonates, 7.5 and 15 mg/kg; adults, 68 and 136 mg/kg). Dose- and time-related changes in body weight and cholinergic signs of toxicity (involuntary movements) were noted in both age groups. With 1x LD(10), relatively similar maximal reductions in ChE activity (95%) and muscarinic receptor binding (approximately 30%) were noted, but receptor binding reductions appeared earlier in adults and were more prolonged in neonates. ... The results suggest that ChE activity (primarily BChE) in neonatal heart may be inherently more sensitive to inhibition by some anticholinesterases and that toxicologically significant binding to muscarinic receptors may be possible with acute chlorpyrifos intoxication, potentially contributing to age-related differences in sensitivity.

PMID:17644233
*Full text: **https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2954647***
Howard MD et al; Toxicology 238 (2-3): 157-65 (2007)

Hazardous Substances Data Bank (HSDB)

/LABORATORY ANIMALS: Acute Exposure/ This study examined the acute effects of chlorpyrifos (CPF) on cholinesterase inhibition and acetylcholine levels in the striatum of freely moving rats using in vivo microdialysis. Adult, male Sprague-Dawley rats were treated with vehicle (peanut oil, 2 ml/kg) or CPF (84, 156 or 279 mg/kg, sc) and functional signs of toxicity, body weight and motor activity recorded. Microdialysis was conducted at 1, 4 and 7 days after CPF exposure for measurement of acetylcholine levels in striatum. Rats were then sacrificed and the contralateral striatum and diaphragm were collected for biochemical measurements. Few overt signs of cholinergic toxicity were noted in any rats. Body weight gain was significantly affected in the high-dose (279 mg/kg) group only, while motor activity (nocturnal rearing) was significantly reduced in all CPF-treated groups at one day (84 mg/kg) or from 1-4 days (156 and 279 mg/kg) after dosing. Cholinesterase activities in both diaphragm and striatum were markedly inhibited (50-92%) in a time-dependent manner, but there were relatively minimal dose-related changes. In contrast, time- and dose-dependent changes in striatal acetylcholine levels were noted, with significantly higher levels noted in the high-dose group compared to other groups. Maximal increases in striatal acetylcholine levels were observed at 4-7 days after dosing (84 mg/kg, 7-9-fold; 156 mg/kg, 10-13-fold; 279 mg/kg, 35-57-fold). Substantially higher acetylcholine levels were noted when an exogenous cholinesterase inhibitor was included in the perfusion buffer, but CPF treatment-related differences were substantially lower in magnitude under those conditions. The results suggest that marked differences in acetylcholine accumulation can occur with dosages of CPF eliciting relatively similar degrees of cholinesterase inhibition. Furthermore, the minimal expression of classic signs of cholinergic toxicity in the presence of extensive brain acetylcholine accumulation suggests that some compensatory process(es) downstream from synaptic neurotransmitter accumulation limits the expression of toxicity following acute CPF exposure.

PMID:16777161

Karanth S et al; Toxicol Appl Pharmacol 216(1): 150-6 (2006).

Hazardous Substances Data Bank (HSDB)

/LABORATORY ANIMALS: Acute Exposure/ When rats were given 10, 50, or 100 mg/kg chlorpyrifos orally and observed 1, 8, and 15 hours later, cholinergic effects occurred only on day 1 in 100-mg/kg treated female rats. One female rat treated with 50 mg/kg had tremors, two exhibited incoordination, and one showed pronounced lacrimation. One male rat given 100 mg/kg exhibited only minimal tremor, and one male exhibited incoordination and lacrimation. Rats treated with 50 or 100 mg/kg were significantly hypoactive only on day 1. Thus, cholinergic effects were widespread at 100 mg/kg, minor at 50 mg/kg, moderated over a few days, and were more severe in females than males.

Bingham, E.; Cohrssen, B.; Powell, C.H.; Patty's Toxicology Volumes 1-9 5th ed. John Wiley & Sons. New York, N.Y. (2001)., p. 793

Hazardous Substances Data Bank (HSDB)

/LABORATORY ANIMALS: Acute Exposure/ Organophosphate (OP) pesticides are likely to alter the regulation of blood pressure (BP) because (i) BP control centers in the brain stem utilize cholinergic synapses and (ii) the irreversible inhibition of acetylcholinesterase activity by OP's causes cholinergic stimulation in the CNS. This study used radiotelemetric techniques to monitor systolic (S), diastolic (D), mean (M) BP, pulse pressure (systolic-diastolic), heart rate (HR), core temperature (T(c)), and motor activity in male Long-Evans rats treated with the OP pesticide chlorpyrifos (CHP) at doses of 0, 5, 10, and 25 mg/kg (p.o.). At 15:00 hr 10 and 25 mg/kg CHP led to parallel elevations in S-BP, M-BP, and D-BP within 2 hr after dosing. BP increased 15-20 mmHg above controls and increases persisted throughout the night and into the next day. HR decreased slightly in rats administered 25 but not 10 mg/kg CHP. T(c) was reduced by treatment with 25 mg/kg CHP and then increased above controls the next day. Motor activity was reduced by treatment with 25 but not 10 mg/kg CHP. Pulse pressure was elevated by 2-4 mm Hg for 40 hr after exposure to 10 and 25 mg/kg CHP. The increase in BP without an increase in HR suggests that CHP increases total peripheral resistance and may alter the baroreflex control of BP. Cholinergic stimulation of the CNS may explain the initial effects of CHP on BP; however, the persistent elevation suggests an involvement of neurohumoral pressor pathways.

PMID:10773358

Gordon CJ, Padnos BK; Toxicology 146(1): 1-13 (2000)

Hazardous Substances Data Bank (HSDB)

For more Non-Human Toxicity Excerpts (Complete) data for CHLORPYRIFOS (75 total), please visit the HSDB record page.

Hazardous Substances Data Bank (HSDB)

13.1.24 Non-Human Toxicity Values

LD50 albino Rats males oral 151 mg/kg /purity 99%/

U.S. Department of the Interior, Fish and Wildlife Service. Handbook of Toxicity of Pesticides to Wildlife. Resource Publication 153. Washington, DC: U.S. Government Printing Office, 1984., p. 23

Hazardous Substances Data Bank (HSDB)

LD50 Rock Doves (domestic pigeons) oral 26.9 mg/kg (95% confidence limit 19.0-38 mg/kg) /purity 94.5%/

U.S. Department of the Interior, Fish and Wildlife Service. Handbook of Toxicity of Pesticides to Wildlife. Resource Publication 153. Washington, DC: U.S. Government Printing Office, 1984., p. 23

Hazardous Substances Data Bank (HSDB)

LD50 domestic goats females oral 500-1000 mg/kg /purity 94.5%/

U.S. Department of the Interior, Fish and Wildlife Service. Handbook of Toxicity of Pesticides to Wildlife. Resource Publication 153. Washington, DC: U.S. Government Printing Office, 1984., p. 23

Hazardous Substances Data Bank (HSDB)

LD50 Rabbit dermal, Himalayan (male & femle) 1233 mg/kg bw

FAO/WHO; Pesticide Residues in Food, Toxicological Evaluations, Chlorpyrifos (1999). Available from, as of September 17, 2007: https://www.inchem.org/documents/jmpr/jmpmono/v99pr03.htm

Hazardous Substances Data Bank (HSDB)

For more Non-Human Toxicity Values (Complete) data for CHLORPYRIFOS (23 total), please visit the HSDB record page.

Hazardous Substances Data Bank (HSDB)

13.1.25 Ecotoxicity Values

LC50; Species: Coturnix (Japanese quail) oral 293 ppm for 5 days (95% confidence limit 112-767 ppm) /Technical material, 97% active ingredient/

Hill, E.F. and Camardese, M.B. Lethal Dietary Toxicities of Environmental Contaminants and Pesticides to Coturnix. Fish and Wildlife Technical Report 2. Washington, DC: United States Department of Interior Fish and Wildlife Service, 1986., p. 44

Hazardous Substances Data Bank (HSDB)

LD50; Species: Coturnix coturnix (Japanese quail) 2.5 month old males; oral 15.9 mg/kg (95% confidence limit: 10.5-24.0 mg/kg) /purity 94.5%/

U.S. Department of the Interior, Fish and Wildlife Service. Handbook of Toxicity of Pesticides to Wildlife. Resource Publication 153. Washington, DC: U.S. Government Printing Office, 1984., p. 23

Hazardous Substances Data Bank (HSDB)

LD50; Species: Coturnix coturnix (Japanese quail) 2-month old males; oral 17.8 mg/kg (95% confidence limit: 15.0-21.2 mg/kg) /purity 94.5%/

U.S. Department of the Interior, Fish and Wildlife Service. Handbook of Toxicity of Pesticides to Wildlife. Resource Publication 153. Washington, DC: U.S. Government Printing Office, 1984., p. 23

Hazardous Substances Data Bank (HSDB)

LD50; Species: Anas platyrhynchos (Mallard duck) female; oral 75.6 mg/kg (95% confidence limit: 35.4-161 mg/kg) /purity 99%/

U.S. Department of the Interior, Fish and Wildlife Service. Handbook of Toxicity of Pesticides to Wildlife. Resource Publication 153. Washington, DC: U.S. Government Printing Office, 1984., p. 23

Hazardous Substances Data Bank (HSDB)

For more Ecotoxicity Values (Complete) data for CHLORPYRIFOS (79 total), please visit the **HSDB record page**.

Hazardous Substances Data Bank (HSDB)

13.1.26 Ecotoxicity Excerpts

/BIRDS and MAMMALS/ Dietary 11-day toxicant feeding tests were used to determine effects of chlorpyrifos on mallards. Avoidance of food was noted at all concentrations tested (56-1124 ppm) with consequential decrease in weight growth.

Kenaga EE et al; Astm Spec Tech Publ; (STP 693, Avian Mamm Wildl Toxicol): 36-44 (1979)

Hazardous Substances Data Bank (HSDB)

/BIRDS and MAMMALS/ This /study/ was designed to determine the effect of using two different ages of mallard (Anas platyrhynchos) adults within the first breeding season on reproductive tests under standard Toxic Substances Control Act avian reproductive guidelines. The adult age groups were 7 and 11 months at test initiation. The test chemical was an organophosphate insecticide, chlorpyrifos. Chlorpyrifos exposure reduced adult body weight, brain acetylcholinesterase activity, egg production, egg shell thickness, egg weight, and day 0 duckling weight in both age groups. Statistically, adult age affected only duckling day 14 weight. However, three of the 7 month hens produced phenotypically different ducklings, suggesting the presence of a different genotype which may have impacted the day 14 weight. Overall age ranging between 7 and 11 months at test initiation did not affect this mallard reproductive test. In addition, the results of this study demonstrate the importance of using phenotypically and genotypically similar test birds.

PMID:3789812

Gile JD, Meyers SM; Arch Environ Contam Toxicol 15 (6): 751-6 (1986)

Hazardous Substances Data Bank (HSDB)

/BIRDS and MAMMALS/ No significant reproductive effects were observed for mallards receiving 8 ppm (mg/kg of feed) chlorpyrifos in their diet. Birds receiving 80 ppm chlorpyrifos hatched significantly ($p<0.05$) fewer ducklings per successful nest (5.8) than control (10.2). None of the ducklings on treatment ponds survived to 7 days. Control birds produced 8.4 ducklings per successful nest surviving 7 days or longer. Birds in the 80 ppm treatment group consumed less feed than did controls ($p<0.01$). Weight loss from reduced feed /intake/ did not /result/ to the extent expected, indicating that the birds supplemented their diets with natural foods found in and around the ponds. In spite of the relatively low treated feed consumption, brain acetylcholinesterase was significantly ($p<0.05$) depressed (57% of controls) for 80 ppm treated birds. Studies on indoor penned mallards fed 80 ppm chlorpyrifos in their diet also resulted in acetylcholinesterase depression to the same extent but at much higher feed consumption levels.

PMID:2431661

Meyers SM, Gile JD; Arch Environ Contam Toxicol 15 (6): 757-61 (1986)

Hazardous Substances Data Bank (HSDB)

/BIRDS and MAMMALS/ Tests were conducted to determine the dietary concentrations at which 14-d-old bobwhite (Colinus virginianus) chicks could discriminate between food treated (TRT) with two organophosphorus (OP) insecticides (chlorpyrifos and **methyl parathion**) and untreated (UNT) food. Results of subacute dietary LC50 tests using one feeder of TRT food per cage were compared with those of tests in which birds were presented with two feeders (one TRT and one UNT, 1:1) or 10 feeders (five TRT and five UNT, 5:5; or nine TRT and one UNT, 9:1). The dietary concentration above which birds discriminated between TRT and UNT feeders by consuming a greater proportion of UNT food was defined as the discrimination threshold (DT). The DT occurred at sublethal dietary concentrations in all chlorpyrifos tests (DT = 45 ppm in 1:1 test, 24 ppm in 5:5 test and 69 ppm in 9:1 test; LC50 = 647 ppm) but increased in the **methyl parathion** tests as the number of choices and the relative proportion of TRT feeders increased (DT = 10 ppm in 1:1 test, 46 ppm in 5:5 test and >126 ppm in 9:1 test; LC50 = 91 ppm). The different responses were probably due to differences in the intensity of sensory cues presented by the two chemicals as the chicks developed conditioned aversions to them. In all tests, mortality was inversely related to total food consumption. No relationship was found between mortality and the amount of active ingredient ingested per bird-day. Consequently, the ability to locate UNT feeders was more important than the amount of chemical ingested. When alternative food choices exist, vulnerability to poisoning can be influenced by the number and relative abundance of those choices, as well as a bird's ability to detect the chemical.

Bennett RS; Environ Toxicol Chem 8 (8): 731-8 (1989)

Hazardous Substances Data Bank (HSDB)

For more Ecotoxicity Excerpts (Complete) data for CHLORPYRIFOS (52 total), please visit the **HSDB record page**.

Hazardous Substances Data Bank (HSDB)

13.1.27 Ongoing Test Status

The following link will take the user to the National Toxicology Program (NTP) Test Agent Search Results page, which tabulates all of the "Standard Toxicology & Carcinogenesis Studies", "Developmental Studies", and "Genetic Toxicity Studies" performed with this chemical. Clicking on the "Testing Status" link will take the user to the status (i.e., in review, in progress, in preparation, on test, completed, etc.) and results of all the studies that the NTP has done on this chemical.[Available from, as of June 3, 2014: http://ntp-apps.niehs.nih.gov/ntp_tox/index.cfm?fuseaction=ntpsearch.searchresults&searchterm=2921-88-2]

Hazardous Substances Data Bank (HSDB)

13.1.28 TSCA Test Submissions

Chlorpyrifos (CAS # 2921-88-2) was evaluated for acute oral toxicity in fasted Fischer 344-derived CDF albino rats (6/sex/group) receiving doses of 250, 500, 1000, and 2000 mg/kg by oral gavage. Like female groups also received the low doses of 63 and 130 mg/kg, while 2 additional groups of males received doses of 630 and 800 mg/kg bodyweight. Mortality associated with treatment occurred from Day 2 to Day 4 post-gavage and, based on the moving average method of Thompson and Weil, was consistent with oral LD50's (with 95% confidence limits) of 774 (687-913) and 235 (164-386) mg/kg bodyweight, respectively, for male and female rats. During 14-day post-gavage observation, all levels of treatment were associated with signs of toxicity including lethargy, rough hair coat, anorexia, diarrhea, excess salivation, watery eyes, labored or rapid shallow breathing, body tremors, and convulsions. All surviving rats gained weight during observation and lacked any treatment-related gross lesions upon necropsy. Accumulated secretions about periocular, perinasal and perioral hair, and fluid fecal-soiled perineum characterized the nonspecific lesions among male and female decedents. Internally, lesions of the gastrointestinal tract were more common among female lethalities, and included decreased ingesta with gaseous distention, peritonitis, and gastric hyperemia with erosions, ulcers and hemorrhage. Isolated cases of thymic atrophy or lobular irregularities of the liver, and thymic hemorrhage were also reported in the male study victims.

Dow Chem Co; Chlorpyrifos: Acute Toxicological Properties and Industrial Handling Hazards; 01/08/81; EPA Document No. 88-9200018925; Fiche No. OTS0539346

Hazardous Substances Data Bank (HSDB)

Chlorpyrifos (CAS # 2921-88-2) was evaluated for eye irritation in 9 New Zealand white rabbits administered 0.1 mL instillations in right eye (6/9) or left eye (3/9) conjunctival sacs, the untreated eyes serving as controls. Following a 30-minute exposure, the 3 treated left eyes were rinsed and the rabbits' right eyes treated as before, but left unwashed for the duration of study. All rabbits blinked excessively upon instillation of the test material indicating minimal discomfort, however no further signs of irritation were noted at any of 5 interval examinations for conjunctival, corneal, or iridic changes throughout 8-day post-treatment observation.

Dow Chem Co; Chlorpyrifos: Acute Toxicological Properties and Industrial Handling Hazards; 01/08/81; EPA Document No. 88-9200018925; Fiche No. OTS0539346

Hazardous Substances Data Bank (HSDB)

Chlorpyrifos (CAS # 2921-88-2) was evaluated for primary dermal irritation in 6 New Zealand white rabbits administered 0.5 mL percutaneous applications upon both abraded and intact sites under semi-occluded wrap for 24 hours. The irritative response to treatment was characterized by moderate erythema, slight to moderate edema, superficial chemical burn (4/6), and irreversible burn (2/6) which, by test criteria, established chlorpyrifos as dermally corrosive in rabbits.

Dow Chem Co; Chlorpyrifos: Acute Toxicological Properties and Industrial Handling Hazards; 01/08/81; EPA Document No. 88-9200018925; Fiche No. OTS0539346

Hazardous Substances Data Bank (HSDB)

Chlorpyrifos (CAS # 2921-88-2) was evaluated for acute dermal toxicity in New Zealand white rabbits (2/sex/dose level) administered undiluted percutaneous applications of 250, 500, 1000, 2000, and 4000 mg/kg upon clipped trunks under occluded wrap. After 24 hours, all application sites were undressed and thoroughly washed of any test material for immediate evaluation of any irritative reactions. Rabbits were also observed frequently throughout the exposure and weekly thereafter for any signs of systemic toxicity. Mortality from Day 3 to Day 6 was consistent with an acute dermal LD50 of 1303 (736-3057, 95% confidence limits) mg/kg bodyweight, based on a moving average method of Thompson and Weil. Irritative signs included slight to marked erythema, slight to moderate edema, and slight necrosis. All treated rabbits exhibited lethargy, and 1/4 of the 250 mg/kg exposure also demonstrated hypersensitivity 4.5 hours post-treatment. Other overt signs of toxicity included hyperemia or congestion at the application site, perioral matting of fur due to excessive salivation, and perineal soiling. Upon necropsy, all rabbits exhibited treatment-related gastrointestinal lesions including gastric hemorrhage and erosions, decreased ingesta, mucous or gas, fluidity of lower bowel contents, and/or cecal petechial hemorrhage. Among 2000 and 4000 mg/kg rabbits, livers with small pale foci or an exaggerated lobular pattern were also observed. Local reactions persisted in 2 rabbits surviving 3 weeks post-treatment and were characterized by slightly roughened skin and flaky debris at the application sites.

Dow Chem Co; Chlorpyrifos: Acute Toxicological Properties and Industrial Handling Hazards; 01/08/81; EPA Document No. 88-9200018925; Fiche No. OTS0539346

Hazardous Substances Data Bank (HSDB)

For more TSCA Test Submissions (Complete) data for CHLORPYRIFOS (6 total), please visit the HSDB record page.

Hazardous Substances Data Bank (HSDB)

13.1.29 Populations at Special Risk

Young persons under 18 yr, expectant or nursing mothers, /alcoholics/, or persons for whom work with toxic chemicals is contraindicated on account of their state of health /are at elevated risk from the toxic effects of organophosphorus pesticides. Those individuals with/ organic diseases of the CNS, mental disorders & epilepsy, pronounced endocrine & vegetative disorders, pulmonary tuberculosis, bronchial asthma, chronic respiratory diseases, cardiovascular diseases and circulatory disorders, gastrointestinal diseases (peptic ulcer), gastroenterocolitis, diseases of the liver & kidneys, eye diseases (chronic conjunctivitis and keratitis) /are at elevated risk from exposure/. /Organophosphorus pesticides/

International Labour Office. Encyclopedia of Occupational Health and Safety. Vols. I&II. Geneva, Switzerland: International Labour Office, 1983., p. 1646

Hazardous Substances Data Bank (HSDB)

Those individuals who are exposed to organophosphorus pesticides with pre-existing/ organic diseases of the central nervous system, mental disorders & epilepsy, pronounced endocrine & vegetative disorders, pulmonary tuberculosis, bronchial asthma, chronic respiratory diseases, cardiovascular diseases & circulatory disorders, gastrointestinal diseases (peptic ulcer), gastroenterocolitis, diseases of liver & kidneys, eye diseases (chronic conjunctivitis & keratitis) /are at elevated risk from exposure/. The blood cholinesterase activity must be determined before work starts. In the event of prolonged work periods, this activity should be determined at intervals of 3-4 days. Persons exhibiting a fall in cholinesterase activity of 25% or more must be transferred to other work where they are not exposed to organophosphorus pesticides until this activity is completely restored. Persons with initial signs of indisposition should cease work with pesticides. /Organophosphorus pesticides/

International Labour Office. Encyclopedia of Occupational Health and Safety. Vols. I&II. Geneva, Switzerland: International Labour Office, 1983., p. 1646

Hazardous Substances Data Bank (HSDB)

13.2 Ecological Information

13.2.1 EPA Ecotoxicity

Pesticide Ecotoxicity Data from EPA

EPA Pesticide Ecotoxicity Database

13.2.2 US EPA Regional Screening Levels for Chemical Contaminants

Resident Soil (mg/kg)	6.30e+00
Industrial Soil (mg/kg)	8.20e+01
Tapwater (ug/L)	8.40e-01
Risk-based SSL (mg/kg)	1.20e-02
Chronic Oral Reference Dose (mg/kg-day)	1.00e-03
Fraction of Contaminant Absorbed in Gastrointestinal Tract	1
Fraction of Contaminant Absorbed Dermally from Soil	0.1

EPA Regional Screening Levels for Chemical Contaminants at Superfund Sites

13.2.3 US EPA Regional Removal Management Levels for Chemical Contaminants

Resident Soil (mg/kg)	6.30e+01
Industrial Soil (mg/kg)	8.20e+02
Tapwater (ug/L)	8.40e+00
Chronic Oral Reference Dose (mg/kg-day)	1.00e-03
Fraction of Contaminant Absorbed in Gastrointestinal Tract	1
Fraction of Contaminant Absorbed Dermally from Soil	0.1

EPA Regional Screening Levels for Chemical Contaminants at Superfund Sites

13.2.4 ICSC Environmental Data

The substance is very toxic to aquatic organisms. This substance may be hazardous to the environment. Special attention should be given to birds and bees. Bioaccumulation of this chemical may occur along the food chain, for example in fish and algae. The substance may cause long-term effects in the aquatic environment. This substance does enter the environment under normal use. Great care, however, should be taken to avoid any additional release, for example through inappropriate disposal.

ILO International Chemical Safety Cards (ICSC)

13.2.5 Environmental Fate/Exposure Summary

Chlorpyrifos' production may result in its release to the environment through various waste streams; its use as an insecticide will result in its direct release to the environment. If released to air, a vapor pressure of 2.02X10-5 mm Hg at 25 °C indicates chlorpyrifos will exist in both the vapor and particulate phases in the atmosphere. Vapor-phase chlorpyrifos will be degraded in the atmosphere by reaction with photochemically-produced **hydroxyl** radicals; the half-life for this reaction in air is estimated to be 5 hours. Particulate-phase chlorpyrifos will be removed from the atmosphere by wet or dry deposition. Chlorpyrifos absorbs light greater than 295 nm and photolysis has been observed in air. The summer photolysis half-life is estimated as 4.2 days with the winter photolysis half-life estimated as 9.7 days. If released to soil, chlorpyrifos is expected to have low to no mobility based upon a measured Koc range of 995 to 31,000. Volatilization from moist soil surfaces may be an important fate process based upon a Henry's Law constant of 3.55X10-5 atm-cu m/mole. The volatilization half-life of chlorpyrifos from 3 moist soils was in the range of 45-163 hours using an airstream of 1 km/hr passed over the soil and a volatilization half-life of 3 days was observed from moist soil surfaces in a laboratory study. A 0.64% volatilization after 3.2 days indicates that chlorpyrifos volatilizes slowly from soil. In several tests lasting 7-11 days, chlorpyrifos applied to turf lost a mean amount of 8.25% to volatilization. Photodegradation on soil surfaces exposed to sunlight has been observed to occur. Results of laboratory studies using non-sterile versus sterilized soils have shown that biodegradation is an important fate process. Field dissipation half-lives can range from 4-139 days. Half-lives can typically range from 33-56 days for soil incorporated applications and 7-15 days for surface applications. The primary route of degradation is transformation to **3,5,6-trichloropyridin-2-ol**, which is subsequently degraded to organochlorine compounds and **carbon dioxide**. If released into **water**, chlorpyrifos is expected to adsorb to suspended solids and sediment based upon the Koc. Volatilization from **water** surfaces is expected to be an important fate process based upon this compound's Henry's Law constant. Estimated volatilization half-lives for a model river and model lake are 2.2 and 21.5 days, respectively. However, volatilization from **water** surfaces is expected to be attenuated by adsorption to suspended solids and sediment in the **water** column. The estimated volatilization half-life from a model pond is 2 years if adsorption is considered. Measured BCF values of 58 to 2880 suggest bioconcentration in aquatic organisms is moderate to very high. Direct photo-transformation of chlorpyrifos was observed in buffer solutions and river waters, under both natural and artificial lighting conditions with approximate 50% conversion after 30-40 days. The hydrolysis half-lives at 25 °C in aqueous buffers at pH 5, pH 7 and pH 9 were 72, 72 and 16 days respectively. Biodegradation is expected to be an important fate process. Chlorpyrifos degraded about 40% faster in active (natural) **water** as compared to the same **water** which had been sterilized with **formalin**. The reported half-life in active **water** was 24.5 days. The aerobic half-life in nursery recycling pond **water** was 30 and 52 days at 22 and 10 °C, respectively; the anaerobic half-life was 52 days at 22 °C. Occupational exposure to chlorpyrifos may occur through inhalation and dermal contact with this compound at workplaces where chlorpyrifos is produced or used. Monitoring and use data indicate that the general population may be exposed to chlorpyrifos via inhalation of ambient air, ingestion of food and drinking **water**, and dermal contact with this compound. (SRC)

Hazardous Substances Data Bank (HSDB)

13.2.6 Artificial Pollution Sources

Chlorpyrifos' production may result in its release to the environment through various waste streams; its use as an insecticide(1) will result in its direct release to the environment(SRC).

(1) MacBean C, ed; e-Pesticide Manual. 15th ed., ver. 5.1, Alton, UK; British Crop Protection Council. Chlorpyrifos (2921-88-2) (2008-2010)

Hazardous Substances Data Bank (HSDB)

13.2.7 Environmental Fate

TERRESTRIAL FATE: Based on a classification scheme(1), measured Koc values of 995 to 31,000(2), indicate that chlorpyrifos is expected to have low to no mobility in soil(SRC). Volatilization of chlorpyrifos from moist soil surfaces is expected to be an important fate process(SRC) given a Henry's Law constant of 3.55X10-5 atm-cu m/mole(3). The volatilization half-life of chlorpyrifos from 3 moist soils was in the range of 45-163 hours using an airstream of 1 km/hr passed over the soil(2). An experimental volatilization half-life of 3 days was determined for chlorpyrifos from moist soil surfaces in one laboratory study(4). Chlorpyrifos volatilizes slowly from dry soil surfaces(SRC); 0.64% of applied chlorpyrifos volatilized after 3.2 days in one study(5). In several tests lasting 7-11 days, chlorpyrifos applied to turf lost a mean amount of 8.25% to volatilization(6). Photodegradation of chlorpyrifos on soil surfaces exposed to sunlight has been observed to occur(7). Results of laboratory studies using non-sterile versus sterilized soils(2) have shown that biodegradation is an important fate process(SRC). In one study, half-lives of one week (sandy loam) and 2.5 weeks (organic) in non-sterile soils versus half-lives of 17 and 40 weeks in the sterilized soils were observed respectively(8). A compilation of field dissipation half-lives reports a half-life range of 4-139 days with an approximate median of 43 days(9). Field dissipation half-lives can typically range from 33-56 days for soil incorporated applications and 7-15 days for surface applications(10). The primary route of degradation is transformation to **3,5,6-trichloropyridin-2-ol**, which is subsequently degraded to organochlorine compounds and **carbon dioxide**(10).

*(1) Swann RL et al; Res Rev 85: 17-28 (1983) (2) Racke KD; Rev Environ Contam Toxicol 131: 1-150 (1993) (3) Cetin B et al; Atmos Environ 40: 4538-4546 (2006) (4) Voutsas E et al; Chemosphere 58: 751-758 (2005) (5) Ferrari F et al; J Environ Qual 32: 1623-1633 (2003) (6) Haith DA et al; J Environ Qual 31: 724-729 (2002) (7) Graebing P, Chib JS; J Agric Food Chem 52: 2606-14 (2004) (8) Miles JRW; Bull Environ Contam Toxicol 22: 312 (1979) (9) USDA; Agric Res Service. ARS Pesticide Properties Database. Last Updated Nov 6, 2009. Chlorpyriofs (2912-88-2). Available from, as of April 3, 2014: **https://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/userguide/ARSPesticideDatabaseUSDA2009.pdf** (10) MacBean C, ed; e-Pesticide Manual. 15th ed., ver. 5.1, Alton, UK; British Crop Protection Council. Chlorpyrifos (2921-88-2) (2008-2010)*

Hazardous Substances Data Bank (HSDB)

TERRESTRIAL FATE: A laboratory experiment was conducted to study the persistence and metabolism of chlorpyrifos in Gangetic Alluvial soil of West Bengal and also to evaluate their effect on the availability of the major plant nutrients (N, P and K) in soil following the application of chlorpyrifos at 1 kg (T1), 10 kg (T2) and 100 kg (T3) a.i./ha. The dissipation followed first order kinetics and the calculated half-life (T1/2) values ranged from 20 to 37 days. The primary metabolite of chlorpyrifos, 3,5,6-trichloropyridinol (TCP) was detected from 3rd day after application and was at maximum on 30th day which decreased progressively to non-detectable level (NDL) on 120th day for all the treatment doses. The secondary metabolite **3,5,6-trichloro-2-methoxy pyridine** (TMP) was detected on 30th, 15th and 7th day in T1, T2 and T3 doses respectively which decreased to NDL during 90-120th day. ...

PMID:15894348
Sardar D, Kole RK; Chemosphere 61 (9): 1273-80 (2005)

Hazardous Substances Data Bank (HSDB)

MODERATELY RESIDUAL ON PLANT SURFACES, QUITE RESIDUAL ON INERT SURFACES /SUCH AS WOOD/. VOLATILE ENOUGH TO FORM RESIDUES ON NEARBY SURFACES ...

Spencer, E. Y. Guide to the Chemicals Used in Crop Protection. 7th ed. Publication 1093. Research Institute, Agriculture Canada, Ottawa, Canada: Information Canada, 1982., p. 123

Hazardous Substances Data Bank (HSDB)

(14)C- & (36)Cl-labeled dursban was applied to cranberry bean & corn leaves. Within 3 days about 80% of radioactivity was lost presumbably by volatilization.

Menzie, C.M. Metabolism of Pesticides. U.S. Department of the Interior, Bureau of Sport Fisheries and Wildlife, Publication 127. Washington, DC: U.S. Government Printing Office, 1969., p. 194

Hazardous Substances Data Bank (HSDB)

For more Environmental Fate (Complete) data for CHLORPYRIFOS (6 total), please visit the HSDB record page.

Hazardous Substances Data Bank (HSDB)

13.2.8 Environmental Biodegradation

AEROBIC: Chlorpyrifos, applied at a concentration of 50 mg/plant, to cauliflower and brussels sprout crops treated with organic fertilizers had measured soil half-lives ranging from 19 to 41 days in soils with an organic carbon content ranging from 0.92 to 2.69%(1). Measured half-lives of 4 weeks (clay loam) and 12 weeks (silt loam) in non-sterile soils versus 24 weeks in both soils sterilized by autoclaving was indicative of measurable biodegradation(2). Half-lives of one week (sandy loam) and 2.5 weeks (organic) in non-sterile soils versus half-life of 17 and 40 weeks, respectively, in the sterilized soils was observed(3). After 4 weeks of incubation, 33-38% of applied chlorpyrifos was degraded in a clay loam sterilized by autoclaving or gamma irradiation; 62% degradation was observed in the non-sterile soil(4). The degradation rate in non-sterile sandy loam and muck soils was found to be significantly faster than in the sterilized soils with the degradation rate in non-sterile soil decreasing with a decrease in temperature (3 to 28 °C) and variable with moisture content(5,6). After applying 300 ppm chlorpyrifos to autoclaved soil, approximately 80% remained after 30 days, but only 50% remained in a non-sterile soil(7). The half-life of chlorpyrifos in Hessaraghatta soil (pH 7.09, clay content 20.2%) was 2.8-11.5 days, the half-life in Chettalli soil (pH 6.24, clay content 22.5%) was 10-25.1 days and the half-life in Bellary soil (pH 9, clay content 33.2%) was 1.6-8.7 days(8). The half-life of chlorpyrifos in a field measurement using a sandy soil was 81 days(9).

(1) Rouchaud J et al; Arch Environ Contam Toxicol 31: 98-106 (1996C) (2) Getzin LW; J Econ Entomol 74: 158 (1981) (3) Miles JRW; Bull Environ Contam Toxicol 22: 312 (1979) (4) Getzin LW, Rosefield I; J Agric Food Chem 16: 598 (1968) (5) Miles JRW et al; J Environ Sci Health B18: 705 (1983) (6) Miles JRW et al; Journal Environ Sci Health B19: 237 (1984) (7) Racke KD; Rev Environ Contam Toxicol 131: 1-150 (1993) (8) Awasthi MD, Prakash NB; Pestic Sci 50: 1-4 (1997) (9) Aylmore LAG et al; pp. 128-36 in Water Qual Model Proc Int Symp Heatwole C ed., St Joseph, MI: Amer Soc Agric Eng (1995)

Hazardous Substances Data Bank (HSDB)

AEROBIC: Chlorpyrifos, present at 10 mg/kg, had measured half-lives ranging from 20.3 to 23.7 days in sediment from an urban freshwater stream(1). The half-life of chlorpyrifos in a sea water-sediment system was 24 days but was well in excess of the 28 day experimental period when the system was sterilized with formalin(2). In a shake-flask screening test similar to a river die-away test, chlorpyrifos degraded about 40% faster in active (natural) water as compared to the same water which had been sterilized with formalin(3). The reported half-life in active water was 24.5 days and in sterilized water was 35 days(3). Chlorpyrifos, present at 100 mg/L, reached 0.2% of its theoretical BOD in 2 weeks using an activated sludge inoculum at 30 mg/L in the Japanese MITI test(4); total degradation over the 2-week period was 9.3%(4).

*(1) Bondarenko S, Gan J; Environ Toxicol Chem 23: 1809-1814 (2004) (2) Schimmel SC et al; J Agric Food Chem 31: 104 (1983) (3) Walker WW; Development of a Fate/Toxicity Screening Test USEPA-600/S4-84-074 (1984) (4) NITE; Chemical Risk Information Platform (CHRIP). Biodegradation and Bioconcentration. Tokyo, Japan: Natl Inst Tech Eval. Available from, as of April 7, 2014: **https://www.safe.nite.go.jp/english/db.html***

Hazardous Substances Data Bank (HSDB)

ANAEROBIC: Chlorpyrifos, present at 10 mg/kg, had an average half-life of 223 days in sediment from a freshwater stream under anaerobic conditions(1). Under anaerobic conditions, the half-life of chlorpyrifos was 31 to 59 days in loamy and clay soils, but 150 to 200 days in pond sediments(2). The initial half-life of chlorpyrifos under anaerobic conditions in a nursery recycling pond was about 52 days at 22 °C(3).

(1) Bondarenko S, Gan J; Environ Toxicol Chem 23: 1809-1814 (2004) (2) Racke KD; Rev Environ Contam Toxicol 131: 1-150 (1993) (3) Lu j et al; J Environ Qual 35: 1795-1802 (2006)

Hazardous Substances Data Bank (HSDB)

13.2.9 Environmental Abiotic Degradation

The rate constant for the vapor-phase reaction of chlorpyrifos with photochemically-produced hydroxyl radicals has been measured as 7.6X10-11 cu cm/molecule-sec at 25 °C(1). This corresponds to an atmospheric half-life of about 5 hours at an atmospheric concentration of 5X10+5 hydroxyl radicals per cu cm(2). Chlorpyrifos has a gas-phase UV-absorption maximum at 280 nm and it absorbs through 320 nm(1) indicating it may be susceptible to direct photolysis by sunlight(SRC). The quantum yield of chlorpyrifos is reported as 0.018(3), and the summer photolysis half-life is estimated as 4.2 days with the winter photolysis half-life estimated as 9.7 days(3). Direct photo-transformation was observed in buffer solutions and river waters, under both natural and artificial lighting conditions with approximate 50% conversion after 30-40 days(3). The rate constant for the reaction of hydroxyl radicals in aqueous solutions has been measured as 1.5X10+13 L/mol-hr(4); this corresponds to an aquatic half-life of 192 days at an aquatic concentration of 1X10-17 hydroxyl radicals per liter(5).

*(1) Hebert VR et al; J. Agric Food Chem 48: 1922-1928 (2000) (2) US EPA; Estimation Program Interface (EPI) Suite. Ver. 4.11. Nov, 2012. Available from, as of April 4, 2014: (3) World Health Org; WHO Specifications and Evaluations for Public Health Pesticides. Chlorpyrifos (March 2009). Available from, as of April 2, 2014: f (4) Armbrust KL; Environ Toxicol Chem 19(9): 2175-2180 (2000) (5) Mill T et al; Science 207: 886-887 (1980) **https://www.epa.gov/oppt/exposure/pubs/episuitedl.htm https://www.who.int/whopes/quality/Chlorpyrifos_WHO_specs_eval_Mar_2009.pd***

Hazardous Substances Data Bank (HSDB)

The hydrolysis half-life of chlorpyrifos at 20 °C buffered solution was measured as 53.0 days at pH 7.4 and 120 days at pH 6.1(1,2). At 25 °C, the hydrolysis rate was found to be relatively independent of pH from pH 1 to pH 7 with a half-life of about 78 days(3). In buffered distilled water, half-lives of 62.7, 35.3, and 22.8 days were measured at pH 4.7, 6.9, and 8.1, respectively at 25 °C; half-lives of 210, 99,and 54 days were measured at pH 4.7, 6.9, and 8.1, respectively at 15 °C(4). The products of the aqueous hydrolysis of chlorpyrifos include 3,5,6-trichloro-2-pyridinol and various trichloropyridyl phosphorothioates(4). The aqueous hydrolysis of chlorpyrifos is catalyzed significantly by the presence of Cu(+2) ions(4-7); the addition of Cu(+2) ions to both a distilled water and natural water solution of chlorpyrifos at pH 8.2-8.3 lowered the half-lives from several weeks to less than one day(7). Chlorpyrifos hydrolyzed 16 times faster in natural canal water containing metal ions than in distilled water at the same pH and temperature(4); however, the level of catalyzing metal ions present in most natural waters is about an order of magnitude lower than necessary to enhance the hydrolysis rate(8). The hydrolysis half-life in three different natural waters at 25 °C was measured to be about 48 days with metal catalysis unimportant(8). The neutral and acid rate of hydrolysis of chlorpyrifos was not substantially altered when absorbed to sediments in laboratory studies as compared to hydrolysis in natural water only; however, the hydrolysis rate was retarded somewhat under alkaline conditions in the sorbed-state(8). Using an EPA test method, the hydrolysis half-lives at 25 °C in aqueous buffers at pH 5, pH 7 and pH 9 were 72, 72 and 16 days respectively(3). In another study using an EPA test method, the hydrolysis half-lives at 30 °C in aqueous buffers at pH 4, pH 7 and pH 9 were 72, 40 and 24 days respectively(3).

*(1) Freed VH et al; Environ Health Perspect 30: 79 (1979) (2) Freed VH et al; J Agric Food Chem 27: 706 (1979) (3) Macalady DL, Wolfe NL; J Agric Food Chem 31: 1139 (1983) (4) Meikle RW, Youngson CR; Arch Environ Contam Toxicol 7: 13 (1978) (5) Blanchet PF, St George A; Pest Sci 13: 85 (1982) (6) Mortland MM, Raman KV; J Agric Food Chem 15: 163 (1967) (7) Chapman RA, Harris C; Journal Environ Sci Health B19: 397 (1984) (8) Macalady DL, Wolfe NL; J Agric Food hem 33: 167 (1985) (9) World Health Org; WHO Specifications and Evaluations for Public Health Pesticides. Chlorpyrifos (March 2009). Available from, as of April 2, 2014: **https://www.who.int/whopes/quality/Chlorpyrifos_WHO_specs_eval_Mar_2009.pdf***

Hazardous Substances Data Bank (HSDB)

Chlorpyrifos absorbs light greater than 295 nm and photolysis has been observed in air and aqueous environments(1). Based on laboratory experimental data, the following photolysis half-lives in water at 40 deg N latitude have been estimated: mid-summer surface conditions - 31 days, mid-winter surface conditions - 345 days, mid-summer 1 m depth pure water - 43 days, mid-summer 1 m depth river water with average light attenuation - 2.7 years(2). Photolysis half-life of 22 days in pure water (at surface conditions) experimentally determined under midday summer sunlight was observed in California(3). The photochemical conversion half-life in air has been reported to be 2.27 hours(4). The photodegradation half-life of a thin film of chlorpyrifos on a glass plate exposed to environmentally relevant wavelengths from a UV light was reported to be 52.45 hours(5). 3,5,6-Trichloro-2-pyridinol was identified as a photodegradation product of chlorpyrifos in both air and aqueous environments(1). The following compounds were identified as photodegradation products of chlorpyrifos in either hexane or methanol solution: O,O-diethyl O-(3,5-dichloro-2-pyridyl)phosphorothioate, O,O-diethyl O-(3,6-dichloro-2-pyridyl)phosphorothioate, O,O-diethyl O-(5,6-dichloro-2-pyridyl)phosphorothioate and O,O-diethyl O-

(monochloro-2-pyridyl)phosphorothioate(1). In a study comparing the photolytic degradation of chlorpyrifos, present at 5 ug/g, in both moist and air-dry microbially viable sandy soils, the irradiated half-life on moist soil was 240 hours, compared to 340 hours on air-dry soil(6). In a dark control, the degradation half-life in moist soil was 420 hours and in air-dry soil was 700 hours, with these longer half-lives demonstrating that chlorpyrifos is photolyzed(6). The shorter half-life in the moist soil was attributed to the increased hydrolysis and microbial activity of the moist soil(6).

(1) Racke KD; Rev Environ Contam Toxicol 131: 1-150 (1993) (2) Dilling WL et al; Environ Sci Technol 18: 540 (1984) (3) Meikle RW et al; Arch Environ Contam Toxicol 12: 189 (1983) (4) Kilsenko MA, Pismennaya MV; Gig Tr Prof Zabol 6: 56 (1979) (5) Chem ZM et al; Ind Eng Chem Prod Res Dev 23: 5 (1984) (6) Graebing P, Chib JS; J Agric Food Chem 52: 2606-14 (2004)

Hazardous Substances Data Bank (HSDB)

13.2.10 Environmental Bioconcentration

A measured log BCF value for chlorpyrifos of 2.67 (BCF of 468) was determined from a 35-day flowing-water study using mosquito fish(1). An experimental log BCF value of 2.50 was determined from a static ecosystem study using mosquito fish(2). In a review of the environmental fate of chlorpyrifos, BCF values of 100-4,667 were reported in a variety of fish under field conditions(3). BCF values of 58-1,000 were reported in a variety of fish using flow-through aquariums(3). A BCF of 2727 was measured in Bluegill (Lepomis macrochirus)(4). A BCF range of 49-2880 was measured in fish for chlorpyrifos using carp (Cyprinus carpio) which were exposed over an 8-week period at concentrations of 1-10 ug/L(5). According to a classification scheme(6), the BCF range suggests the potential for bioconcentration in aquatic organisms is moderate to very high(SRC), provided the compound is not metabolized by the organism(SRC).

(1) Veith GD et al; J Fish Res Board Can 36: 1040 (1979) (2) Kenaga EE; Environ Sci Technol 14: 553 (1980) (3) Racke KD; Rev Environ Contam Toxicol 131: 1-150 (1993) (4) Jackson SH et al; J Agric Food Chem 57: 958-967 (2009) (5) Chemicals Inspection and Testing Institute; Biodegradation and bioaccumulation data of existing chemicals based on the CSCL Japan. Japan Chemical Industry Ecology - Toxicology and Information Center. ISBN 4-89074-101-1 (1992) (6) Franke C et al; Chemosphere 29: 1501-14 (1994)

Hazardous Substances Data Bank (HSDB)

13.2.11 Soil Adsorption/Mobility

Koc values of 4,381 to 6,129 were measured in four different soils with organic carbon content varying from 0.88 to 6.55%; virtually complete adsorption was noted in soil of organic content of 31.65%(1). An average Koc value of 6,070 was determined in soil column studies using 3 agricultural soils(2). An experimental Koc value of 13,600 was reported for a single soil type(3). After incubation for 1 day in sediment from an urban freshwater stream, the Koc for chlorpyrifos was reported as 2,900 to 17,000(4). Koc values of 2740 and 995 were determined in a clay loam and high clay soil respectively, with a mean Koc of 1868(5). In a review of the environmental fate of chlorpyrifos, Koc values of 995-31,000 were reported in a variety of soils(6). Based on multiple Koc values, chlorpyrifos was assigned a selected Koc value of 9930(7). According to a classification scheme(8), these measured Koc values suggest that chlorpyrifos is expected to have low to no mobility in soil. Greater than 99% of chlorpyrifos applied to a loam soil remained in the upper 2.5 cm soil layer after periodic irrigation with overhead sprinklers indicating relative immobility(9). In laboratory studies using a sandy loam soil, chlorpyrifos was determined to be relatively immobile(10). In a simulated ecosystem study, the chlorpyrifos concentration in the sediment was as much as 4 times greater than in the water-phase(11). Chlorpyrifos applied to a natural pond was observed to rapidly absorb to bottom sediments(12). Koc of >7430 was observed with sediment in a nursery recycling pond study(13).

*(1) Felsot A, Dahm PA; J Agr Food Chem 27: 557 (1979) (2) McCall PJ et al; Bull Environ Contam Toxicol 24: 190 (1980) (3) Kenaga EE; Environ Sci Technol 14: 553 (1980) (4) Bondarenko S, Gan J; Environ Toxicol Chem 23: 1809-1814 (2004) (5) Kanazawa J; Environ Toxicol Chem 8: 477-84 (1989) (6) Racke KD; Rev Environ Contam Toxicol 131: 1-150 (1993) (7) USDA; Agric Res Service. ARS Pesticide Properties Database. Last Updated Nov 6, 2009. Chlorpyriofs (2912-88-2). Available from, as of April 3, 2014: **https://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/userguide/ARSPesticideDatabaseUSDA2009.pdf** (8) Swann RL et al; Res Rev 85: 17-28 (1983) (9) Pike KJ, Getzin LW; J Econ Entomol 74: 385 (1981) (10) Sharom MS et al; Water Res 14: 1095 (1980) (11) Neely WB; Int J Environ Stud 13: 101 (1979) (12) Hughes DN et al; Arch Environ Contam Toxicol 9: 269 (1980) (13) Lu J et al; J Environ Qual 35: 1795-1802 (2006)*

Hazardous Substances Data Bank (HSDB)

13.2.12 Volatilization from Water/Soil

The Henry's Law constant for chlorpyrifos is 3.55X10-5 atm-cu m/mole at 25 °C(1). This Henry's Law constant indicates that chlorpyrifos is expected to volatilize from water surfaces(2). Based on this Henry's Law constant, the volatilization half-life from a model river (1 m deep, flowing 1 m/sec, wind velocity of 3 m/sec)(2) is estimated as 2.2 days(SRC). The volatilization half-life from a model lake (1 m deep, flowing 0.05 m/sec, wind velocity of 0.5 m/sec)(2) is estimated as 21.5 days(SRC). However, volatilization from water surfaces is expected to be attenuated by adsorption to suspended solids and sediment in the water column. The estimated volatilization half-life from a model pond is about 2 years if adsorption is considered(3). In a laboratory study, 50 ppb of chlorpyrifos added to 10 liters of water was volatilized 85% in 24 hours(4). In marine sediment under moist and flooded conditions using a continuous flow system, volatilization of chlorpyrifos accounted for 0.8 to 1% loss during the first ten days of application(5). The volatilization half-life of chlorpyrifos from 3 moist soils was in the range of 45-163 hours using an airstream of 1 km/hr passed over the soil(4). The volatility of chlorpyrifos was studied under field conditions(6,7); following application of 1.5 kg/ha, the highest flux rates were observed in the first few hours after application, with particularly large values when heavy dew was present on the surface(6,7); flux rates usually declined to non-detectable levels by about noon each day(6,7). Chlorpyrifos applied to dry soil lost 0.64% of dose applied via volatilization after 3.2 days at an air temperature of 25 °C(8). In several tests lasting 7-11 days, chlorpyrifos applied to turf lost a mean amount of 8.25% to volatilization(9). In field tests studying volatilization of chlorpyrifos applied to potato crops, as much as 65% of applied dose was estimated to have volatilized, most within the first few days(10). An experimental volatilization half-life of 3 days was determined for chlorpyrifos from moist soil surfaces in a laboratory study(11).

(1) Cetin B et al; Atmos Environ 40: 4538-4546 (2006) (2) Lyman WJ et al; Handbook of Chemical Property Estimation Methods. Washington, DC: Amer Chem Soc pp. 15-1 to 15-29 (1990) (3) US EPA; EXAMS II Computer Simulation (1987) (4) Racke KD; Rev Environ Contam Toxicol 131: 1-150 (1993) (5) Kale SP et al; Chemosphere 39: 969-76 (1999) (6) Majewski MS et al; Atmos Environ 23: 929-38 (1989) (7) Majewski MS et al; Environ Sci Technol 24: 1490-97 (1990) (8) Ferrari F et al; J Environ Qual 32: 1623-1633 (2003) (9) Haith DA et al; J Environ Qual 31: 724-729 (2002) (10) Leistra M et al; Environ Sci Technol 40: 96-102 (2006) (11) Voutsas E et al; Chemosphere 58: 751-758 (2005)

Hazardous Substances Data Bank (HSDB)

13.2.13 Environmental Water Concentrations

GROUNDWATER: Chlorpyrifos was detected in 0.37% of 2459 groundwater samples collected from 20 of the nation's major hydrologic basins during the National Water Quality Assessment (1992 to 1996) at a maximum concentration of 0.013 ug/L(1). Chlorpyrifos was detected at a concentration of 0.04 ug/L in groundwater of a golf course in Cape Cod, MA(2). Waters from 21 wells and 2 springs located in a typically farmed, mostly agricultural PA watershed (the Mahantango Creek Watershed) were analyzed for chlorpyrifos during Dec 1985, Aug 1986, and Mar/Apr 1987(3); chlorpyrifos was applied in 1985 but not in 1986, and no chlorpyrifos was found in any sampling (< 4 ng/L)(3). Chlorpyrifos were detected in samples of cave spring waters collected from northeastern Oklahoma and northwestern Arkansas in 2006(4).

(1) Kolpin DW et al; Ground Water 38: 858-63 (2000) (2) Cohen SZ et al; Ground Wat Monit Rev 10: 160-73 (1990) (3) Pionke HB, Glotfelty DE; Water Res 23(8): 1031-7 (1989) (4) Bidwell JR et al; Arch Environ Toxicol 58: 286-298 (2010)

Hazardous Substances Data Bank (HSDB)

DRINKING WATER: Chlorpyrifos was detected in one water sample collected from 53 deep groundwater wells in a residential suburban community in Connecticut at a concentration of 0.06 ug/L(1). Chlorpyrifos was detected in about 9% of water samples collected 139 wells distributed among 13 different hydrogeological units in rural areas of Catalonia, Spain between 1997 and 1998(2). Chlorpyrifos was detected in 3% of 206 drinking water reservoir samples collected from 15 reservoirs in the northern Great Plains of North America in 2003 at a maximum concentration of 20.1 ng/L(3).

(1) Eitzer BD, Chevalier A; Bull Environ Contam Toxicol 62: 420-7 (1999) (2) Garrido T et al; Intern J Environ Anal Chem 78: 51-65 (2000) (3) Donald DB et al; Environ Health Perspect 115: 1183-1191 (2007)

Hazardous Substances Data Bank (HSDB)

SURFACE WATER: Chlorpyrifos was detected in surface water samples collected from seven sites in the Beijing Guanting reservoir in September and November 2003 and June and August 2004 at concentrations ranging from 0.30 to 1.89 ng/L, mean 1.5 ng/L(1). Chlorpyrifos was detected in surface water samples collected from 3 sites along the Patuxent River in Maryland during spring/summer 1995 at concentrations ranging from 9.2 to 190 ng/L, <0.0050 to 21 ng/L, and <0.0050 to 30 ng/L, respectively(2). Chlorpyrifos was detected in 3 of 949 water samples taken from 11 agricultural watersheds in southern Ontario during 1975-1977 at concentrations ranging from less than 0.01 ppb to 1.6 ppb(3,4). Chlorpyrifos was qualitatively identified in waters from Lake Erie and Lake St. Clair(5). Chlorpyrifos was detected in 5 out of 6 samples from the Segre River, Spain at 0.01 ug/L(6). Chlorpyrifos was detected at concentrations of less than 1 ng/L in the San Joaquin River and its tributaries(7). Chlorpyrifos was detected at 0-0.6 ppb in surface water in golf courses in North Carolina(8). Chlorpyrifos was detected in the South Platte River, CO at a max concentration of 0.22 ug/L in agricultural areas and a max concentration of 0.30 ug/L in urban areas(9). Chlorpyrifos concentrations of <15-312 ng/L were detected in waters from the Ebro River basin in Spain during 2001-2003 sampling(10). Surface water samples collected from lakes of Pirgacha Thana, Rangpur District, Bangladesh from May to July 2010 contained chlorpyrifor

levels of 0.544-0.895 ug/L(11). Water samples collected from two southern California watersheds in 2009 (Santa Clara River and Calleguas Creek) contained chlorpyrifos concentrations of 0.5-729.5 ng/L(12). Water samples collected at remote inland lake sites in Ontario Canada in 2003-2005 monitoring contained median chlorpyrifos concentrations of 0.02 ng/L (maximum 0.5 ng/L) (13).

(1) Xue N et al; Chemosphere 61: 1594-1606 (2005) (2) Harman-Fetcho JA et al; J Environ Qual 28: 928-38 (1999) (3) Braun He, Frank R; Sci Total Environ 15: 169 (1980) (4) Frank R et al; J Environ Qual 11: 497 (1982) (5) Great Lakes Water Quality Board; An Inventory of Chemical Substances Identified in the Great Lakes Ecosystem, Volume 1-Summary, Report to the Great Lakes Water Quality Board Windsor Ontario, Canada (1983) (6) Planas C et al; Chemosphere 34: 2393-2406 (1997) (7) Pereira WE et al; Environ Toxicol Chem 15: 172-80 (1996) (8) Ryals SC et al; Environ Toxicol Chem 17: 1934-42 (1998) (9) Kimbrough RA, Litke DW; Environ Sci Technol 30: 908-916 (1996) (10) Claver A et al; Chemosphere 64: 1437-1443 (2006) (11) Chowdhury AZ et al; Bull Environ Contam Toxicol 89: 202-207 (2012) (12) Delgado-Moreno L et al; J Agric Food Chem 59: 9448-9456 (2011) (13) Kurt-Karakus PB et al; Environ Toxicol Chem 30(7): 1539-1548 (2011)

Hazardous Substances Data Bank (HSDB)

SEAWATER: Chlorpyrifos was detected in the waters of Chesapeake Bay on four occasions in 1993 at 8 different sites at a maximum concentration of 1.67 ng/L(1). Chlorpyrifos was detected at a maximum concentration of 111 pg/L at a site in the Sea of Japan in 2010(2).

PMID:16802478

(1) Giesy JP et al; Rev Environ Contam Toxicol 160: 1-129 (1999) (2) Zhong G et al; Environ Sci Technol 46: 259-267 (2012)

Hazardous Substances Data Bank (HSDB)

RAIN/SNOW/FOG: At elevations of 533 meters and 1,920 meters in Sequoia National Park in the southern Sierra Nevada mountains, California, chlorpyrifos was detected at concentration ranges of 1.3 to 4.4 ng/L and 1.1 to 13 ng/L, respectively, in snow and rain samples collected from December 1995 to April 1996(1). Chlorpyrifos was detected at a concentration range of 0.30 to 3.4 ng/L in snow samples collected from the Lake Tahoe Basin, California from December 1995 to April 1996(1). Chlorpyrifos was detected in 63% of 16 rain samples collected from Jackson, Mississippi between April and September 1995 at maximum and median concentrations of 0.009 and 0.005 ug/L, respectively(2). Chlorpyrifos was detected in fog samples collected from three locations, Parlier, Corcoran, and Lodi, in California's San Joaquin Valley during wintertime at concentrations of 1,020, 320, and 6,500 ng/L, respectively(3). Chlorpyrifos was detected in fog deposition from San Joaquin Valley, CA at concentrations of 17.8-171.9 ng/cu m and an average concentration of 64.9 ng/cu m(4). Chlorpyrifos was detected in atmospheric deposition at trace concentrations in Regina, Saskatchewan(5). Chlorpyrifos was detected in 39% of rainwater samples collected during a four year sampling period of April-Sept 2000-2004 at a concentration range of 0.4-17 ng/L(6). The mean concentration of chlorpyrifos in snowpack samples collected National Parks in the western US in 2003 was as follows(7): Denali - 0.020 ng/L, Rainier - 0.052 ng/L, Sequoia - 2.3 ng/L, Rocky - 0.033 ng/L, Glacier - 0.069 ng/L, Noatak & Gate - 0.027 ng/L(7). Precipitation samples collected at remote inland lake sites in Ontario Canada in 2003-2005 monitoring contained median chlorpyrifos concentrations of 0.76 ng/L (maximum 43 ng/L)(8). Rainwater monitoring in Flanders Belgium between 1997-2001 detected chlorpyrifos levels 0.3-68 ng/L(9).

(1) McConnell LL et al; Environ Toxicol Chem 17: 1908-16 (1998) (2) Coupe RH et al; Water-Resour Invest Rep 99-4018B: 301-312 (1999) (3) Seiber JN, Woodrow JE; Transport and Fate of Pesticides in Fog in California's Central Valley, In: Agrochemical Fate and Movement, Steinheimer T et al. Eds, Amer Chem Soc: Washington, DC, pp 323-346 (2000) (4) Seiber JN et al; Environ Sci Technol 27: 2236-43 (1993) (5) Waite DT et al; Environ Toxicol Chem 14: 1171-75 (1995) (6) Goel A et al; J Agric Food Chem 53: 7915-7924 (2005) (7) Hageman KJ et al; Environ Sci Technol 40: 3174-3180 (2006) (8) Kurt-Karakus PB et al; Environ Toxicol Chem 30(7): 1539-1548 (2011) (9) Quaghebeur D et al; J Environ Monit 6: 182-190 (2004)

Hazardous Substances Data Bank (HSDB)

13.2.14 Effluent Concentrations

Chlorpyrifos was detected at a concentration of 0.139 ug/L in rainwater runoff 28 days after application of 0.298 mg/kg to a maize field in Hungary(1). Chlorpyrifos concentrations were analyzed for 128 storm **water** runoff samples from 8 different land uses over five storm events in Southern California in 2001(2); only 12% of the samples had detectable chlorpyrifos concentrations encompassing 2 of 13 site events and only the mixed agricultural land use had concentrations above the detection limit, measuring 49.3 and 22.9 ng/L(2). Chlorpyrifos was identified, not quantified, in **water** runoff from golf courses in Singapore where it was applied as an insecticide(3). Chlorpyrifos was measured at concentrations of less than 0.025 to 0.26 ug/L in stormwater runoff in California(4).

(1) Konda LN, Pasztor Z; J Agric Food Chem 49: 3859-63 (2001) (2) Schiff K, Sutula M; Environ Toxicol Chem 23: 1815-21 (2004) (3) Wan GB et al; Bull Environ Contam Toxicol 56: 205-209 (1996) (4) Domagalski JL et al; J Environ Qual 26: 454-465 (1997)

Hazardous Substances Data Bank (HSDB)

13.2.15 Sediment/Soil Concentrations

SEDIMENT: Chlorpyrifos was detected at a concentration of 0.007 mg/kg in stream sediment 28 days after application of 0.298 mg/kg to a nearby maize field in Hungary(1). Chlorpyrifos was detected in sediment samples collected from seven sites in the Beijing Guanting reservior in September and November 2003 and June and August 2004 at concentrations ranging from 52.9 to 165 pg/g dry weight, mean 65.9 pg/g dry weight(2). Chlorpyrifos was detected in suspended particulates of the San Joaquin River and its tributaries at less than 0.5 to 153 ng/L and sediment at concentrations of less than 0.5 to 7.2 ng/g(3). Chlorpyrifos was detected in sediment of the Chesapeake Bay at a concentration of 0.0016 ug/kg(4). Chlorpyrifos was detected at mean concentrations of 0-40 ng/g in sediment of Sarasota Bay, FL(5). Sediment samples collected from two southern California watersheds in 2009 (Santa Clara River and Calleguas Creek) contained median chlorpyrifos concentrations of 19 and 2 ng/g(6). Sediment samples collected from 19 depositional areas along the lower Missouri River from Omaha, NE to Jeffersin City, MO in 2002 contained chlorpyrifos levels as high as 6 ng/g(7).

(1) Konda LN, Pasztor Z; J Agric Food Chem 49: 3859-63 (2001) (2) Xue N et al; Chemosphere 61: 1594-1606 (2005) (3) Pereira WE et al; Environ Toxicol Chem 15: 172-80 (1996) (4) Hall LW, Alden RW; Environ Toxicol Chem 16: 1606-1617 (1997) (5) Sherbloom PM et al; Mar Pollut Bull 30: 568-73 (1995) (6) Delgado-Moreno L et al; J Agric Food Chem 59: 9448-9456 (2011) (7) Echols KR et al; Arch Environ Contam Toxicol 55: 161-172 (2008)

Hazardous Substances Data Bank (HSDB)

SOIL: Chlorpyrifos was detected in soil samples collected from 13 farms in the Herbert region and 16 farms in the Burdekin region of the Great Barrier Reef lagoon, Australia in 1995 and 1996 at concentration ranges of <0.005 to 0.936 ng/g dry weight and <0.005 to 0.987 ng/g dry weight, respectively(1). Chlorpyrifos was detected at a concentration of 1.106 ppb in soil near a factory in Kafr El-Zayat, Egypt(2). Chlorpyrifos was detected in soil from households of farmers and farm workers at a mean concentration of 17 ng/g and in soil from non agriculturally employed households at a mean concentration of 11 ng/g(3).

(1) Cavanagh JE et al; Mar Pollut Bull 39: 367-75 (1999) (2) Dogheim SM et al; J AOAC Int 79: 111-116 (1997) (3) Simcox NJ et al; Environ Health Pers 103: 1126-34 (1995)

Hazardous Substances Data Bank (HSDB)

13.2.16 Atmospheric Concentrations

URBAN/SUBURBAN: Chlorpyrifos was detected in 96% of 24 air samples collected from Jackson, MI between April and September 1995 at maximum and median concentrations of 3.5 and 1.5 ng/cu m, respectively(1). Chlorpyrifos was positively identified in 14 of 123 ambient air samples collected at ten US locations in 1980 with a mean concentration of 2.1 ng/cu m and a max concentration of 100 ng/cu m(2). Chlorpyrifos was detected in the atmosphere of the Chesapeake Bay at concentrations of 2 to 97 pg/cu m(3). Chlorpyrifos was detected in the air above the Mississippi River from New Orleans, LA to St. Paul, MN at concentrations of 0.17 to 1.6 ng/cu m(4). Typical outdoor concentrations of chlorpyrifos were reported as 200 ng/cu m and typical indoor air concentrations were reported as 1 ng/cu m(5). Chlorpyrifos was detected at mean concentrations of 16.7 ng/cu m (summer), 3.5 ng/cu m (spring) and 2.5 ng/cu m (winter) in Jacksonville, FL(6). Chlorpyrifos was detected at mean concentrations of 13.9 ng/cu m (spring) and less than 0.05 ng/cu m (winter) in Springfield/Chicopee, MA(6). Chlorpyrifos was detected in personal air of residents of Jacksonville, FL at concentrations of 118.2-280.4 ng/cu m and in personal air of residents of Springfield/Chicopee, MA at 5.9-7.5 ng/cu m(6).

(1) Coupe RH et al; Water-Resour Invest Rep 99-4018B: 301-312 (1999) (2) Carey AE, Kutz FW; Environ Monit and Assess 5: 155 (1985) (3) McConnell LL et al; Environ Sci Technol 31: 1390-98 (1997) (4) Majewski MS et al; Environ Sci Technol 32: 3689-98 (1998) (5) Ott WR, Roberts JW; Sci Amer 278: 86-91 (1998) (6) Whitmore RW et al; Arch Contam Toxicol 26: 47-59 (1994)

Hazardous Substances Data Bank (HSDB)

INDOOR: Chlorpyrifos was detected in 8 of 22 indoor air samples collected from houses in Western Australia at a mean concentration of 2.554 ug/cu m(1). Chlorpyrifos was detected at concentrations of 0.3-70.3 ug/cu m in dorm rooms 1-7 days following its application for flea control(2). Chlorpyrifos was detected in 12 homes located in Bloomington, IN at concentrations of 0.2-150 ng/cu m(3). Chlorpyrifos was detected in 4 homes in Bloomington, IN at concentrations of 0-89 ng/cu m(4). Chlorpyrifos was detected in indoor air at mean concentrations of 366.6 ng/cu m (summer), 205.4 ng/cu m (spring) and 120.3 ng/cu m (winter) in Jacksonville, FL(5). Chlorpyrifos was detected in indoor air at mean concentrations of 9.8 ng/cu m (spring) and 5.1 ng/cu m (winter) in Springfield/Chicopee, MA(5). Chlorpyrifos was detected in 100% of indoor air samples collected from 12 homes along the Arizona-Mexico border(6). A 2001-2004

monitoring study of indoor air samples near pregnant African-American and Dominican women in New York City detected chlorpyrifos in 99.7% of 337 air samples at a concentration range of <0.4-171 ng/cu m and a median concentration of 3.0 ng/cu m(7).

(1) Dingle P et al; Bull Environ Contam Toxicol 62: 309-14 (1999) (2) Lu C, Fenske RA; Environ Sci Technol 32: 1386-1390 (1998) (3) Anderson DJ, Hites RA; Environ Sci Technol 22: 717-720 (1988) (4) Anderson DJ, Hites RA; Atmos Environ 23: 2063-66 (1989) (5) Whitmore RW et al; Arch Contam Toxicol 26: 47-59 (1994) (6) Gale RW et al; Environ Sci Technol 43: 3054-3060 (2009) (7) Whyatt RM et al; Environ Health Perspect 115(3): 383-389 (2007)

▸ **Hazardous Substances Data Bank (HSDB)**

RURAL/REMOTE: Chlorpyrifos was detected in air samples collected from three sites in the Sierra Nevada Mountains, the Kaweah Reservoir (200 m elevation), Ash Mountain (533 m elevation), and Lower Kaweah (1,920 m elevation), in May to September 1996 at concentrations ranging from 1.08 to 17.5 ng/cu m, 0.05 to 1.71 ng/cu m, and 0.16 to 0.35 ng/cu m, respectively(1). Chlorpyrifos was detected in mountain air samples collected from western Canada during Aug 2003 to Aug 2004 sampling(2). Air samples collected at remote inland lake sites in Ontario Canada in 2004 and 2005 contained median chlorpyrifos concentrations of 0.007 ng/cu m (maximum 0.06 ng/cu m)(3). Air monitoring in the Sea of Japan in 2010 detected average chlorpyrifos levels of 146 pg/cu m(4).

(1) Lenoir JS et al; Environ Toxicol Chem 18: 2715-22 (1999) (2) Daly GL et al; Environ Sci Technol 41: 6020-6025 (2007) (3) Kurt-Karakus PB et al; Environ Toxicol Chem 30(7): 1539-1548 (2011) (4) Zhong G et al; Environ Sci Technol 46: 259-267 (2012)

▸ **Hazardous Substances Data Bank (HSDB)**

SOURCE DOMINATED: Chlorpyrifos that was aerially and ground applied to the South Tobacco Creek Watershed, Manitoba, Canada was detected at concentrations ranging from 10 to 103 ng/cu m in air samples collected in May through November in 1994 to 1996(1).

(1) Rawn DFK, Muir DCG; Environ Sci Technol 33: 3317-23 (1999)

▸ **Hazardous Substances Data Bank (HSDB)**

13.2.17 Food Survey Values

Chlorpyrifos was detected in 2 of 360 food composites collected between Aug 1972 and July 1973 during the FDA's Total Diet Study at a concentration of 0.005 ppm in one fruit composite and 0.003 ppm in one grain-cereal composite(1). It was detected in 4 of 240 food composites collected between Oct 1977 and Sept 1978 during FDA's Total Diet Study at concentrations of 0.006-0.009 ppm in 3 grain-cereal composites and 0.012 ppm in one fruit composite(2). It was detected in 9 of 240 adult food composites collected between Oct 1978 and Sept 1979 during the FDA's Total Diet Study at concentrations of trace to 0.008 ppm(3); it was detected in one of 110 infant and toddler food composites collected between Oct 1978 and Sept 1979 a concentration of 0.004 ppm in one grain-cereal composite(4). It was detected in 2 of 240 food composites collected between Oct 1979 and Sept 1980 during the FDA's Total Diet Study at a concentration of 0.002 ppm in one grain-cereal composite and at a trace level (below 0.0001 ppm) in one garden fruit composite (5). In a summary of monitoring results from three Federal programs (FDA Total Diet Study, FDA Monitoring Program, USDA National Residue Program), chlorpyrifos was reported as infrequently detected in various food products such as fruit, vegetables, grains, and processed foods(6). Chlorpyrifos was identified, not quantified, in 3% of adult foods during an FDA survey from 1978-1982(7) and in 8% of adult foods from 1982-1986(8).

(1) Johnson RD, Manske DD; Pest Monit J 9: 157 (1976) (2) Podrebarac DS; J Assoc Off Anal Chem 67: 176 (1984) (3) Gartrell MJ et al; J Assoc Off Anal Chem 68: 862 (1985) (4) Gartrell MJ et al; J Assoc Off Anal Chem 68: 842 (1985) (5) Gartrell MJ et al; J Assoc Off Anal Chem 68: 1184 (1985) (6) Duggan RE et al; Pesticide Residue Levels in Foods in the United States from July 1,1969 to June 30, 1976. Washington,DC: US Food and Drug Administration, Div Chem Technol (1983) (7) Yess NJ et al; J AOAC Int 74: 273-280 (1991) (8) Yess NJ et al; J AOAC Int 74: 265-272 (1991)

▸ **Hazardous Substances Data Bank (HSDB)**

During an FDA survey of domestic foods from 1985-1991 chlorpyrifos was detected in 283 of 2,464 apples at a max concentration of 0.9 ppm, 3 of 2,739 milk samples at trace concentrations, 297 of 862 oranges at a max concentration of 0.76 ppm and 3 of 571 pears at a max concentration of 0.01 ppm(1). In an FDA survey of imported foods from 1985-1991, chlorpyrifos was detected in 87 of 735 apples at a max concentration of 0.11 ppm, 121 of 1,097 bananas at a max concentration of 0.25 ppm, 1 of 64 orange juice samples at trace concentrations, 17 of 474 oranges at a max concentration of 0.28 ppm and 25 of 816 pears at a max concentration of 0.06 ppm(1). In an FDA survey of children foods, chlorpyrifos was detected in cereals (max concentrations 0.001-0.003 ppm), meat dinners (max concentration 0.0008-0.004 ppm), poultry dinners (max concentrations 0.004-0.005 ppm), deserts (max concentrations 0.002-0.003 ppm), fruits and juices (max concentration 0.001-0.006 ppm) and vegetables (max concentration 0.001-0.004 ppm)(1). Chlorpyrifos was detected in citrus fruit from Spain in 1994-1995 at concentrations of 0.1-0.6 mg/kg(2). In an FDA survey of foods in 1993-1994, chlorpyrifos was detected in 132 of 769 domestic apples at a max concentration of 0.21 ppm and in 98 of 1,062 imported apples at a max concentration of 0.05 ppm(3). In a study of 21 commercial juice samples purchased in Madrid, Spain supermarkets chlorpyrifos was detected in 2 of 3 apple juice samples at concentrations of 0.5 and 1.4 ug/kg, 5 of 5 peach juice samples at a concentration range of 0.6 to 3.2 ug/kg, 2 of 6 orange juice samples at concentrations of 1.2 and 2.1 ug/kg, 1 of 5 pineapple juice samples at a concentration of 1.1 ug/kg, and was not detected in a grape juice sample(4). Chlorpyrifos was detected in honey samples collected from 33 cities in Turkey in 2004 at a mean concentration of 132 ng/g(5). Spinach from a retail market in Nanjing China contained chlorpyrifos residues of 0.106-0.204 ug/g fresh wt(6).

(1) Yess NJ et al; J AOAC Int 76: 492-507 (1993) (2) Torres CM et al; J AOAC Int 80: 1122-28 (1997) (3) Roy RR et al; J AOAC Int 80: 883-94 (1997) (4) Albero B et al; J Agric Food Chem 51: 6915-21 (2003) (5) Das YK, Kaya S; Bull Environ Contam Toxicol 83: 378-383 (2009) (6) Wang L et al; Bull Environ Contam Toxicol 81: 377-382 (2008)

▸ **Hazardous Substances Data Bank (HSDB)**

Imported wheat samples in Pakistan (22.5% of samples tested) were found to contain chlorpyrifos at levels of 0.073-0.230 ug/g(1).

(1) Riazuddin R et al; Bull Environ Contam Toxicol 87: 303-306 (2011)

▸ **Hazardous Substances Data Bank (HSDB)**

13.2.18 Fish/Seafood Concentrations

In the National Oceanic and Atmospheric Administration's Mussel Watch Project, chlorpyrifos was measured in bivalves collected from 1994 to 1997 from US coastal sites including the Great Lakes(1). Chlorpyrifos concentrations for 244 bivalve collection sites ranged from <0.25 to 52.9 ng/g dry weight, median 0.78 ng/g dry weight, with 27.5% of the sites having concentration means below the estimated average detection limit(1). Chlorpyrifos was detected in 6 samples of Corvina fish species collected from the Salton Sea, California in May 2001 at concentration ranges of <0.18 to 0.6, <0.18 to 3, 0.6 to 2.5, and 0.5 to 2.4 ng/g wet weight in muscle, liver, gonads, and gills samples, respectively(2). Chlorpyrifos was identified, not quantified, from fish in the San Francisco Bay(3). Chlorpyrifos was identified, not quantified, in mussels from the Mediterranean coast(4). Chlorpyrifos was detected in zebra mussels at concentrations of less than 5 ug/kg and eels at concentrations of less than 20 ug/kg from the Rhine and Meuse Rivers, Netherlands(5).

(1) Wade TL et al; Mar Pollut Bull 37: 20-26 (1998) (2) Sapozhnikova Y et al; Chemosphere 55: 797-809 (2004) (3) Fairey R et al; Mar Pollut Bull 12: 1058-71 (1997) (4) Hernandez F et al; J AOAC Int 79: 123-131 (1996) (5) Hendricks AJ et al; Environ Toxicol Chem 17: 1885-98 (1998)

▸ **Hazardous Substances Data Bank (HSDB)**

13.2.19 Milk Concentrations

ENVIRONMENTAL: Chlorpyrifos was positively detected in 9 of 298 samples of raw cow's milk (1 ug/kg limit of detection) collected in Italy(1). Samples of human milk collected from 2002-2007 in the San Francisco Bay area (urban) and Salinas, CA area (agricultural) contained median chlorpyrifos concentrations of 24.5 and 28.0 pg/g respectively(2).

(1) Gazzotti T et al; Bull Environ Contam Toxicol 82: 251-254 (2009) (2) Weldon RH et al; J Environ Monit 13(11): 3136-3144 (2011)

▸ **Hazardous Substances Data Bank (HSDB)**

EXPERIMENTAL: ... lactating goats were fed [(14)C]ring labeled chlorpyrifos twice daily by capsule; little radiolabel (0.05-0.14%), mainly associated with chlorpyrifos, was recovered in milk.

*FAO/WHO; Pesticide Residues in Food, Toxicological Evaluations, Chlorpyrifos (1999). Available from, as of September 17, 2007: **https://www.inchem.org/documents/jmpr/jmpmono/v99pr03.htm***

▸ **Hazardous Substances Data Bank (HSDB)**

EXPERIMENTAL: In study of chlorpyrifos residues in cow milk, parent compound & 3,5,6-trichloropyridinol were present in very small amt (about 0.01 ug/g) following dose of 30 ppm daily for 2 wk.

The Chemical Society. Foreign Compound Metabolism in Mammals. Volume 5: A Review of the Literature Published during 1976 and 1977. London: The Chemical Society, 1979., p. 446

Hazardous Substances Data Bank (HSDB)

Many of /the organophosphorus insecticides/ are excreted in the milk ... /Organophosphorus insecticides/

Humphreys, D.J. Veterinary Toxicology. 3rd ed. London, England: Bailliere Tindell, 1988., p. 157

Hazardous Substances Data Bank (HSDB)

13.2.20 Other Environmental Concentrations

Chlorpyrifos was detected in household dust at a mean concentration of 429 ng/g (12-17,100 ng/g) in homes of farmers and farm workers; it was detected at a mean concentration of 168 ng/g (17-483 ng/g) in household dust of non-agriculturally employed families(1). Chlorpyrifos was detected in 67% of household dust samples from 9 states in the US at a mean concentration of 0.46 ug/g(2). Chlorpyrifos was detected in 20 of 26 dust samples (0.01 ug/g detection limit) collected in farmworker housing in Hood River, Oregon in 1999 and a mean concentration of 0.20 ug/g and maximum of 1.2 ug/g(3). In a US Dept of Housing and Urban Development survey of randomly selected residential homes in the US, conducted in collaboration with the USEPA, chlorpyrifos was detected in 78% of 479 samples of surface floor swipes at a mean level of 0.50 ng/sq cm(4). A compilation of measured levels of chlorpyrifos in surface swipes from various US residential and child care center monitoring studies reports mean chlorpyrifos levels ranging from 0.0063 to 0.89 ng/sq cm(4).

(1) Simcox NJ et al; Environ Health Pers 103: 1126-34 (1995) (2) Roberts JW, Dickey P; Environ Contam Toxicol 143: 59-78 (1995) (3) Rothlein J et al; Environ Health Perspect 114(5): 691-696 (2006) (4) Stout DM et al; Environ Sci Technol 43(12): 4294-4300 (2009)

Hazardous Substances Data Bank (HSDB)

13.2.21 Probable Routes of Human Exposure

NIOSH (NOES Survey 1981-1983) has statistically estimated that 11,404 workers (842 of these are female) are potentially exposed to chlorpyrifos in the US(1); this NOES Survey number does not include farm workers who may be exposed to chlorpyrifos through its application as an insecticide. The 1980 worker exposure number for Pest Control, Groundskeeper and Gardeners (except farms), and Janitor and Cleaner occupations is 15,136(1). Occupational exposure to chlorpyrifos may occur through inhalation and dermal contact with this compound at workplaces where chlorpyrifos is produced or used. Monitoring and use data indicate that the general population may be exposed to chlorpyrifos via inhalation of ambient air, ingestion of food and drinking water, and dermal contact with this compound(SRC).

*(1) NIOSH; NOES. National Occupational Exposure Survey conducted from 1981-1983. Estimated numbers of employees potentially exposed to specific agents by 2-digit standard industrial classification (SIC). Available from, as of April 4, 2014: **https://www.cdc.gov/noes/***

Hazardous Substances Data Bank (HSDB)

An occupational study of pest control operators in Texas using chlorpyrifos determined a mean air concentration of 7540 ng/cu m during an eight hour work shift with a maximum concentration of 27600 ng/cu m(1). Airborne levels of chlorpyrifos in a test room (simulating a typical American home) containing pest control strips (gradual release) ranged from 100 to 230 ng/cu m over a 30 day period after application(2). Airborne average concentration of chlorpyrifos in dormitory rooms receiving spray applications to cracks and crevices were 100, 1100, 1100, 800 and 300 ng/cu m before treatment, immediately after treatment, one day after, two days after and three days after treatment, respectively(3). Airborne concentration in rooms receiving either spray or aerosol application of chlorpyrifos to cracks and crevices ranged from 2700 ng/cu m immediately after application to 50 ng/cu m three days later(4). Mean levels of 220, 126 and 96 ng/cu m were detected in storage rooms, offices and vehicles, respectively, of commercial pest control operators(5). Airborne levels found after spraying cracks and crevices in food-preparation serving areas were 20-1488 ng/cu m immediately after spraying and 4-361 ng/cu m 24 hours later(5). Chlorpyrifos biomarkers have been detected in the urine of pet owners (both adults and children) who have been exposed to chlorpyrifos through the use of shampoos, dips and impregnated collars containing chlorpyrifos(6).

(1) Hayes AL et al; Am Ind Hyg Assoc J 41: 568 (1980) (2) Jackson MD, Lewis RG; Bull Environ Contam Toxicol 27: 122 (1981) (3) Wright CG et al; Bull Environ Contam Toxicol 26: 548 (1981) (4) Wright CG, Leidy RB; Bull Environ Contam Toxicol 19: 340 (1978) (5) Wright CG, Leidy RB; Bull Environ Contam Toxicol 24: 582 (1980) (6) Dyk MB et al; J Environ Sci Health, Part B: 46(1): 97-104 (2011)

Hazardous Substances Data Bank (HSDB)

13.2.22 Average Daily Intake

AIR INTAKE: Based on the FDA's Total Diet Study of food composites collected between Oct 1979 and Sept 1980, the FDA has estimated the average daily food intake of chlorpyrifos to be 0.04 ug(1).

PMID:4086442

(1) Gartrell MJ et al; J Assoc Off Anal Chem 68: 1184 (1985)

Hazardous Substances Data Bank (HSDB)

The AVDI of chlorpyrifos estimated for farmworkers was reported as 2.9X10-6 to 2.1X10-4 mg/kg/day(1). The AVDI for children residing in farmworkers homes was 1.95X10-5 to 4.7X10-5 mg/kg/day(1). The AVDI of chlorpyrifos from 1986-1991 was estimated as 0.0147 ug/kg/day (6-11 months old), 0.0138 ug/kg/day (2 years old), 0.0038 ug/kg/day (14-16 years old female), 0.006 ug/kg/day (14-16 years old male), 0.0038 ug/kg/day (25-30 years old female), 0.0038 ug/kg/day (25-30 years old male), 0.0041 ug/kg/day (60-65 years old female) and 0.0040 (60-65 years old male)(2). The AVDI of chlorpyrifos from 1984-1986 was estimated as 0.0125 ug/kg/day (6-11 months old), 0.0172 ug/kg/day (2 years old), 0.0044 ug/kg/day (14-16 years old female), 0.006 ug/kg/day (14-16 years old male), 0.0045 ug/kg/day (25-30 years old female), 0.0039 ug/kg/day (25-30 years old male), 0.0047 ug/kg/day (60-65 years old female) and 0.0046 (60-65 years old male)(3). Based on data from 78,882 adult females and 38,075 adult males in 1990, the mean AVDI of chlorpyrifos in the US was reported as 0.8 ug/day(4). During the Minnesota Children's Pesticide Exposure Study, in which monitoring was performed on children aged 3 to 12, 56 participants for whom both an inhalation and an ingestion intake for chlorpyrifos could be determined, the median partial aggregate intake was 11.7 ng/day/kg BW and the 90th percentile was 30.7 ng/day/kg BW(5). Post-application of chlorpyrifos to rice farmers in Vietnam yielded a mean absorbed daily dose of 19.4 ug/kg/day(6).

(1) Bradman MA et al; J Exposure Anal Environ Epidemiol 7: 217-34 (1997) (2) Gunderson EL; J AOAC Int 78: 1353-63 (1995) (3) Gunderson EL; J AOAC Int 78: 910-921 (1995) (4) MacIntosh DL et al; Environ Health Per 104: 202-209 (1996) (5) Clayton CA et al; J Expo Anal Environ Epidemiol 13: 100-111 (2003) (6) Phung DT et al; Chemosphere 87: 292-300 (2012)

Hazardous Substances Data Bank (HSDB)

13.2.23 Body Burden

During the Minnesota Children's Pesticide Exposure Study, in which monitoring was performed on children aged 3 to 12, 3,4,6-trichloro-2-pyridinol, a metabolite of chlorpyrifos, was detected in urine samples collected on day 3 (detected in 93% of 87 samples), 5 (detected in 87% of 87 samples), and 7 (detected in 97% of 89 samples) at median concentrations of 7.2, 6.7, and 8.3 ug/L, respectively(1). A urinary metabolite (3,5,6-trichloro-2-pyridinol) of chlorpyrifos was detected in the urine of 5.8% of 6990 samples collected from the general population (persons 12-74 years old) during 1976-1980(2). The mean concentration of urinary chlorpyrifos metabolites found in the urine of pest control operators in Texas was 5.6-8.3 ug/8 hours(3). Chlorpyrifos metabolites were detected in 50 of 60 samples of urine of children 1-6 years of age living in farm-worker households in eastern North Carolina in 2004(4). Chlorpyrifos was one of several pesticides that were most frequently detected in umbilical cord serum samples from a study of 150 women in New Jersey that underwent elective cesarean delivery(5). Chlorpyrifos biomarkers have been detected in the urine of pet owners (both adults and children) who have been exposed to chlorpyrifos through the use of shampoos, dips and impregnated collars containing chlorpyrifos(6).

(1) Clayton CA et al; J Expo Anal Environ Epidemiol 13: 100-111 (2003) (2) Carey AE, Kutz FW; Environmental Monitoring and Assessment 5: 155 (1985) (3) Hayes AL et al; Am Ind Hyg Assoc Journal 41: 568 (1980) (4) Arcury TA et al; Environ Health Perspect 115(7): 1254-1260 (2007) (5) Barr DB et al; Sci Total Environ 408(4): 790-795 (2010) (6) Dyk MB et al; J Environ Sci Health, Part B: 46(1): 97-104 (2011)

Hazardous Substances Data Bank (HSDB)

14 Associated Disorders and Diseases

- Comparative Toxicogenomics Database (CTD)

Associated Occupational Diseases with Exposure to the Compound

Organophosphates & carbamates, acute poisoning [Category: Acute Poisoning]

- Haz-Map, Information on Hazardous Chemicals and Occupational Diseases

15 Literature

15.1 Coronavirus Studies

PubChem

15.2 NLM Curated PubMed Citations

PubChem

15.3 Springer Nature References

Springer Nature

15.4 Thieme References

Thieme Chemistry

15.5 Wiley References

Wiley

15.6 Depositor Provided PubMed Citations

PubChem

15.7 General References

Nomura et al. Activation of the endocannabinoid system by organophosphorus nerve agents Nature Chemical Biology, doi: 10.1038/nchembio.86, published online 27 April 2008. http://www.nature.com/naturechemicalbiology

Nature Chemical Biology

15.8 Chemical Co-Occurrences in Literature

PubChem

15.9 Chemical-Gene Co-Occurrences in Literature

PubChem

15.10 Chemical-Disease Co-Occurrences in Literature

PubChem

16 Patents

16.1 Depositor-Supplied Patent Identifiers

PubChem

Link to all deposited patent identifiers

PubChem

16.2 WIPO PATENTSCOPE

Patents are available for this chemical structure:

https://patentscope.wipo.int/search/en/result.jsf?inchikey=SBPBAQFWLVIOKP-UHFFFAOYSA-N

PATENTSCOPE (WIPO)

17 Interactions and Pathways

17.1 Chemical-Target Interactions

Comparative Toxicogenomics Database (CTD); Drug Gene Interaction database (DGIdb); Therapeutic Target Database (TTD); Toxin and Toxin Target Database (T3DB)

18 Biological Test Results

18.1 BioAssay Results

PubChem

19 Classification

19.1 MeSH Tree

Medical Subject Headings (MeSH)

19.2 NCI Thesaurus Tree

NCI Thesaurus (NCIt)

19.3 ChEBI Ontology

ChEBI

19.4 KEGG: Pesticides

KEGG

19.5 KEGG: OTC drugs

KEGG

19.6 ChemIDplus

ChemIDplus

19.7 CAMEO Chemicals

CAMEO Chemicals

19.8 ChEMBL Target Tree

ChEMBL

19.9 UN GHS Classification

UN Globally Harmonized System of Classification and Labelling of Chemicals (GHS)

19.10 EPA CPDat Classification

EPA Chemical and Products Database (CPDat)

19.11 NORMAN Suspect List Exchange Classification

NORMAN Suspect List Exchange

19.12 CCSBase Classification

CCSbase

19.13 EPA DSSTox Classification

EPA DSSTox

19.14 Consumer Product Information Database Classification

Consumer Product Information Database (CPID)

19.15 EPA Substance Registry Services Tree

EPA Substance Registry Services

20 Information Sources

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   CAMEO Chemical Reactivity Classification
   https://cameochemicals.noaa.gov/browse/react

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   https://dtp.cancer.gov/dtpstandard/servlet/dwindex?searchtype=NSC&outputformat=html&searchlist=755891

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   https://comptox.epa.gov/dashboard/DTXSID4020458

   CompTox Chemicals Dashboard Chemical Lists
   https://comptox.epa.gov/dashboard/chemical-lists/

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   https://echa.europa.eu/substance-information/-/substanceinfo/100.018.969

   Chlorpyrifos
   https://echa.europa.eu/information-on-chemicals/cl-inventory-database/-/discli/details/68566

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   https://www.fda.gov/about-fda/about-website/website-policies#linking

   CHLORPYRIFOS
   https://gsrs.ncats.nih.gov/ginas/app/beta/substances/JCS58I644W

7. **Hazardous Substances Data Bank (HSDB)**

   CHLORPYRIFOS
   https://pubchem.ncbi.nlm.nih.gov/source/hsdb/389

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   http://www.hmdb.ca/citing

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   http://www.hmdb.ca/metabolites/HMDB0041856

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   https://hmdb.ca/metabolites/HMDB0041856#spectra

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   https://www.ilo.org/dyn/icsc/showcard.display?p_version=2&p_card_id=0851

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    https://www.osha.gov/chemicaldata/339

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Phosphorothioic acid, O,O-diethyl O-(3,5,6-trichloro-2-pyridyl) ester
https://www.cdc.gov/niosh-rtecs/TF602160.html

Chlorpyrifos
https://www.cdc.gov/niosh/npg/npgd0137.html

12. ## Haz-Map, Information on Hazardous Chemicals and Occupational Diseases

Chlorpyrifos
https://haz-map.com/Agents/249

13. ## CDC-ATSDR Toxic Substances Portal

Chlorpyrifos
https://wwwn.cdc.gov/TSP/substances/ToxSubstance.aspx?toxid=88

14. ## ChEBI

Chlorpyrifos
http://www.ebi.ac.uk/chebi/searchId.do?chebiId=CHEBI:34631

ChEBI Ontology
http://www.ebi.ac.uk/chebi/userManualForward.do#ChEBI%20Ontology

15. ## NCI Thesaurus (NCIt)

https://ncithesaurus.nci.nih.gov/ncitbrowser/ConceptReport.jsp?dictionary=NCI_Thesaurus&ns=ncit&code=C163641

NCI Thesaurus Tree
https://ncit.nci.nih.gov

16. ## Toxin and Toxin Target Database (T3DB)

Chlorpyrifos
http://www.t3db.ca/toxins/T3D0127

17. ## CCSbase

CHLORPYRIFOS

CCSbase Classification
https://ccsbase.net/

18. ## NORMAN Suspect List Exchange

chlorpyrifos

NORMAN Suspect List Exchange Classification
https://www.norman-network.com/nds/SLE/

19. ## EU Pesticides Database

Chlorpyrifos
https://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/active-substances/?event=as.details&as_id=548

20. ## USGS Columbia Environmental Research Center

CHLORPYRIFOS
https://www.cerc.usgs.gov/data/acute/qrychemdesc.asp?Chemical=C0280

21. ## ChemIDplus

https://pubchem.ncbi.nlm.nih.gov/substance/?source=chemidplus&sourceid=0002921882

ChemIDplus Chemical Information Classification
https://pubchem.ncbi.nlm.nih.gov/source/ChemIDplus

22. ## Comparative Toxicogenomics Database (CTD)

Chlorpyrifos
https://ctdbase.org/detail.go?type=chem&acc=D004390

23. ## Drug Gene Interaction database (DGIdb)

CHLORPYRIFOS
https://www.dgidb.org/drugs/CHLORPYRIFOS

24. ## Therapeutic Target Database (TTD)

CHLORPYRIFOS
https://idrblab.net/ttd/data/drug/details/D0M5ES

25. ## Consumer Product Information Database (CPID)

Chlorpyrifos
https://www.whatsinproducts.com/chemicals/view/1/590/002921-88-2

Consumer Products Category Classification
https://www.whatsinproducts.com/

26. ## EPA Chemical and Products Database (CPDat)

https://comptox.epa.gov/dashboard/DTXSID4020458#exposure

EPA CPDat Classification
https://www.epa.gov/chemical-research/chemical-and-products-database-cpdat

27. ## EPA Pesticide Ecotoxicity Database

https://ecotox.ipmcenters.org/

28. ## EPA Regional Screening Levels for Chemical Contaminants at Superfund Sites

Chlorpyrifos
https://epa-prgs.ornl.gov/cgi-bin/chemicals/csl_search

Chlorpyrifos
https://epa-prgs.ornl.gov/cgi-bin/chemicals/csl_search?tool=rml

29. ## EU REGULATION (EC) No 1272/2008

chlorpyrifos (ISO);O,O-diethyl O-3,5,6-trichloro-2-pyridyl phosphorothioate
https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02008R1272-20221217

30. ## Hazardous Chemical Information System (HCIS), Safe Work Australia

chlorpyrifos (ISO)
http://hcis.safeworkaustralia.gov.au/HazardousChemical/Details?chemicalID=985

31. ## NITE-CMC

Chlorpyrifos - FY2006
https://www.nite.go.jp/chem/english/ghs/06-imcg-0040e.html

32. ## MassBank of North America (MoNA)

PHOSPHOROTHIOIC ACID O,O-DIETHYL O-(3,5,6-TRICHLORO-2-PYRIDINYL) ESTER
https://mona.fiehnlab.ucdavis.edu/spectra/browse?query=compound.metaData%3Dq%3D%27name%3D%3D%22InChIKey%22%20and%20value%3D%3D%22SBPBAQFWLVIOKP-UHFFFAOYSA-N%22%27

33. ## NIST Mass Spectrometry Data Center

Chlorpyrifos
http://www.nist.gov/srd/nist1a.cfm

34. ## SpectraBase

CHLORPYRIFOS
https://spectrabase.com/spectrum/AB8b1u8jayi

Chlorpyriphos
https://spectrabase.com/spectrum/7ZRkv30BSUa

phosphorothioic acid, O,O-diethyl O-(3,5,6-trichloro-2-pyridyl) ester
https://spectrabase.com/spectrum/AbtOE3fbi6I

DURSBAN
https://spectrabase.com/spectrum/1ERGeA7TAZf

PHOSPHOROTHIOIC ACID O,O-DIETHYL O-(3,5,6-TRICHLORO-2-PYRIDYL) ESTER
https://spectrabase.com/spectrum/EEeL87ySGAa

Chlorpyrifos
https://spectrabase.com/spectrum/Ixuu7sjyAMk

Chlorpyrifos
https://spectrabase.com/spectrum/EXsxeqUiNVG

35. ## NJDOH RTK Hazardous Substance List

chlorpyrifos
http://nj.gov/health/eoh/rtkweb/documents/fs/0426.pdf

36. ## Japan Chemical Substance Dictionary (Nikkaji)

http://jglobal.jst.go.jp/en/redirect?Nikkaji_No=J3.041D

37. ## MassBank Europe

SBPBAQFWLVIOKP-UHFFFAOYSA-N
https://massbank.eu/MassBank/Result.jsp?inchikey=SBPBAQFWLVIOKP-UHFFFAOYSA-N

38. ## Metabolomics Workbench

Chlorpyrifos
https://www.metabolomicsworkbench.org/data/StructureData.php?RegNo=49582

39. ## Nature Chemical Biology

https://pubchem.ncbi.nlm.nih.gov/substance/49681183

40. ## NIOSH Manual of Analytical Methods

> https://www.cdc.gov/Other/disclaimer.html

2921-88-2
https://www.cdc.gov/niosh/docs/2003-154/pdfs/5600-F.pdf
2921-88-2
https://www.cdc.gov/niosh/docs/2003-154/pdfs/5600.pdf

41. **NMRShiftDB**
https://pubchem.ncbi.nlm.nih.gov/substance/114916537

42. **PubChem**
https://pubchem.ncbi.nlm.nih.gov

43. **Springer Nature**
https://pubchem.ncbi.nlm.nih.gov/substance/?source=15745&sourceid=18058201-980674739

44. **SpringerMaterials**
O,O-diethyl O-3,5,6-trichloro-2-pyridyl phosphorothioate
https://materials.springer.com/substanceprofile/docs/smsid_ndsvxcyesrniyjfv

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46. **USDA Pesticide Data Program**
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https://www.ams.usda.gov/datasets/pdp/pdpdata

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https://www.wikidata.org/wiki/Q414915

48. **Wikipedia**
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https://en.wikipedia.org/wiki/Chlorpyrifos

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https://www.ncbi.nlm.nih.gov/mesh/68004390
MeSH Tree
http://www.nlm.nih.gov/mesh/meshhome.html
Cholinesterase Inhibitors
https://www.ncbi.nlm.nih.gov/mesh/68002800
Insecticides
https://www.ncbi.nlm.nih.gov/mesh/68007306

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Pesticides
http://www.genome.jp/kegg-bin/get_htext?br08007.keg
Classification of Japanese OTC drugs
http://www.genome.jp/kegg-bin/get_htext?br08313.keg

52. **UN Globally Harmonized System of Classification and Labelling of Chemicals (GHS)**
GHS Classification Tree
http://www.unece.org/trans/danger/publi/ghs/ghs_welcome_e.html

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https://www.ebi.ac.uk/chembl/g/#browse/targets

54. **Services d'enregistrement des substances de l'EPA**

> LICENCE
> https://www.epa.gov/privacy/privacy-act-laws-policies-and-resources

Classification de la liste SRS de l'EPA
https://sor.epa.gov/sor_internet/registry/substreg/LandingPage.do

55. **PATENTSCOPE (OMPI)**
SID 403029392
https://pubchem.ncbi.nlm.nih.gov/substance/403029392

56. **NCBI**
https://www.ncbi.nlm.nih.gov/projects/linkout

TOXICOLOGICAL PROFILE FOR CHLORPYRIFOS

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Agency for Toxic Substances and Disease Registry

September 1997

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UPDATE STATEMENT

A Toxicological Profile for chlorpyrifos was released in August 1995 for public comment. This edition supersedes any previously released draft or final profile.

Toxicological profiles are revised and republished as necessary, but no less than once every three years. For information regarding the update status of previously released profiles, contact ATSDR at:

Agency for Toxic Substances and Disease Registry
Division of Toxicology/Toxicology Information Branch
1600 Clifton Road NE, E-29
Atlanta, Georgia 30333

FOREWORD

This toxicological profile is prepared in accordance with guidelines* developed by the Agency for Toxic Substances and Disease Registry (ATSDR) and the Environmental Protection Agency (EPA). The original guidelines were published in the *Federal Register* on April 17, 1987. Each profile will be revised and republished as necessary.

The ATSDR toxicological profile succinctly characterizes the toxicologic and adverse health effects information for the hazardous substance described therein. Each peer-reviewed profile identifies and reviews the key literature that describes a hazardous substance's toxicologic properties. Other pertinent literature is also presented, but is described in less detail than the key studies. The profile is not intended to be an exhaustive document; however, more comprehensive sources of specialty information are referenced.

The focus of the profiles is on health and toxicologic information; therefore, each toxicological profile begins with a public health statement that describes, in nontechnical language, a substance's relevant toxicological properties. Following the public health statement is information concerning levels of significant human exposure and, where known, significant health effects. The adequacy of information to determine a substance's health effects is described in a health effects summary. Data needs that are of significance to protection of public health are identified by ATSDR and EPA.

Each profile includes the following:

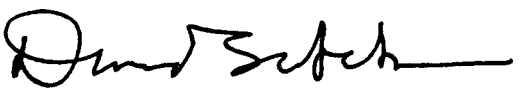
(A) The examination, summary, and interpretation of available toxicologic information and epidemiologic evaluations on a hazardous substance to ascertain the levels of significant human exposure for the substance and the associated acute, subacute, and chronic health effects;

(B) A determination of whether adequate information on the health effects of each substance is available or in the process of development to determine levels of exposure that present a significant risk to human health of acute, subacute, and chronic health effects; and

(C) Where appropriate, identification of toxicologic testing needed to identify the types or levels of exposure that may present significant risk of adverse health effects in humans.

The principal audiences for the toxicological profiles are health professionals at the Federal, State, and local levels; interested private sector organizations and groups; and members of the public.

This profile reflects ATSDR's assessment of all relevant toxicologic testing and information that has been peer-reviewed. Staff of the Centers for Disease Control and Prevention and other Federal scientists have also reviewed the profile. In addition, this profile has been peer-reviewed by a nongovernmental panel and was made available for public review. Final responsibility for the contents and views expressed in this toxicological profile resides with ATSDR.



David Satcher, M.D., Ph.D.
Administrator
Agency for Toxic Substances and
Disease Registry

*Legislative Background

The toxicological profiles are developed in response to the Super-fund Amendments and Reauthorization Act (SARA) of 1986 (Public Law 99-499) which amended the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA or Superfkd). This public law directed ATSDR to prepare toxicological profiles for hazardous substances most commonly found at facilities on the CERCLA National Priorities List and that pose the most significant potential threat to human health, as determined by ATSDR and the EPA. The availability of the revised priority list of 275 hazardous substances was announced in the *Federal Register* on April 29, 1996 (61 FR 18744). For prior versions of the list of substances, see *Federal Register* notices dated April 17, 1987 (52 FR 12866); October 20, 1988 (53 FR 41280); October 26, 1989 (54 FR 43619); October 17,199O (55 FR 42067); October 17, 1991 (56 FR 52166); October 28, 1992 (57 FR 48801); and February 28, 1994 (59 FR 9486). Section 104(i)(3) of CERCLA, as amended, directs the Administrator of ATSDR to prepare a toxicological profile for each substance on the list.

CONTRIBUTORS

CHEMICAL MANAGER(S)/AUTHORS(S):

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Research Triangle Institute, Research Triangle Park, NC

THE PROFILE HAS UNDERGONE THE FOLLOWING ATSDR INTERNAL REVIEWS:

1. Health Effects Review. The Health Effects Review Committee examines the health effects chapter of each profile for consistency and accuracy in interpreting health effects and classifying end points.

2. Minimal Risk Level Review. The Minimal Risk Level Workgroup considers issues relevant to substance-specific minimal risk levels (MRLs), reviews the health effects database of each profile, and makes recommendations for derivation of MRLs.

3. Data Needs Review. The Research Implementation Branch reviews data needs sections to assure consistency across profiles and adherence to instructions in the Guidance.

PEER REVIEW

A peer review panel was assembled for chlorpyrifos. The panel consisted of the following members:

1 . Dr. William Buck, Professor of Toxicology, University of Illinois, Tolono, IL 61880;

2 . Dr. Joel Coats, Professor, Department of Entomology, Iowa State University, Ames, IA 50011; and

3 . Dr. Frederick Oehme, Professor, Comparative Toxicology Laboratories, Kansas State University, Manhattan, KS 66506-5606

These experts collectively have knowledge of chlorpyrifos' physical and chemical properties, toxicokinetics, key health end points, mechanisms of action, human and animal exposure, and quantification of risk to humans. All reviewers were selected in conformity with the conditions for peer review specified in Section 104(i)(13) of the Comprehensive Environmental Response, Compensation, and Liability Act, as amended.

Scientists from the Agency for Toxic Substances and Disease Registry (ATSDR) have reviewed the peer reviewers' comments and determined which comments will be addressed in the profile. A listing of the peer reviewers' comments not incorporated in the profile, with a brief explanation of the rationale for their exclusion, exists as part of the administrative record for this compound. A list of databases reviewed and a list of unpublished documents cited are also included in the administrative record.

The citation of the peer review panel should not be understood to imply its approval of the profile's final content. The responsibility for the content of this profile lies with the ATSDR.

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1. PUBLIC HEALTH STATEMENT

This public health statement tells you about chlorpyrifos and the effects of exposure.

The Environmental Protection Agency (EPA) identifies the most serious hazardous waste sites in the nation. These sites make up the National Priorities List (NPL) and are the sites targeted for long-term federal cleanup. Chlorpyrifos has been found in at least 7 of the 1,428 current or former NPL sites. However, it's unknown how many NPL sites have been evaluated for this substance. As more sites are evaluated, the sites with chlorpyrifos may increase. This information is important because exposure to this substance may harm you and because these sites may be sources of exposure.

When a substance is released from a large area, such as an industrial plant, or from a container, such as a drum or bottle, it enters the environment. This release does not always lead to exposure. You are exposed to a substance only when you come in contact with it. You may be exposed by breathing, eating, or drinking the substance or by skin contact.

If you are exposed to chlorpyrifos, many factors determine whether you'll be harmed. These factors include the dose (how much), the duration (how long), and how you come in contact with it. You must also consider the other chemicals you're exposed to and your age, sex, diet, family traits, lifestyle, and state of health.

1.1 WHAT IS CHLORPYRIFOS?

Chlorpyrifos is an organophosphorus insecticide that has been widely used in the home and on the farm. In the home, chlorpyrifos has been used to control cockroaches, fleas, and termites; it has also been an active ingredient in some pet flea and tick collars. On the farm, it is used to control ticks on cattle and as a spray to control crop pests. In 1997, chlorpyrifos was voluntarily withdrawn from most indoor and pet uses by the manufacturer, DowElanco.

1. PUBLIC HEALTH STATEMENT

Chlorpyrifos is a white crystal-like solid with a strong odor. It does not mix well with water, so it is usually mixed with oily liquids before it is applied to crops or animals. It may also be applied to crops in a microencapsulated form. Chlorpyrifos is the active ingredient of various commercial insecticides including Dursban® and Lorsban®. See Chapter 3 for more information on the chemical and physical properties of chlorpyrifos. See Chapter 4 for more information on the production and use of chlorpyrifos.

1.2 WHAT HAPPENS TO CHLORPYRIFOS WHEN IT ENTERS THE ENVIRONMENT?

Chlorpyrifos enters the environment through direct application to crops, lawns, domesticated animals, and in the home and workplace. Chlorpyrifos may also enter the environment through volatilization, spills, and the disposal of chlorpyrifos waste. Chlorpyrifos that has been applied to the soil generally stays in the area where it has been applied because it sticks tightly to soil particles. Because of this, there is a low chance that chlorpyrifos will be washed off the soil and enter local water systems. Also, since it does not mix well with water, if it does get into the natural waters, it will be in small amounts and will remain on or near the surface and will evaporate. Volatilization is the major way in which chlorpyrifos disperses after it has been applied. Once in the environment (soil, air, or water), chlorpyrifos is broken down by sunlight, bacteria, or other chemical processes. Please refer to Chapters 4 and 5 for more information.

1.3 HOW MIGHT I BE EXPOSED TO CHLORPYRIFOS?

You can be exposed to chlorpyrifos in many places because of its wide range of uses. You can be exposed to it in your home or office if chlorpyrifos has recently been used to control household pests such as fleas or cockroaches. Exposure can also occur outside your home if chlorpyrifos has been applied to the ground around the foundation to control termites. Chlorpyrifos degrades rapidly in the environment; however, low levels may persist for long

periods of time after it has been applied either inside or outside the home. Opening windows before and after chlorpyrifos spraying rapidly lowers airborne levels in a house.

You can also be exposed to chlorpyrifos in a farm setting. The greatest risk occurs soon after a crop has been sprayed, because that is when its levels will be the highest. However, chlorpyrifos rapidly degrades and becomes bound to plants and the ground. The EPA recommends a 24-hour waiting period before entering fields where chlorpyrifos has been applied. In addition, there is the risk of exposure to chlorpyrifos when it is being prepared for use. Care should be taken to ensure that only a licensed applicator sprays chlorpyrifos, and that unnecessary or unprotected individuals remain away from the site of application during the spraying.

Chlorpyrifos can also be found at some waste disposal sites, so exposure to higher levels than what is commonly found after home or commercial use may occur there.

1.4 HOW CAN CHLORPYRIFOS ENTER AND LEAVE MY BODY?

Chlorpyrifos can enter your body through your mouth, lungs, and skin. After being eaten or drunk, chlorpyrifos quickly passes from the intestines to the bloodstream, where it is distributed to the rest of the body. It can also enter the body through the lungs by breathing chlorpyrifos sprays or dust. When chlorpyrifos enters the body this way, it passes quickly into the blood. It may also enter your body through the skin, but the chances of being exposed to harmful levels of chlorpyrifos this way are not as great as with inhalation and oral exposure, because the amount that gets through the skin is relatively small (less than 3% of what was put on the skin). Dermal exposure of infants represents a greater health risk than with adults because of the texture of infant skin and because infants laying or crawling on an area sprayed with chlorpyrifos may have a greater amount of their skin exposed to chlorpyrifos. Infants crawling on areas recently sprayed with chlorpyrifos may also be exposed to greater amounts of chlorpyrifos through inhalation of its vapors. For more information, please refer to Chapter 2.

1.5 HOW CAN CHLORPYRIFOS AFFECT MY HEALTH?

To protect the public from the harmful effects of toxic chemicals and to find ways to treat people who have been harmed, scientists use many tests.

One way to see if a chemical can harm people is to learn how the chemical is absorbed, used, and released by the body; for some chemicals, animal testing may be necessary. Animal testing may also be used to identify health effects such as cancer or birth defects. Without laboratory animals, scientists would lose a basic method to get information needed to make wise decisions to protect public health. Scientists have the responsibility to treat research animals with care and compassion. Laws today protect the welfare of research animals, and scientists must comply with strict animal care guidelines.

In people, short-term oral exposure (one day) to low (milligrams) levels of chlorpyrifos can cause dizziness, fatigue, runny nose or eyes, salivation, nausea, intestinal discomfort, sweating, and changes in heart rate. Short-term oral exposure to much higher (grams) levels of chlorpyrifos may cause paralysis, seizures, loss of consciousness, and death. Reports in people also show that short-term exposure to chlorpyrifos may cause muscle weakness weeks after the original symptoms have disappeared. Other effects of exposure to chlorpyrifos include changes in behavior or sleeping pattern, mood changes, and effects on the nerves and/or muscles in the limbs (which may appear as odd sensations such as numbness or tingling, or as muscle weakness). The EPA has not classified chlorpyrifos for carcinogenicity (Class D). For more information, please refer to Chapter 2.

1.6 IS THERE A MEDICAL TEST TO DETERMINE WHETHER I HAVE BEEN EXPOSED TO CHLORPYRIFOS?

There is a general test that can be performed to determine if you have been exposed to carbamate or organophosphate insecticides. Those types of pesticides inhibit the activity of acetylcholinesterase, the enzyme responsible for inactivating acetylcholine, the compound ultimately responsible for most of the

toxic symptoms seen with chlorpyrifos. The test measures the activity of the enzyme acetylcholinesterase in the blood or a similar enzyme, pseudocholinesterase, in the plasma, or both. If enzyme activity is inhibited, then exposure to an organophosphate or carbamate pesticide is suspected. There is also a biochemical test that can determine if you have been specifically exposed to chlorpyrifos. After chlorpyrifos enters the body, it is changed by the liver into other forms of the compound that may or may not be less toxic than the original material. The major nontoxic chlorpyrifos metabolic product formed by the liver is 3,5,6-trichloro-2-pyridinol, or TCP. TCP is primarily eliminated from the body in the urine and can be detected in the urine using readily available laboratory equipment. The extent of the exposure, length of time after exposure, and the amount of water in the body will affect the level of TCP in the urine. Typically, TCP can be found in the urine for several days after exposure to chlorpyrifos. In addition to chlorpyrifos, TCP is a metabolite of methyl chlorpyrifos and triclopyr. TCP may also be found in the environment, but it is unlikely that urinary levels of TCP result from environmental-TCP exposure. Direct exposure to chlorpyrifos or chlorpyrifos-like compounds is the most likely cause. For more information, please refer to Chapter 2.

1.7 WHAT RECOMMENDATIONS HAS THE FEDERAL GOVERNMENT MADE TO PROTECT HUMAN HEALTH?

The federal government develops regulations and recommendations to protect public health. Regulations can be enforced by law. Federal agencies that develop regulations for toxic substances include the Environmental Protection Agency (EPA), the Occupational Safety and Health Administration (OSHA), and the Food and Drug Administration (FDA). Recommendations, on the other hand, provide valuable guidelines to protect public health but cannot be enforced by law. Federal organizations that develop recommendations for toxic substances include the Agency for Toxic Substances and Disease Registry (ATSDR) and the National Institute for Occupational Safety and Health (NIOSH).

Regulations and recommendations can be expressed in not-to-exceed levels in air, water, soil, or food that are usually based on levels that affect animals; then the levels are adjusted to help protect people.

because of different exposure times (an 8-hour workday or a 24-hour day), the use of different animal studies, or other factors.

Recommendations and regulations are also periodically updated as more information becomes available. For the most current information, check with the federal agency or organization that provides it. Some regulations and recommendations for chlorpyrifos include the following:

- Chlorpyrifos is one of a list of chemicals regulated under "The Emergency Planning and Community Right-to-Know Act of 1986" (EPCRA). This requires owners and operators of certain facilities that manufacture, import, process, or otherwise use the chemicals on this list to report their release of those chemicals to any environmental media annually.

- Chlorpyrifos is designated a hazardous substance and subject to regulations in the Federal Water Pollution Act and the Clean Water Act.

- EPA has established tolerances for chlorpyrifos in raw agricultural commodities, foods, and animal feeds.

See Chapter 7 for specific regulatory values for chlorpyrifos.

1.8 WHERE CAN I GET MORE INFORMATION?

If you have any more questions or concerns, please contact your community or state health or environmental quality department or:

Agency for Toxic Substances and Disease Registry
Division of Toxicology
1600 Clifton Road NE, Mailstop E-29
Atlanta, GA 30333

* Information line and technical assistance

Phone: (404) 639-6000
Fax: (404) 639-63 15 or 6324

ATSDR can also tell you the location of occupational and environmental health clinics. These clinics specialize in recognizing, evaluating, and treating illnesses resulting from exposure to hazardous substances.

* To order toxicological profiles. contact

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22 161
Phone: (800) 553-6847 or (703) 487-4650

2. HEALTH EFFECTS

2.1 INTRODUCTION

The primary purpose of this chapter is to provide public health officials, physicians, toxicologists, and other interested individuals and groups with an overall perspective of the toxicology of chlorpyrifos. It contains descriptions and evaluations of toxicological studies and epidemiological investigations and provides conclusions, where possible, on the relevance of toxicity and toxicokinetic data to public health guidance.

A glossary and list of acronyms, abbreviations, and symbols can be found at the end of this profile.

2.2 DISCUSSION OF HEALTH EFFECTS BY ROUTE OF EXPOSURE

To help public health professionals and others address the needs of persons living or working near hazardous waste sites, the information in this section is organized first by route of exposureinhalation, oral, and dermal; and then by health effect-death, systemic, immunological, neurological, reproductive, developmental, genotoxic, and carcinogenic effects. These data are discussed in terms of three exposure periods-acute (14 days or less), intermediate (15-364 days), and chronic (365 days or more).

Levels of significant exposure for each route and duration are presented in tables and illustrated in figures. The points in the figures showing no-observed-adverse-effect levels (NOAELs) or lowestobserved-adverse-effect levels (LOAELs) reflect the actual doses (levels of exposure) used in the studies. LOAELS have been classified into “less serious” or “serious” effects. “Serious” effects are those that evoke failure in a biological system and can lead to morbidity or mortality (e.g., acute respiratory distress or death). “Less serious” effects are those that are not expected to cause significant dysfunction or death, or those whose significance to the organism is not entirely clear. ATSDR acknowledges that a considerable amount of judgment may be required in establishing whether an end point should be classified as a NOAEL, “less serious” LOAEL, or “serious” LOAEL, and that in some cases, there will be insufficient data to decide whether the effect is indicative of significant dys-function. However, the Agency has established guidelines and policies that are used to classify these end points. ATSDR believes that there is sufficient merit in this approach to warrant an attempt

at distinguishing between “less serious” and “serious” effects. The distinction between “less serious”effects and “serious” effects is considered to be important because it helps the users of the profiles to identify levels of exposure at which major health effects start to appear. LOAELs or NOAELs should also help in determining whether or not the effects vary with dose and/or duration, and place into perspective the possible significance of these effects to human health.

The significance of the exposure levels shown in the Levels of Significant Exposure (LSE) tables and figures may differ depending on the user’s perspective. Public health officials and others concerned with appropriate actions to take at hazardous waste sites may want information on levels of exposure associated with more subtle effects in humans or animals (LOAEL) or exposure levels below which no adverse effects (NOAELs) have been observed. Estimates of levels posing minimal risk to humans (Minimal Risk Levels or MRLs) may be of interest to health professionals and citizens alike.

Estimates of exposure levels posing minimal risk to humans (Minimal Risk Levels or MRLs) have been made for chlorpyrifos. An MRL is defined as an estimate of daily human exposure to a substance that is likely to be without an appreciable risk of adverse effects (noncarcinogenic) over a specified duration of exposure. MRLs are derived when reliable and sufficient data exist to identify the target organ(s) of effect or the most sensitive health effect(s) for a specific duration within a given route of exposure. MRLs are based on noncancerous health effects only and do not consider carcinogenic effects. MRLs can be derived for acute-, intermediate-, and chronic-duration exposures for inhalation and oral routes. Appropriate methodology does not exist to develop MRLs for dermal exposure.

Although methods have been established to derive these levels (Barnes and Dourson 1988; EPA 1990), uncertainties are associated with these techniques. Furthermore, ATSDR acknowledges additional uncertainties inherent in the application of the procedures to derive less than lifetime MRLs. As an example, acute-duration inhalation MRLs may not be protective for health effects that are delayed in development or are acquired following repeated acute insults, such as hypersensitivity reactions, asthma, or chronic bronchitis. As these kinds of health effects data become available and methods to assess levels of significant human exposure improve, these MRLs will be revised.

A User’s Guide has been provided at the end of this profile (see Appendix B). This guide should aid in the interpretation of the tables and figures for Levels of Significant Exposure and the MRLs.

Chlorpyrifos (O,O-diethyl O-[3,5,6-trichloro-2-pyridyl] phosphorothioate) is a clear to white crystalline solid pesticide (EPA 1988b) with a strong mercaptan odor (Worthing 1987). Chlorpyrifos is widely used to control insects in the home, workplace, and in agriculture; it has also been found in at least 7 current and former EPA National Priorities List (NPL) hazardous waste sites (HazDat 1996). Thus, the potential for chlorpyrifos exposure is significant.

2.2.1 Inhalation Exposure

2.2.1.1 Death

No information was found concerning the potential for death in humans following acute-, intermediate-, or chronic-duration inhalation exposure. For animals, no data were located for death following intermediate- or chronic-exposure to chlorpyrifos, but limited LD_{50} (lethal dose, 50% kill) studies were available.

The LD_{50} for acute-duration inhalation exposure to chlorpyrifos aerosol has been determined for mice and female rats (Berteau and Deen 1978). In mice, an LD_{50} of 94 mg/kg (milligrams per killogram of body weight) was determined after whole-body inhalation exposure to 6,700-7,900 mg/m^3 chlorpyrifos in 65% xylene. In that study, the dose range was achieved by varying the length of exposure from 27 to 50 minutes. Virgin female Sprague-Dawley rats were similarly exposed to 5,900-7,500 mg/m^3 chlorpyrifos in 65% xylene, and an acute-exposure inhalation LD_{50} of 78 mg/kg was determined by varying the exposure duration from 60 to 180 minutes. Numerous assumptions about minute ventilation and pulmonary absorption were made in this study, and no correction was made for the large amount of xylene in the formulation or for the percutaneous and oral absorption of chlorpyrifos entrapped in the fur. Thus, the LD_{50} values are crude estimates.

Mortality was also observed in 5 male and 5 female Sprague-Dawley rats acutely exposed to a lower concentration of chlorpyrifos but for a longer duration (Dow 1983a). In males, 80% mortality was observed following a single 4-hour, whole-body exposure to an atmosphere containing 5,300 mg/m^3 of the commercial chlorpyrifos preparation Pyrenone-Dursban®. In similarly exposed females, 20% mortality was observed. However, no mortality was observed in 5 male or 5 female Sprague-Dawley rats exposed to 2,500 mg/m^3 of Pyrenone-Dursban® W.B. Pressurized Spray for 4 hours (Dow 1984).

It should be noted that in these and other animal whole-body inhalation studies, exposure may include ingestion as a route of exposure because the compound gets on the fur of the animals and may then be ingested during grooming.

The LOAEL values for lethality in each reliable study for each species and duration category are shown in Table 2-l and Figure 2-l.

2.2.1.2 Systemic Effects

No studies were located concerning endocrine or metabolic effects of chlorpyrifos in humans or animals following acute-, intermediate-, or chronic-duration inhalation exposure to chlorpyrifos. The highest NOAEL value and all LOAEL values for systemic effects in each reliable study for each species and duration category are shown in Table 2-l and Figure 2- 1.

Respiratory Effects. No information was located concerning the potential respiratory effects of inhaled chlorpyrifos in humans following acute- or intermediate-duration exposure. In a chronicduration exposure study by Brenner et al. (1984), the prevalence of selected illnesses and symptoms in 175 employees involved in the production of chlorpyrifos and 335 matched controls with no history of exposure to organophosphorus chemicals were compared. Employees were further subdivided for dose-response testing into three exposure intensity groups on the basis of job title and air-monitoring data. The prevalence of respiratory illness or other respiratory symptoms were compared. There were no statistically significant differences in the number of subjects with respiratory illness or other respiratory symptoms between the exposed and control groups. Exposure was assumed to be via inhalation and dermal routes.

The respiratory effects of acute-duration exposure to the commercial chlorpyrifos preparation, Pyrenone-Dursban®, were investigated in 5 male and 5 female Sprague-Dawley rats (Dow 1983a). One male rat was observed gasping the day after a single 4-hour whole-body exposure to 5,300 mg/m^3. The animal was found dead later that day. Two additional males were found dead 2 days post-exposure and one male was found dead three days post-exposure. Scattered dark red areas ranging from 2 mm to extensive hepatization involving up to 75% of lung tissue were observed in these rats. Fibrinous pleurisy was observed in 1 female rat that died 14 days post-exposure (Dow 1983a). No respiratory effects were observed, however, in male or female Sprague-Dawley rats

Table 2-1. Levels of Significant Exposure to Chlorpyrifos - Inhalation

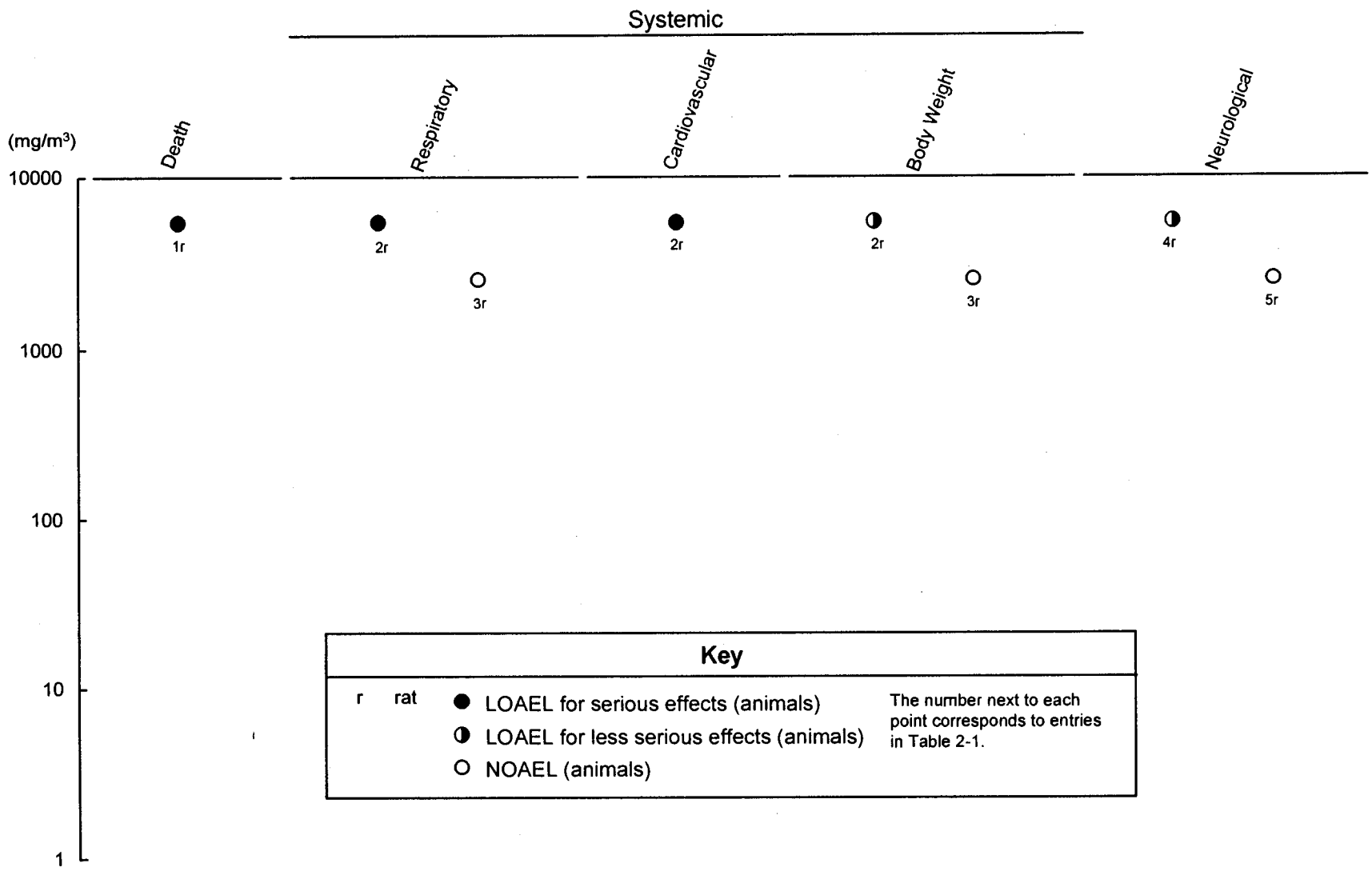
Key to[a] figure	Species/ (strain)	Exposure/ duration/ frequency	System	NOAEL (mg/m3)	LOAEL Less serious (mg/m3)		LOAEL Serious (mg/m3)		Reference
	ACUTE EXPOSURE								
	Death								
1	Rat (Sprague-Dawley)	4 hr					5300	(80% mortality in males, 20% mortality in females)	Dow 1983a
	Systemic								
2	Rat (Sprague-Dawley)	4 hr	Resp				5300	(gasping and pneumonia in males, fibrinous pleuritis in females)	Dow 1983a
			Cardio				5300 F	(pericarditis)	
			Bd Wt		5300	(9-11% decreased Day 2 weight)			
3	Rat (Sprague-Dawley)	4 hr	Resp	2500					Dow 1984
			Bd Wt	2500					
	Neurological								
4	Rat (Sprague-Dawley)	4 hr			5300	(reduced locomotor activity up to Day 2)			Dow 1983a
5	Rat (Sprague-Dawley)	4 hr		2500					Dow 1984

[a]The number corresponds to entries in Figure 2-1.

Bd Wt = body weight; Cardio = cardiovascular; F = female; hr = hour(s); LOAEL = lowest-observable-adverse-effect level; M = male; NOAEL = no-observable-adverse-effect level; Resp = respiratory

Figure 2-1. Levels of Significant Exposure to Chlorpyrifos - Inhalation

Acute (≤14 days)



exposed to an atmosphere containing 2,500 mg/m^3 Pyrenone-Dursban® Pressurized Spray for 4 hours (Dow 1984).

The effects of intermediate-duration exposure to chlorpyrifos on lung histology were assessed in male and female Fischer 344 rats (Corley et al. 1989). The rats were exposed nose-only to 0, 0.075, 0.148, or 0.295 mg/m^3 chlorpyrifos for 6 hours a day, 5 days a week for 13 weeks. Histopathological evaluation of lungs from the control and 0.295 mg/m^3 groups revealed normal lung histology. The exposure levels in this study did not inhibit erythrocyte or plasma cholinesterase activity.

No data were located for respiratory effects in animals following chronic-exposure to chlorpyrifos.

Cardiovascular Effects. No information was located concerning the cardiovascular effects of inhaled chlorpyrifos in humans following intermediate- or chronic-duration exposure. Unstable blood pressure and pulse were noted in a 33-year-old male acutely exposed to an unspecified concentration of Dursban® that was accidentally sprayed into the ventilating system at his place of work. The symptoms began approximately 6 weeks after exposure and slowly resolved over 8-10 weeks (Kaplan et al. 1993). Exposure was assumed to be via inhalation and dermal routes. While cardiovascular effects are possible after acute-duration exposure to chlorpyrifos because of cholinergic overstimulation, the 6-week interval between a single exposure and onset of symptoms raises doubts as to whether chlorpyrifos was the causative agent in this case.

The cardiovascular effects of acute-duration exposure to the commercial chlorpyrifos preparation Pyrenone-Dursban® were investigated in 5 male and 5 female Sprague-Dawley rats (Dow 1983a). Pericarditis was observed in one female rat that died 14 days after a single 4-hour whole-body exposure to 5,300 mg/m^3. No cardiovascular effects were noted in the male rats. Intermediate-duration exposure caused cardiovascular effects in a female domestic short-hair cat (Jaggy and Oliver 1992). The cat was exposed to an unspecified amount of chlorpyrifos used to spray the apartment for fleas. The apartment was sprayed 6 times (every 3 days) during an 1%day period. The-cat was kept in another apartment during the first 2-3 hours after the spraying on each day. The cat became anorexic and lethargic, and was taken for treatment. The cat was found to have elevated levels of creatine kinase, but the lectrocardio gram was negative. It is assumed that exposure was via inhalation, although oral exposure from grooming may also have occurred. No data were located for cardiovascular effects in animals following chronic-exposure to chlorpyrifos.

Gastrointestinal Effects. Gastrointestinal effects following acute-duration exposure to chlorpyrifos have been observed in humans (Kaplan et al. 1993). A family became ill and complained of feeling nauseated after their house was sprayed with Dursban® (Kaplan et al. 1993). The time from exposure to the onset of symptoms and exposure-level data were not reported. Exposure was assumed to be via inhalation and dermal routes. Intermediate-duration exposure to chlorpyrifos may be associated with diarrhea in humans. Diarrhea developed in a 40-year-old male exterminator who was repeatedly exposed to an unknown concentration of Dursban® in a closed environment over a 6-month period (Kaplan et al. 1993). Exposure was assumed to be via inhalation and dermal routes. Erythrocyte cholinesterase levels determined at the onset of symptoms were initially low (value not given). The diarrhea probably resulted from stimulation of the parasympathetic nervous system as a consequence of cholinesterase inhibition. Stimulation of the parasympathetic nervous system increases gastrointestinal motility, thereby decreasing food transit times. The net result is that there is less time for water to be absorbed by the gastrointestinal tract and diarrhea results. In a chronic-duration exposure study by Brenner et al. (1984), the prevalence of selected illnesses and symptoms in 175 employees involved in the production of chlorpyrifos were compared with 335 matched controls with no history of exposure to organophosphorus chemicals. Employees were further subdivided for dose-response testing into three exposure intensity groups on the basis of job title and air-monitoring data. No statistically significant differences in the prevalence of illnesses of the gastrointestinal tract were found in the exposed groups compared to matched controls. Exposure was assumed to be via inhalation and dermal routes.

No data were located for gastrointestinal effects for animals following acute-, intermediate-, or chronic-duration inhalation exposure to chlorpyrifos.

Hematological Effects. A 33-year-old man acutely exposed to an undetermined amount of chlorpyrifos after it was sprayed into the ventilation system of his place of work was examined 2 weeks later because of neurological problems (Kaplan et al. 1993). Routine blood chemistry and hematological evaluations were performed and found to be within normal limits. Similar tests performed on a 40-year-old male exterminator repeatedly exposed to Dursban® in a closed environment over a 6-month interval were also negative. In both cases, exposure was assumed to be via inhalation and dermal routes. No information was located concerning the hematological effects of chronic-duration exposure to inhaled chlorpyrifos in humans.

No information was located concerning the hematological effects of inhaled chlorpyrifos after acute- or chronic-duration exposure in animals. No effects on hematological parameters were seen in Fischer 344 rats exposed to up to 0.295 mg/m^3 chlorpyrifos 6 hours a day, 5 days a week for 13 weeks (Corley et al. 1989).

Musculoskeletal Effects. In humans, acute- and intermediate-duration exposures have been associated with musculoskeletal effects. A family became ill, and family members complained of muscle cramps, after their house was sprayed with Dursban® (Kaplan et al. 1993). Exposure-level data and the time from exposure to the onset of symptoms were not reported. Muscle twitching developed in a 40-year-old male exterminator who was repeatedly exposed to an unknown concentration of Dursban® in a closed environment over a 6-month interval (Kaplan et al. 1993). In both cases, exposure was assumed to be via inhalation and dermal routes. In a chronic-duration exposure study by Brenner et al. (1984), the prevalence of selected illnesses and symptoms in 175 employees involved in the production of chlorpyrifos was compared with 335 matched controls with no history of exposure to organophosphorus chemicals. Employees were further subdivided for dose-response testing into three exposure intensity groups on the basis of job title and air-monitoring data. No statistically significant differences in the prevalence of illnesses or symptoms involving the musculoskeletal system were found in the exposed groups compared to matched controls. Exposure was assumed to be via inhalation and dermal routes.

For animals, no data were located for musculoskeletal effects following acute- or chronic-duration exposure to chlorpyrifos. Musculoskeletal effects have been observed following intermediate-duration oral exposure in cats. Creatine kinase activity increased an undetermined amount in a female cat exposed to an unspecified amount of chlorpyrifos every third day for 18 days via inhalation (Jaggy and Oliver 1992). It is assumed that all exposure was via inhalation, although oral exposure may also have occurred through grooming.

Hepatic Effects. No information was located concerning hepatic effects of inhaled chlorpyrifos in humans following acute- or intermediate-duration exposure. In a chronic-duration exposure study (Brenner et al. 1984), the prevalence of selected illnesses and symptoms in 175 employees involved in the production of chlorpyrifos was compared with 335 matched controls with no history of exposure to organophosphorns chemicals. Employees were further subdivided for dose-response testing into three exposure intensity groups on the basis of job title and air-monitoring data. No statistically significant

differences in the prevalence of liver illnesses were found in the exposed groups compared to matched controls or among the three exposure subgroups. Exposure was assumed to be via inhalation and dermal routes.

The effect of intermediate-duration exposure to chlorpyrifos on liver histology was assessed in male and female Fischer 344 rats (Corley et al. 1989). The rats were exposed nose-only to 0, 0.075, 0.148, or 0.295 mg/m^3 chlorpyrifos for 6 hours a day, 5 days a week for 13 weeks. Histopathological evaluation of livers from the control and 0.295 mg/m^3 groups revealed normal liver histology in the chlorpyrifos-treated rats. The exposure levels in this study were not sufficient to inhibit erythrocyte or plasma cholinesterase. No data were located for hepatic effects in animals following acute- or chronicduration exposure to chlorpyrifos.

Renal Effects. The acute-duration exposure of a 33-year-old male to an unspecified amount of chlorpyrifos that was sprayed into a workplace ventilation system caused an increase in urinary frequency (Kaplan et al. 1993). Exposure was assumed to be via inhalation and dermal routes. Intermediate-duration inhalation exposure (data collected over a 3-month period) to undetermined amounts of chlorpyrifos in humans was assessed in a survey of pesticide applicators working in a variety of settings (Ames et al. 1989). Exposure was assumed to be via inhalation and dermal routes. The applicators in this study reported an unspecified decrease in urinary frequency. In a chronic-duration exposure study by Brenner et al. (1984), the prevalence of selected illnesses and symptoms in 175 employees involved in the production of chlorpyrifos was compared with 335 matched controls with no history of exposure to organophosphorus chemicals. Illnesses and symptoms included those of the kidney. Employees were further subdivided for dose-response testing into three exposure intensity groups on the basis of job title and air-monitoring data. No statistically significant differences in the prevalence of renal illnesses were found in the exposed groups compared to matched controls. Exposure was assumed to be via inhalation and dermal routes.

The effects of intermediate-duration exposure to chlorpyrifos on urine chemistry have also been assessed in male and female Fischer 344 rats (Corley et al. 1989). The rats were exposed nose-only to 0, 0.075, 0.148, or 0.295 mg/m^3 chlorpyrifos for 6 hours a day, 5 days a week for 13 weeks. Urinary chemistry in the treated groups was comparable to controls. The exposure levels in this study were not sufficient to inhibit erythrocyte or plasma cholinesterase. No effects on kidney weight or histopathology were seen in the rats exposed to up to 0.295 mg/m3 chlorpyrifos for 13 weeks.

No data were located in for renal effects in animals following acute- or chronic-duration exposure to chlorpyrifos.

Dermal Effects. No information was located concerning dermal effects of inhaled chlorpyrifos in humans following acute-duration exposure. The intermediate-duration inhalation exposure to undetermined amounts of chlorpyrifos in humans was assessed in a survey of pesticide applicators working in a variety of settings (Ames et al. 1989). Exposure was assumed to be via inhalation and dermal routes. The applicators in this study reported an unspecified increase in skin flushing. This effect may be related to a disruption of autonomic function. In a chronic-duration exposure study by Brenner et al. (1984) the prevalence of selected illnesses and symptoms in 175 employees involved in the production of chlorpyrifos was compared with 335 matched controls with no history of exposure to organophosphorus chemicals. Employees were further subdivided for dose-response testing into three exposure intensity groups on the basis of job title and air-monitoring data. No statistically significant differences in the prevalence of illnesses of the skin or other integumentary tissue were found in the exposed groups compared to matched controls. Exposure was assumed to be via inhalation and dermal routes.

For other animals, no data were located for dermal effects following acute-, intermediate- or chronicduration inhalation exposure to chlorpyrifos.

Ocular Effects. Intermediate-duration exposure to an undetermined amount of chlorpyrifos caused an unspecified increase in tearing in a 40-year-old male exterminator repeatedly exposed to Dursban® over a 6-month period (Kaplan et al. 1993). Exposure was assumed to be via inhalation and dermal routes. Additionally, intermediate-duration inhalation exposure to undetermined amounts of chlorpyrifos in humans was assessed in a survey of pesticide applicators working in a variety of settings (Ames et al. 1989). Exposure was assumed to be via inhalation and dermal routes. The applicators reported an unspecified increase in blurred vision. It should be noted that in the Kaplan et al. (1993) and Ames et al. (1989) studies, exposure concentration data were not available. Additionally, because these incidences occurred in pesticide applicators, the possibility of exposure to other compounds must be considered; blurred vision is a common symptom after high exposure to organophosphate insecticides.

No information was located concerning ocular effects of inhaled chlorpyrifos in humans following acute- or chronic-duration exposure.

For other animals, no data were located for ocular effects following acute-, intermediate-, or chronicduration exposure to chlorpyrifos.

Body Weight Effects. No information was located concerning the effects on body weight of inhaled chlorpyrifos in humans following acute-, intermediate-, or chronic-duration exposure.

The effects on body weight of acute-duration exposure to the commercial chlorpyrifos preparation Pyrenone-Dursban® weight were investigated in male and female Sprague-Dawley rats exposed for 4 hours to an atmosphere containing 5,300 mg/m^3 (Dow 1983a). Male rats that survived 2 days postexposure lost 9-l1% of their body weight. Exposed females also lost weight during the first two days post-exposure. Weight loss ranged from 1 to 33% with a mean of 10%. Surviving male and female rats subsequently gained weight within normal ranges (Dow 1983a). No body weight effects were observed, however, in male or female Sprague-Dawley rats exposed to an atmosphere containing 2,500 mg/m3 Pyrenone-Dursban® Pressurized Spray (Dow 1984). The effects of intermediate-duration exposure to chlorpyrifos on body weight were assessed in male and female Fischer 344 rats (Corley et al. 1989). The rats were exposed nose-only to 0, 0.075, 0.148, or 0.295 mg/m^3 chlorpyrifos for 6 hours a day, 5 days a week for 13 weeks. Body weight was not affected by any concentration of chlorpyrifos. The exposure levels in this study were not sufficient to inhibit erythrocyte or plasma cholinesterase. No data were located for body weight effects following chronic-duration exposure to chlorpyrifos.

2.2.1.3 Immunological and Lymphoreticular Effects

No data were located for immunological and lymphoreticular effects in humans or animals following acute-, intermediate-, or chronic-duration inhalation exposure to chlorpyrifos.

2.2.1.4 Neurological Effects

The majority of the neurological symptoms associated with chlorpyrifos exposure result from its inhibition of acetylcholinesterase and the subsequent cholinergic overstimulation. Common symptoms

related to excessive cholinergic activity include headache, diaphoresis, nausea, vomiting, diarrhea, epigastric cramping, bradycardia, blurred vision, miosis, bronchoconstriction and excess mucous secretions, pulmonary edema, dyspnea, muscle fasciculations, salivation, lacrimation, and urination (Ballantyne and Marts 1992). In adults and children, acute-duration inhalation exposure to unspecified concentrations of chlorpyrifos is associated with paresthesia and lightheadedness (Kaplan et al. 1993;Sherman 1995). Headache is also a common occurrence (Kaplan et al. 1993; Sherman 1995). Additionally, in the Sherman (1995) report, acute-duration chlorpyrifos exposure may produce signs of neurological toxicity weeks or months after the initial symptoms have resolved. For example, a family which became ill after an unspecified concentration of chlorpyrifos was applied in their home initially presented with headaches, nausea, and muscle cramps (Kaplan et al. 1993). However, numbness, paresthesia (most prominent in the legs), and memory impairment were reported by the family 1 month later. The children also showed a decline in scholastic performance that lasted for approximately 6 months. Neurological exams conducted 6 months post-exposure revealed mild shortterm memory loss on all routine mental status testing of recall of multiple objects. Neuropsychological testing was declined by the subjects, all other neurological exams were normal. Nerve conduction studies revealed low-amplitude sural nerve action potentials in all family members. Motor and upper-extremity sensory nerve action potentials were normal. Sural nerve amplitudes in all but one family member had returned to normal 6 months later. Although inhalation was the most likely route of exposure, the family could also have been exposed dermally.

Other patients in the compilation of case reports by Kaplan et al. (1993) presented with similar deferred neurotoxicity that resolved after a period of weeks or months. In a review of the physical, neurotoxic, and respiratory problems suffered by people exposed to organophosphate pesticidal products, similar symptoms of severe organophosphate poisoning were reported in men and women exposed to unspecified amounts of chlorpyrifos at home or at work (Sherman 1995). However, in the Kaplan et al. (1993) and Sherman (1995) reports, no exposure-level data were presented, and the cognitive complaints were nonspecific, nonquantitative, and possibly attributable to a wide variety of possible causes. Additionally, measurements of erythrocyte acetylcholinesterase, a biomarker for chlorpyrifos exposure, were not taken.

Intermediate-duration inhalation exposure to unspecified concentrations of chlorpyrifos in humans have been associated with deferred neurotoxicity similar to that observed after acute-duration exposure (Kaplan et al. 1993). For example, sensory loss, mild distal weakness, and are flexia in the lower

extremities were revealed in a neurological evaluation of a man 6 weeks after being exposed to Dursban® in a closed environment for over a 6-month interval. Nerve conduction studies and quantitative sensory threshold studies revealed changes consistent with peripheral neuropathy of the distal axonopathy type. However, follow-up one year later revealed normalization of the results of the neurological examination, nerve conduction studies, and quantitative sensory threshold studies, and remission of all symptoms (Kaplan et al. 1993).

In a chronic-duration exposure study by Brenner et al. (1984), the prevalence of selected illnesses and symptoms in 175 employees involved in the production of chlorpyrifos was compared with 335 matched controls with no history of exposure to organophosphorus chemicals. Employees were further subdivided for dose-response testing into three exposure intensity groups on the basis of job title and air-monitoring data. No statistically significant differences in the prevalence of central and peripheral nervous system symptom were found in the exposed groups compared to matched controls. Exposure was assumed to be via inhalation and dermal routes.

In female mice, acute-duration inhalation exposure to 95.6 mg/kg chlorpyrifos (total dose received during 5 hours of exposure) caused an approximate 90% decrease in plasma cholinesterase, a marker for exposure, 3 days after exposure (Berteau and Deen 1978). Fourteen days after exposure, plasma cholinesterase had returned to within 20% of predosing levels. The effects of acute-duration inhalation exposure to the commercial chlorpyrifos Pyrenone-Dursban® on behavior were investigated in male and female Sprague-Dawley rats exposed for 4 hours to an atmosphere containing 5,300 mg/m^3 (Dow 1983a). Locomotor activity was reduced for up to 2 days post-exposure (Dow 1983a). No behavioral effects were observed, however, in male or female Sprague-Dawley rats exposed to an atmosphere containing 2,500 mg/m^3 Pyrenone-Dursban® Pressurized Spray (Dow 1984). The effects of intermediate-duration exposure to chlorpyrifos on brain weight and brain cholinesterase were assessed in male and female Fischer 344 rats (Corley et al. 1989). The rats were exposed nose-only to 0, 0.075, 0.148, or 0.295 mg/m^3 chlorpyrifos for 6 hours a day, 5 days a week for 13 weeks. Brain weight and brain acetylcholinesterase activity were not affected by any concentration of chlorpyrifos. The concentrations of chlorpyrifos used in this study were not sufficient to inhibit erythrocyte or plasma cholinesterase activity. No data were located for neurological effects in animals following chronic-duration exposure to chlorpyrifos.

All LOAEL values for neurological effects in each reliable study for each species and duration category are shown in Table 2-l and Figure 2-l.

2.2.1.5 Reproductive Effects

No information was located concerning reproductive effects of inhaled chlorpyrifos in humans following acute-, intermediate-, or chronic-duration exposure.

The effect of intermediate-duration exposure to chlorpyrifos on testicular weight and histology was assessed in male Fischer 344 rats (Corley et al. 1989). The rats were exposed nose-only to 0, 0.075, 0.148, or 0.295 mg/m^3 chlorpyrifos for 6 hours a day, 5 days a week for 13 weeks. No effects of treatment on testes weight or histology were detected. The air concentrations of chlorpyrifos used in this study were not sufficient to inhibit erythrocyte or plasma cholinesterase activity. No data were located for reproductive effects in animals following acute- or chronic-duration exposure to chlorpyrifos.

2.2.1.6 Developmental Effects

No information was located concerning developmental effects of inhaled chlorpyrifos in humans or other animals following acute-, intermediate-, or chronic-duration exposure.

2.2.1.7 Genotoxic Effects

No information was located concerning genotoxic effects of inhaled chlorpyrifos in humans following acute-, intermediate-, or chronic-duration exposure.

Chlorpyrifos was tested for its ability to induce complete and partial chromosome losses in *Drosophila melunogaster* males (Woodruff et al. 1983). Initial attempts were made to identify an approximate LD_{50} (lethal dose, 30% kill) dose prior to treatment, with toxicity defined as the number of dead flies out of the total number treated over a 3-day period. Mortality was recorded at 24, 48, and 72 hours. At 72 hours, males were removed and mated with *mus*-302 repair-defective females, and F_1 male progeny were screened for complete and partial chromosome loss. Treated and control males that had a ring-X chromosome and a doubly-marked Y chromosome were used in a screen for ring

chromosome loss and for loss of Y-chromosome markers. A significant increase in complete chromosome loss was induced by 0.717 mg/m^3 chlorpyrifos, but no effect on partial chromosome loss was observed. No information was located concerning genotoxic effects of inhaled chlorpyrifos in animals following intermediate- or chronic-duration exposure. Genotoxicity studies are also discussed in Section 2.5.

2.2.1.8 Cancer

No information was located concerning the cancer risk of inhaled chlorpyrifos in humans or other animals following acute-, intermediate-, or chronic-duration exposure.

2.2.2 Oral Exposure

2.2.2.1 Death

No information was found concerning death in humans following acute-, intermediate-, or chronicduration oral exposure.

Acute oral LD_{50} has been assessed in rodents (El-Sebae et al. 1978; Gaines 1969; McCollister et al.1974). In rats, chlorpyrifos appears to be more toxic to females than males. Gaines (1969) reported an LD_{50} of 82 mg/kg for female Sherman rats and an LD_{50} of 155 mg/kg for males. Similarly, McCollister et al. (1974) reported an LD_{50} of 135 mg/kg for female Dow-Wistar rats and an LD_{50} of 163 mg/kg for males. However, in contrast to this apparent sex effect suggested by Gaines' (1969) data, an LD_{50} of 155 mg/kg was reported for female Sherman rats while the male LD_{50} was 118 mg/kg (McCollister et al. 1974). An LD_{50} of 60 mg/kg has been determined for mice (unspecified gender) (El-Sebae et al. 1978). In male guinea pigs, an oral LD_{50} of 504 mg/kg has been reported (McCollister et al. 1974). In chickens, a single oral dose of 75 mg/kg chlorpyrifos caused death in 1 of 3 animals following regurgitation and aspiration within 8 hours of dosing (Richardson et al. 1983a). However, no hens exposed to 150 or 300 mg/kg died in that study, although at the time of sacrifice, 1 of 3 in the 150 mg/kg group and all in the 300 mg/kg group appeared moribund. In other chicken studies, LD_{50} values of 32 mg/kg (McCollister et al. 1974) and 34.8 mg/kg (Miyazaki and Hodgson 1972) were reported in male Leghorns. In adult hens, acute-duration oral administration of "pure" chlorpyrifos resulted in deaths within 48 hours in all dose groups (20-60%). In hens dosed

with 4, 6, 16, or 32 mg/kg chlorpyrifos, 1 of 5, 1 of 5, 3 of 5, and 3 of 5, respectively, died (Capodicasa et al. 1991). In pregnant CF-1 mice, 25 mg/kg/day Dursban F® (96.8% chlorpyrifos) as a solution in cottonseed oil administered via gavage from gestation day (Gd) 6-15 caused death in 4 of 47 of the treated. mice (Deacon et al. 1980); one death was observed at each 1 mg/kg/day and 10 mg/kg/day chlorpyrifos dose.

Intermediate-duration oral exposure to chlorpyrifos has also been shown to cause death in rodents (Chiappa et al. 1995). Death was observed in 6 of 10 male Long-Evans rats exposed to 100 mg/kg/day chlorpyrifos in corn oil via gavage for 3 days, followed by 75 mg/kg/day chlorpyrifos for 2-4 weeks (Chiappa et al. 1995), time to death was not specifically reported. No treatment-related deaths were observed in a multigeneration study where rats (30 males and 30 females per dose group) received 0, 0.1, 1, or 5 mg/kg/day chlorpyrifos in feed (Breslin et al. 1996). In another multigeneration study, no deaths were observed in male and female Sprague-Dawley rats (30/sex/group) exposed to 0.5, 0.8, or 1.2 mg/kg/day Dursban ® in feed for 120-135 days (Dow 1983b). Similarly, exposure to up to 15 mg/kg/day Dursban® in feed for 13 weeks caused no deaths in Fischer 344 rats (Dow 1993). Intermediate-duration (90 days) oral exposure did not cause deaths in two Leghorn hens exposed to 10 mg/kg/day chlorpyrifos in capsules. In chronic-duration oral exposure studies, no deaths were observed in Sherman rats or Beagle dogs exposed to up to 3 mg/kg/day chlorpyrifos in feed for up to 2 years (McCollister et al. 1974).

The LOAEL and LD_{50} values for lethality in each reliable study for each species and duration category are shown in Table 2-2 and Figure 2-2.

2.2.2.2 Systemic Effects

The highest NOAEL value and all LOAEL values for systemic effects in each reliable study for each species and duration category are shown in Table 2-2 and Figure 2-2.

Respiratory Effects. In humans, acute-duration oral exposure to chlorpyrifos has been shown to cause respiratory distress resulting from cholinesterase inhibition. A 3-year-old boy was taken to the hospital in respiratory distress following the ingestion of an unknown amount of chlorpyrifos (Aiuto et al. 1993). He lapsed into a coma and was placed on a respirator. After 3 days, the endotracheal tube was removed, but the boy soon developed severe stridor and respiratory distress. Upper-airway edema

Table 2-2. Levels of Significant Exposure to Chlorpyrifos - Oral

Key to[a] figure	Species/ (Strain)	Exposure/ Duration/ Frequency (Specific Route)	System	NOAEL (mg/kg/day)	LOAEL Less Serious (mg/kg/day)	LOAEL Serious (mg/kg/day)	Reference Chemical Form
	ACUTE EXPOSURE						
	Death						
1	Rat (Sherman)	once (GO)				82 F (LD_{50}) 155 M (LD_{50})	Gaines 1969
2	Rat (Dow- Wistar)	once (GO)				163 M (LD_{50}) 135 F (LD_{50})	McCollister et al. 1974
3	Rat (Sherman)	once (GO)				118 M (LD_{50}) 155 F (LD_{50})	McCollister et al. 1974
4	Mouse (CF-1)	Gd 6-15 1x/d (GO)				1 F (1/40 died)	Deacon et al. 1980
5	Gn Pig (NS)	once (GO)				504 M (LD_{50})	McCollister et al. 1974
	Systemic						
6	Rat (Fischer- 344)	Gd 6-15 1x/d (GO)	Hepatic	3 F	15 F (porphyrin deposits)		Breslin et al. 1996
			Bd Wt	3 F		15 F (44% decreased body weight gain on Gd 12-16)	
7	Rat (Long- Evans)	once (GO)	Bd Wt	50 M	100 M (13.3% decreased body weight)		Moser 1995
			Metab	20 M	50 M (hypothermia)		
8	Mouse (CF-1)	Gd 6-15 1x/d (GO)	Hepatic	25 F			Deacon et al. 1980
			Bd Wt	10 F	25 F (14% mean body weight gain decrease Gd 6-17)		

Table 2-2. Levels of Significant Exposure to Chlorpyrifos - Oral (continued)

Key to[a] figure	Species/ (Strain)	Exposure/ Duration/ Frequency (Specific Route)	System	NOAEL (mg/kg/day)	LOAEL Less Serious (mg/kg/day)	LOAEL Serious (mg/kg/day)	Reference Chemical Form
9	Mouse (CF-1)	Gd 6-15 1x/d (GO)	Hepatic	10 F			Deacon et al. 1980
			Bd Wt	10 F			
	Neurological						
10	Human	9 d (C)		0.03 [b]	0.10 M (rhinorrhea; blurred vision)		Coulston et al. 1972
11	Rat (Fischer- 344)	Gd 6-15 1x/d (GO)		0.1 F	3 F (26% decreased erythrocyte ChE)	15 F (excessive salivation, tremors, urine staining of the perineal region)	Breslin et al. 1996
12	Rat (Long- Evans)	once (GO)			20 M (unspecified decreased motor activity)		Moser 1995
13	Mouse (CF-1)	Gd 6-15 1x/d (GO)		1 F	10 F (increased salivation in 5/44)	25 F (symptoms of severe ChE inhibition in 32/47 mice)	Deacon et al. 1980
14	Mouse (CF-1)	Gd 6, 6-10, or 6-15 1x/d (GO)		0.1 F	1 F (25-29% decreased erythrocyte ChE Gds 6-10 and 6-15)		Deacon et al. 1980
15	Cat (Domestic Short-hair)	once (GO)				40 M (hypersalivation, muscular tremors, mild ataxia; decr. brain ChE activity)	Hooser et al. 1988
	Reproductive						
16	Rat (Fischer- 344)	Gd 6-15 1x/d (GO)		3 F	15 F (vaginal bleeding)		Breslin et al. 1996

Table 2-2. Levels of Significant Exposure to Chlorpyrifos - Oral (continued)

Key to[a] figure	Species/ (Strain)	Exposure/ Duration/ Frequency (Specific Route)	System	NOAEL (mg/kg/day)	LOAEL Less Serious (mg/kg/day)	LOAEL Serious (mg/kg/day)	Reference Chemical Form
17	Mouse (CF-1)	Gd 6-15 1x/d (GO)		25 F			Deacon et al. 1980
	Developmental						
18	Rat (Fischer- 344)	Gd 6-15 1x/d (GO)		15			Breslin et al. 1996
19	Mouse (CF-1)	Gd 6-15 1x/d (GO)		1	10 (35% decreased fetal homogenate ChE activity)		Deacon et al. 1980

Table 2-2. Levels of Significant Exposure to Chlorpyrifos - Oral (continued)

Key to[a] figure	Species/ (Strain)	Exposure/ Duration/ Frequency (Specific Route)	System	NOAEL (mg/kg/day)	LOAEL Less Serious (mg/kg/day)	LOAEL Serious (mg/kg/day)	Reference Chemical Form
	INTERMEDIATE EXPOSURE						
	Death						
20	Rat (Long- Evans)	2-4 wk 5 d/wk 1x/d (GO)				75 M (6/10 died)	Chiappa et al. 1995
	Systemic						
21	Rat (Sprague-Dawley)	multigen (F)	Endocr	1	5 (slight vacuolation of adrenal gland zona fasiculata in both sexes, altered tinctorial properties in females)		Breslin et al. 1996
			Bd Wt	5			
22	Rat (Sprague-Dawley)	135 d ad lib (F)	Renal	1.2			Dow 1983b
			Bd Wt	1.2			
23	Rat (Sprague-Dawley)	120 d ad lib (F)	Bd Wt	1.2			Dow 1983b
24	Rat (Fischer- 344)	13 wk 7 d/wk (F)	Gastro	1 F 15 M	5 F (perineal soiling)		Dow 1993
			Musc/skel	15			
			Ocular	15			
			Bd Wt	15			

Table 2-2. Levels of Significant Exposure to Chlorpyrifos - Oral (continued)

Key to[a] figure	Species/ (Strain)	Exposure/ Duration/ Frequency (Specific Route)	System	NOAEL (mg/kg/day)	LOAEL Less Serious (mg/kg/day)	LOAEL Serious (mg/kg/day)	Reference Chemical Form
Neurological							
25	Human	20 d (C)		0.03[c] M	0.10 M (runny nose; blurred vision)		Coulston et al. 1972
26	Rat (Sprague-Dawley)	multigen (F)		0.1		1 (65-69% decreased erythrocyte ChE)	Breslin et al. 1996
27	Rat (Long- Evans)	2-4 wk 5 d/wk 1x/d (GO)				75 M (73-91% decreased AChE activity in all regions examined; 26-56% increased AChE-IR in all regions examined)	Chiappa et al. 1995
28	Rat (Fischer- 344)	13 wk 7 d/wk (F)		5	15 (decreased motor activity)		Dow 1993
29	Chicken (Leghorn)	90 d 1x/d (C)				10 F (extreme debilitation, weakness and lethargy 35-60 days postdosing)	Francis et al. 1985
Reproductive							
30	Rat (Sprague-Dawley)	multigen (F)		5			Breslin et al. 1996
31	Rat (Sprague-Dawley)	135 d ad lib (F)		1.2			Dow 1983b

Table 2-2. Levels of Significant Exposure to Chlorpyrifos - Oral (continued)

Key to[a] figure	Species/ (Strain)	Exposure/ Duration/ Frequency (Specific Route)	System	NOAEL (mg/kg/day)	LOAEL Less Serious (mg/kg/day)	LOAEL Serious (mg/kg/day)	Reference Chemical Form
32	Rat (Sprague-Dawley)	120 d ad lib (F)		1.2			Dow 1983b
	Developmental						
33	Rat (Sprague-Dawley)	multigen (F)		1	5 (10-11% decreased pup body weight)		Breslin et al. 1996
34	Rat (Sprague-Dawley)	135 d ad lib (F)		1.2			Dow 1983b
35	Rat (Sprague-Dawley)	120 d ad lib (F)		1.2			Dow 1983b

Table 2-2. Levels of Significant Exposure to Chlorpyrifos - Oral (continued)

Key to[a] figure	Species/ (Strain)	Exposure/ Duration/ Frequency (Specific Route)	System	NOAEL (mg/kg/day)	LOAEL		Reference Chemical Form
					Less Serious (mg/kg/day)	Serious (mg/kg/day)	
	CHRONIC EXPOSURE						
	Systemic						
36	Rat (Sherman)	2 yr (F)	Resp	3.0			McCollister et al. 1974
			Cardio	3.0			
			Gastro	3.0			
			Hemato	3.0			
			Musc/skel	3.0			
			Hepatic	3.0			
			Renal	3.0			
			Ocular	3.0			
			Bd Wt	3.0			
37	Dog (Beagle)	1 yr (F)	Resp	3.0			McCollister et al. 1974
			Cardio	3.0			
			Gastro	3.0			
			Hemato	3.0			
			Musc/skel	3.0			
			Hepatic	3.0			
			Renal	3.0			
			Ocular	3.0			
			Bd Wt	3.0			

Table 2-2. Levels of Significant Exposure to Chlorpyrifos - Oral (continued)

Key to figure[a]	Species/ (Strain)	Exposure/ Duration/ Frequency (Specific Route)	System	NOAEL (mg/kg/day)	LOAEL Less Serious (mg/kg/day)	LOAEL Serious (mg/kg/day)	Reference Chemical Form
38	Dog (Beagle)	2 yr (F)	Resp	3.0			McCollister et al. 1974
			Cardio	3.0			
			Gastro	3.0			
			Hemato	3.0			
			Musc/skel	3.0			
			Hepatic	3.0			
			Renal	3.0			
			Ocular	3.0			
			Bd Wt	3.0			
	Immunological/Lymphoreticular						
39	Rat (Sherman)	2 yr (F)		3.0			McCollister et al. 1974
40	Dog (Beagle)	1 yr (F)		3.0			McCollister et al. 1974
41	Dog (Beagle)	2 yr (F)		3.0			McCollister et al. 1974
	Neurological						
42	Rat (Sherman)	2 yr (F)		0.1[d]		1.0 (65-70% decreased red blood cell ChE activity)	McCollister et al. 1974
43	Dog (Beagle)	1 yr (F)		0.1 M	1.0 M (red blood cell ChE decreased 42-45% of pretest and control values)		McCollister et al. 1974

Table 2-2. Levels of Significant Exposure to Chlorpyrifos - Oral (continued)

Key to[a] figure	Species/ (Strain)	Exposure/ Duration/ Frequency (Specific Route)	System	NOAEL (mg/kg/day)	LOAEL			Reference Chemical Form
					Less Serious (mg/kg/day)		Serious (mg/kg/day)	
44	Dog (Beagle)	2 yr (F)		0.1	1.0	(27% decreased RBC ChE activity - females only)		McCollister et al. 1974
	Reproductive							
45	Rat (Sherman)	2 yr (F)		3.0				McCollister et al. 1974
46	Dog (Beagle)	1 yr (F)		3.0				McCollister et al. 1974
47	Dog (Beagle)	2 yr (F)		3.0				McCollister et al. 1974

[a]The number corresponds to entries in Figure 2-2.

[b]Used to derive an acute oral minimal risk level (MRL) of 0.003 mg/kg/day; dose divided by an uncertainty factor of 10 for human variability.

[c]Used to derive an intermediate oral MRL of 0.003 mg/kg/day; dose divided by an uncertainty factor of 10 for human variability.

[d]Used to derive a chronic oral MRL of 0.001 mg/kg/day; dose divided by an uncertainty factor of 100 (10 for extrapolation from animals to humans and 10 for human variability).

AChE = acetylcholinesterase; ad lib = ad libitum; Bd Wt = body weight; (C) = capsule; Cardio = cardiovascular; ChE = cholinesterase; d = day(s); Endocr = endocrine; F = female; (F) = food; (G) = gavage; Gastro = gastrointestinal; Gd = gestational day; Gn Pig = guinea pig; (GO) = gavage in oil; (GW) = gavage in water; Hemato = hematological; IR = immunoreactivity; LD_{50} = lethal dose, 50% kill; LOAEL = lowest-observable-adverse-effect level; M = male; Musc/skel = musculoskeletal; multigen = multigenerational; NOAEL = no-observable-adverse-effect level; NS = not specified; RBC = red blood cell; Resp = respiratory; wk = week(s); x = times; yr = year(s)

Figure 2-2. Levels of Significant Exposure to Chlorpyrifos - Oral

Acute (≤14 days)

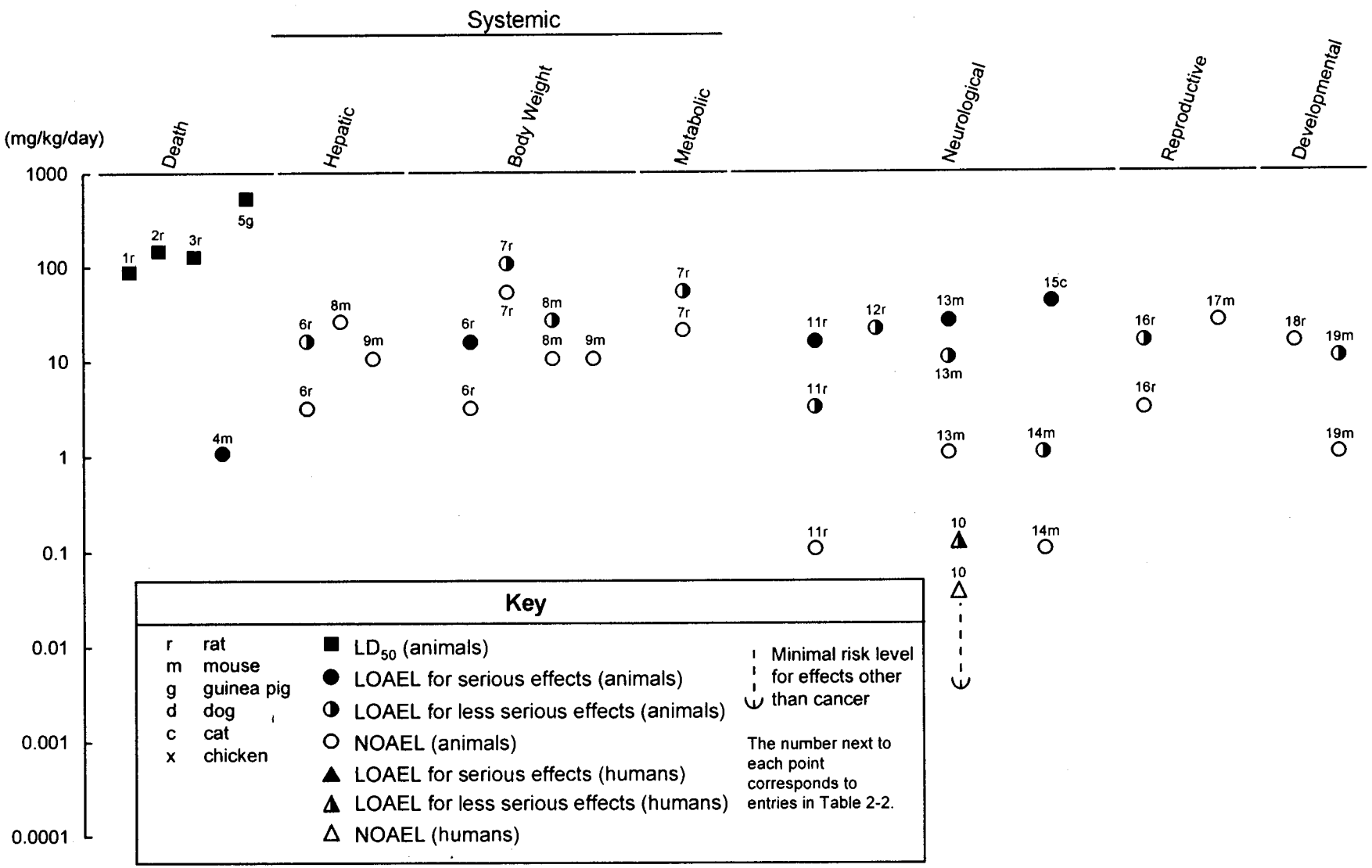


Figure 2-2. Levels of Significant Exposure to Chlorpyrifos - Oral (cont.)

Intermediate (15-364 days)

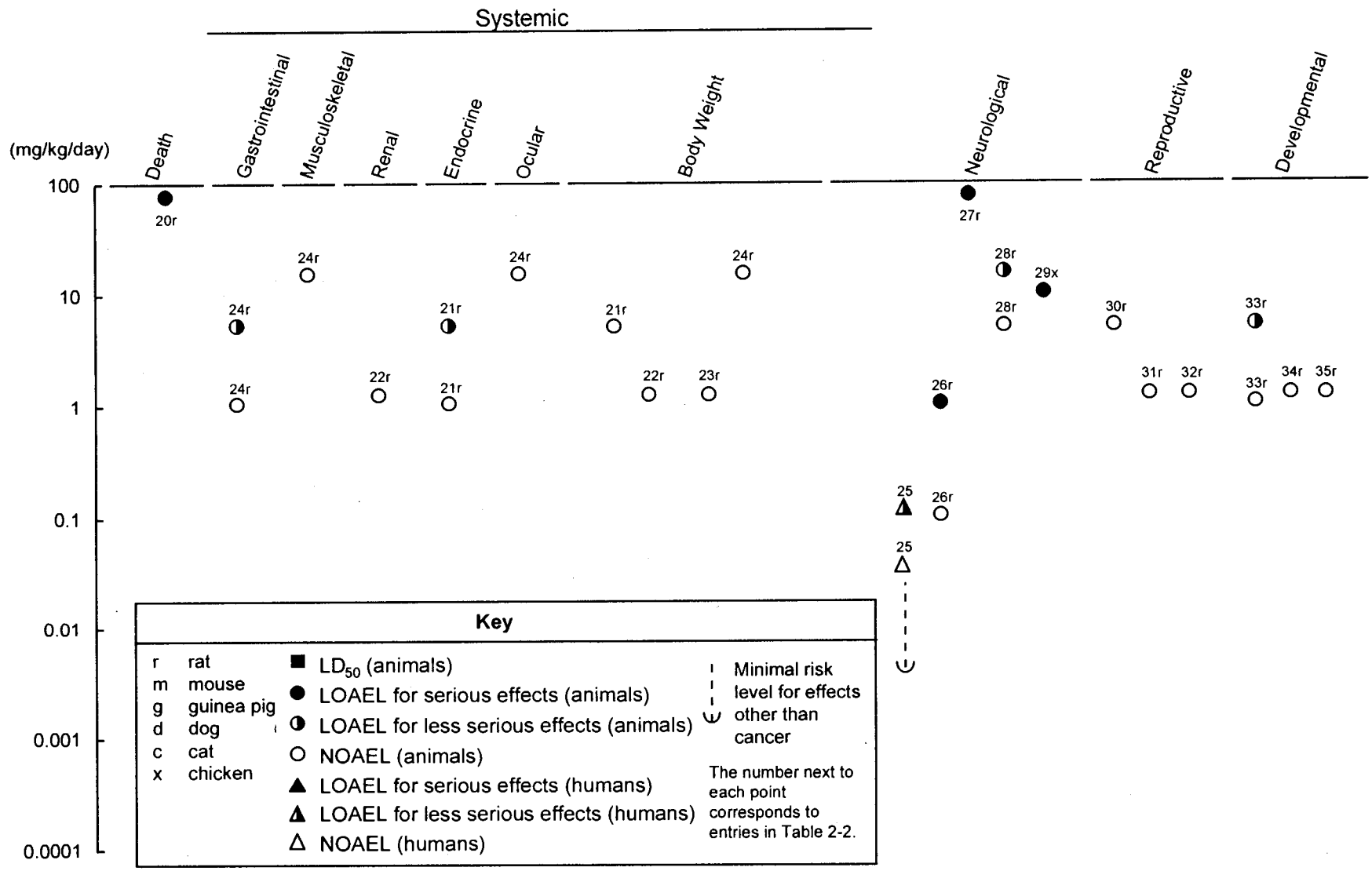
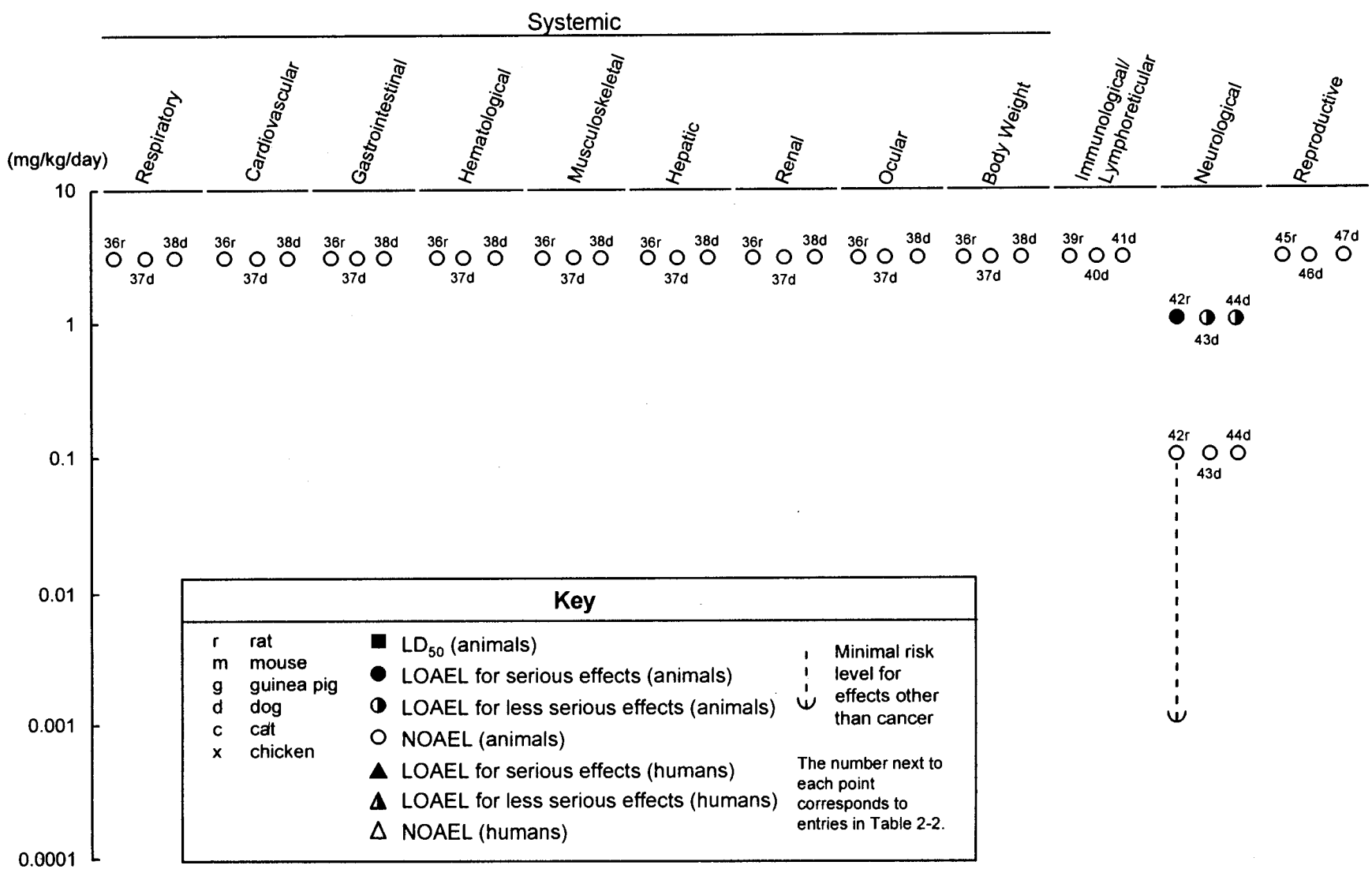


Figure 2-2. Levels of Significant Exposure to Chlorpyrifos - Oral (cont.)

Chronic (≥365 days)



was also evident. It should be noted that stridor often develops in children after they are removed from artificial respirators. Stridor recurred, but the boy responded well to aerosolized racemic epinephrine and cool mist. An acute episode of stridor that did not respond to the aforementioned treatment occurred on day 11 of hospitalization. The airway appeared normal after direct laryngoscopy and bronchoscopy. Bilateral vocal cord paralysis was noted. However, this may have been caused or exacerbated by the intubation. All respiratory symptoms had resolved by day 52 of hospitalization. Similar symptoms were reported in a 5-year-old girl who drank an undetermined amount of Rid-A-Bug®, a pesticide preparation containing chlorpyrifos. When she arrived at the hospital, she presented with rapid and labored breathing, wheezing, and copious secretions in the nose and mouth that required frequent suctioning (Selden and Curry 1987). The symptoms resolved by day 6 of hospitalization. Respiratory distress was also observed in an adult following acute-duration oral exposure to approximately 300 mg/kg chlorpyrifos (Lotti et al. 1986). No information was found concerning respiratory effects in humans following intermediate- or chronic-duration oral exposure.

No histopathological lesions of the lungs were noted following acute-duration exposure to 40 mg/kg chlorpyrifos dissolved in methylene chloride and administered via gavage in olive oil to male domestic short-hair cats (Hooser et al. 1988) or chronic-duration exposure of Sherman rats and Beagle dogs to as much as 3 mg/kg/day chlorpyrifos in feed (McCollister et al. 1974). No data were located for respiratory effects in animals following intermediate-duration oral exposure to chlorpyrifos.

Cardiovascular Effects. Acute-duration oral exposure to undetermined amounts of chlorpyrifos in humans has been shown to cause tachycardia (Aiuto et al. 1993; Selden and Curry 1987). Although these studies only found tachycardia, the initial response after exposure to an acetylcholinesterase inhibitor is likely to be bradycardia because of stimulation of muscarinic receptors in the heart. No information was found concerning cardiovascular effects in humans following intermediate- or chronicduration oral exposure to chlorpyrifos.

No histopathological lesions of the heart were noted following acute-duration exposure to 40 mg/kg chlorpyrifos dissolved in methylene chloride and administered in olive oil to cats (Hooser et al. 1988). Similarly, no heart weight changes or histopathological lesions were observed following chronic-duration exposure of Sherman rats and Beagle dogs to as much as 3 mg/kg/day chlorpyrifos in feed (McCollister et al. 1974). Intermediate-duration exposure of a female domestic short-hair cat to an unspecified concentration of chlorpyrifos 2-3 hours after an apartment was sprayed for fleas did result

in increased creatine kinase levels in the cat. No effect was seen on an electrocardiogram, however (Jaggy and Oliver 1992). It is assumed that at least some of the exposure to this animal was oral through grooming.

Gastrointestinal Effects. No information was found concerning gastrointestinal effects in humans following acute-, intermediate-, or chronic-duration oral exposure to chlorpyrifos.

Limited gastrointestinal effects have been noted in rats following intermediate-duration oral exposure to chlorpyrifos. In female Fischer 344 rats, perineal soiling was observed in animals exposed to 5 mg/kg/day chlorpyrifos in feed for 13 weeks and may have been related to cholinesterase inhibition (Dow 1993). This effect was not seen in male rats exposed to as much as 15 mg/kg/day in feed for the same duration. This effect may be part of the spectrum of cholinergic effects. No histopathological lesions of the stomach were noted following either acute-duration exposure to 40 mg/kg chlorpyrifos in male domestic short-hair cats (Hooser et al. 1988) or chronic-duration exposure of Sherman rats and Beagle dogs to as much as 3 mg/kg/day chlorpyrifos in feed (McCollister et al. 1974).

Hematological Effects. Acute-duration oral exposure to an undetermined amount of chlorpyrifos by ingestion caused elevated serum glucose and creatinine kinase levels and low lactate dehydrogenase levels in a 3-year-old boy who ingested an unknown amount of Dursban® (Aiuto et al. 1993). No effect on hematological or serum chemistry parameters were seen, however, in adult male volunteers treated with up to 0.1 mg/kg/day chlorpyrifos by capsule for 9 days or up to 0.03 mg/kg/day chlorpyrifos for 20 days (Coulston et al. 1972). No information was found concerning hematological effects in humans following chronic-duration oral exposure to chlorpyrifos. No information was found concerning hematological effects in other animals following acute- or intermediate-duration oral exposure to chlorpyrifos. No effect was seen on hematological parameters monitored in Sherman rats and Beagle dogs exposed to up to 3 mg/kg/day chlorpyrifos in the feed for l-2 years (McCollister et al. 1974).

Musculoskeletal Effects. Acute-duration oral exposure to an undetermined amount of chlorpyrifos caused increased muscle tone in a 23-year-old woman (Joubert et al. 1984), and fasciculations in a 42-year-old male (Lotti et al. 1986). Bilateral vocal cord paralysis was also

observed in a 3-year-old boy who swallowed an undetermined amount of chlorpyrifos (Aiuto et al.1993); the vocal cord paralysis, however, may have been caused or exacerbated by the intubation of this patient. No information was found concerning musculoskeletal effects in humans following intermediate- or chronic-duration oral exposure to chlorpyrifos.

No histopathological lesions of the skeletal muscle were noted following acute-, intermediate-, or chronic-duration exposure to chlorpyrifos. Exposure to 40 mg/kg chlorpyrifos dissolved in methylene chloride and administered in olive oil to male domestic short-hair cats (Hooser et al. 1988), to 15 mg/kg/day Dursban® in feed administered to male and female Fischer 344 rats (Dow 1993), or chronic-duration exposure of Sherman rats and Beagle dogs to as much as 3 mg/kg/day chlorpyrifos in feed (McCollister et al. 1974) caused no histopathology of the skeletal muscles. No data were located for musculoskeletal effects in animals following acute- or chronic-duration oral exposure to chlorpyrifos.

Hepatic Effects. No information was found concerning hepatic effects in humans following acute-, intermediate-, or chronic-duration oral exposure to chlorpyrifos.

The effects on liver weight and relative liver weight (liver weight/body weight) were assessed in pregnant CF-1 mice following acute-duration oral exposure to doses as high as 25 mg/kg/day chlorpyrifos from Gd 6 to 15 (Deacon et al. 1980). Liver weight and relative liver weight determined on Gd 18 were comparable to controls in all treatment groups. Hepatic effects were also noted in pregnant female Fischer 344 rats dosed by gavage with 0, 0.1, 3, or 15 mg/kg/day of the technicalgrade chlorpyrifos Dursban F® in corn oil on Gd 6-15. Porphyrin deposits about the eyes were observed during the dosing period in maternal animals exposed to 15 mg/kg/day chlorpyrifos. This effect was not seen at doses of 3 mg/kg/day or below (Breslin et al. 1996). Increased serum total protein and albumin levels were observed in a female domestic short-hair cat exposed to an unspecified amount of chlorpyrifos in an apartment that was sprayed with chlorpyrifos every third day for 18 days (Jaggy and Oliver 1992). It is assumed that some of the exposure was via the oral route as a result of grooming. No histopathological lesions or organ weight changes were observed in livers of Sherman rats or Beagle dogs chronically exposed to as much as 3 mg/kg/day chlorpyrifos in feed (McCollister et al. 1974).

Renal Effects. No chlorpyrifos-induced renal effects have been observed in humans. Urinalyses conducted for adult male volunteers treated with up to 0.1 mg/kg/day chlorpyrifos by capsule for 9 days or up to 0.03 mg/kg/day chlorpyrifos for 20 days were normal (Coulston et al. 1972). No information was found concerning renal effects in humans following chronic-duration oral exposure to chlorpyrifos.

In laboratory animals, chlorpyrifos-induced renal effects were few. No renal lesions were noted following a single oral exposure to 40 mg/kg chlorpyrifos dissolved in methylene chloride and administered in olive oil to adult male domestic short-hair cats (Hooser et al. 1988). Urine staining of the perineal region was observed in pregnant Fischer 344 rats exposed via gavage on Gd 6-15 to 15 mg/kg/day of the technical-grade chlorpyrifos, Dursban F®, in corn oil (Breslin et al. 1996). In the same study, no renal effects were noted in rats exposed to 0.1 or 3 mg/kg/day chlorpyrifos. Renal effects have been observed following intermediate-duration oral exposure. Unspecified increases in urea nitrogen, alkaline phosphatase, and alanine aminotransferase were observed in a female domestic short-hair cat orally exposed to an unspecified amount of chlorpyrifos every third day for 18 days (Jaggy and Oliver 1992). It is assumed that some of the exposure was oral through grooming. No renal effects were seen in the parental generation of Sprague-Dawley rats exposed to 0, 0.5, 0.8, or 1.2 mg/kg/day chlorpyrifos in feed for 135 days (Dow 1983b). Chronic-duration oral exposure to up to 3 mg/kg/day chlorpyrifos in feed also caused no organ weight changes or histopathological lesions of the kidneys in either male or female Sherman rats or Beagle dogs exposed to chlorpyrifos in feed for l-2 years (McCollister et al. 1974).

Endocrine Effects. No information was found concerning endocrine effects in humans following acute-, intermediate-, or chronic-duration oral exposure to chlorpyrifos.

Acute-duration oral exposure to 40 mg/kg chlorpyrifos dissolved in methylene chloride and administered in olive oil to male domestic short-hair cats caused no microscopic lesions of the thyroid or adrenal glands (Hooser et al. 1988). Mild endocrine effects were, however, observed-following intermediate-duration oral exposure (Breslin et al. 1996). In a multigeneration study, rats (30 males and females per dose group) received chlorpyrifos dosages equivalent to 0, 0.1, 1, or 5 mg/kg/day/day in feed. Very slight to slight vacuolation of the adrenal gland fasiculata was observed at 5 mg/kg/day in both males and females in the parental generation. These alterations were characterized by very slight to slight vacuolation in males and very slight vacuolation and altered tinctorial

properties in females. The toxicological significance of these effects is unclear. No endocrine effects were observed at the 0.1 or 1 mg/kg/day doses (Breslin et al. 1996). No information was found concerning endocrine effects in animals following chronic-duration oral exposure to chlorpyrifos.

Ocular Effects. No information was found concerning ocular effects in humans following intermediate- or chronic-duration oral exposure to chlorpyrifos.

Miosis was observed in a man after a single oral exposure to 300 mg/kg chlorpyrifos (Lotti et al.1986). No data were located for ocular effects in other animals following acute-duration oral exposure to chlorpyrifos. No ocular histopathology was found in male and female Fisher 344 rats exposed for 13 weeks to 0, 0.1, 1, 5, or 15 mg/kg/day chlorpyrifos in feed (Dow 1993). Chronic-duration oral exposure in feed to as high as 3 mgikg/day chlorpyrifos caused no ocular effects in either male or female Sherman (30-32/sex/group) rats dosed for 2 years or Beagle dogs (3/sex/group) exposed for 1-2 years (McCollister et al. 1974).

Body Weight Effects. No information was found concerning effects on body weight in humans following acute-, intermediate-, or chronic-duration oral exposure to chlorpyrifos.

The effects on body weight and body weight gain were assessed in pregnant CF-1 mice following acute-duration oral exposure to doses as high as 25 mg/kg/day chlorpyrifos in cottonseed oil on Gd 615 (Deacon et al. 1980). A statistically significant decrease in mean body weight gain for Gd lo-15 (33.3%) and overall (Gd 6-17, 14%) was observed in animals exposed to 25 mg/kg/day chlorpyrifos. Food consumption was unaffected. The body weight gain and food consumption of dams exposed to 1 or 10 mg/kg/day chlorpyrifos were comparable to controls. Additionally, body weights determined on Gd 18 for all the treatment groups were similar to control values. Similar effects have been observed in rats (Breslin et al. 1996; Moser 1995). A single dose of 100 mg/kg technical-grade chlorpyrifos (99%) administered via gavage in corn oil caused a 13.3% decrease in the body weight of male Long-Evans rats by 24 hours post-dosing. Recovery was seen at one week postdosing. Decreased body weight was not seen at doses of 50 mg/kg or less (Moser 1995). Similarly, pregnant Fischer 344 rats exposed via gavage to 15 mg/kg/day Dursban F® (technical-grade chlorpyrifos) in corn oil on Gd 6-15 experienced a statistically significant decrease in mean body weight gain for Gd 9-12 (44%). The body weight gain of dams exposed to 0.1 or 3 mg/kg/day chlorpyrifos was comparable to controls (Breslin et al. 1996).

Body weight effects have not been seen following intermediate-duration oral exposure of rodents (Breslin et al. 1996; Dow 1983b, 1993). No body weight changes were observed in male and female Fischer 344 rats exposed to up to 15 mg/kg/day Dursban ® in feed for 13 weeks (Dow 1993). Similarly, in a rat multigeneration study, no body weight or feed intake changes were observed in male and female Sprague-Dawley rats exposed to 0, 0.1, 1, or 5 mg/kg/day chlorpyrifos in feed (Breslin et al. 1996). I n another rat multigeneration study, no body weight or feed intake changes were observed in male and female Sprague-Dawley parental animals or first generation offspring exposed to 0, 0.5, 0.8, or 1.2 mg/kg/day Dursban® for 135 or 120 days, respectively (Dow 1983b). However, body weight decreases following intermediate-duration chlorpyrifos exposure have been observed in chickens. A dose of 10 mgtkglday chlorpyrifos for 20 days caused a 25% decrease in body weight in hens by the end of the dosing period (Richardson et al. 1993b). Chronic-duration oral exposure to ≤3 mg/kg/day chlorpyrifos in feed also caused no body weight effects in either male or female Sherman rats or Beagle dogs exposed for l-2 years (McCollister et al. 1974).

Metabolic Effects. No information was found concerning the metabolic effects in humans following acute-, intermediate-, or chronic-duration oral exposure to chlorpyrifos.

Hypothermia was observed in male Long-Evans rats 3.5 hours after acute-duration exposure to 50 or 100 mg/kg technical-grade (99%) chlorpyrifos in corn oil via gavage (Moser 1995). Hypothermia was present at 24 hours post-dosing only in the 100 mg/kg group and was no longer detectable at 72 hours post-dosing. Hypothermia was not observed in animals exposed to 20 mg/kg. No information was found concerning the potential metabolic effects in animals following intermediate- or chronic-duration exposure to chlorpyrifos.

2.2.2.3 Immunological and Lymphoreticular Effects.

No information was found concerning immunological or lymphoreticular effects in humans following acute-, intermediate-, or chronic-duration oral exposure to chlorpyrifos. No immunological or lymphoreticular effects were observed microscopically in the spleen or mesenteric lymph nodes of 2 male domestic short-hair cats acutely exposed to 40 mg/kg chlorpyrifos (Hooser et al. 1988). Similarly, chickens exposed orally to 10 mg/kg/day chlorpyrifos for 20 days also exhibited no immunological or lymphoreticular effects (Richardson et al. 1993b). Breslin et al. (1996)

investigated the reproductive and developmental effects of chlorpyrifos at 0.1, 1, and 5 mg/kg/day/day in a 2-generation reproductive study in Sprague-Dawley rats. Their results indicated no treatmentrelated histopathological changes in thymus, spleen, mesenteric lymph node, or bone marrow in any of the F_0 or F_1 adults. Chronic-duration oral exposure to up to 3 mg/kg/day chlorpyrifos in feed also caused no histopathology of the spleen or organ weight change in either male or female Sherman rats or Beagle dogs orally exposed for l-2 years (McCollister et al. 1974). Taken together, the available evidence indicates that exposure to chlorpyrifos produces little or no structural changes in the immune system, even when administered chronically at doses causing statistically significant decreases in acetylcholinesterase activity.

2.2.2.4 Neurological Effects

In humans, acute-duration oral exposure to 0.1 mg/kg/day/day of chlorpyrifos for 9 days has been reported to inhibit plasma cholinesterase activity 66% (Coulston et al. 1972). Additionally, acuteduration oral exposure to undetermined amounts of chlorpyrifos has been reported to inhibit both erythrocyte and plasma cholinester ase activity 78-95% (Joubert et al. 1984; Selden and Curry 1987). These latter levels of inhibition were associated with life-threatening cholinergic symptoms requiring hospitalization. Acute-duration oral exposure to undetermined amounts of chlorpyrifos caused stupor in a 23-year-old woman (Joubert et al. 1984), seizure-like motor activity in a 5-year-old girl (Selden and Curry 1987), and coma in a 42-year-old man (Lotti et al. 1986) and a 3-year-old boy (Aiuto et al. 1993). A variety of other symptoms have also been associated with exposure to unspecified amounts of chlorpyrifos: miosis, muscle twitching and fasciculations, hyper- or hyporeflexia, lacrimation, salivation, sweating, bronchorrhea, diaphoresis, and coreo-athetotic motions (Aiuto et al. 1993; Joubert et al. 1984; Selden and Curry 1987). Similar chlorpyrifos-related effects have been observed for CF-1 mice at 25 mg/kg/day, but not at 10 mg/kg/day chlorpyrifos (Deacon et al. 1980); in domestic shorthair cats at 40 mg/kg (Hooser et al. 1988); and in hens at 90 mg/kg (Capodicasa et al. 1991). Plasma and erythrocyte cholinesterase activity in adult humans volunteers following intermediate-duration oral exposure to doses up to 0.03 mg/kg/day chlorpyrifos for 20 days were unaffected (Coulston et al. 1972). No information was found concerning neurological effects in humans following chronicduration oral exposure to chlorpyrifos.

In male domestic short-hair cats, acute-duration oral exposure to 40 mg/kg chlorpyrifos caused a 43-57% decrease in whole blood acetylcholinesterase activity and a 71% decrease in plasma

cholinesterase activity (Hooser et al. 1988). Similar effects were observed in pregnant Fischer 344 rats exposed to technical-grade chlorpyrifos Dursban F® administered via gavage on Gd 6-15. Erythrocyte acetylcholinesterase activity decreased 74 and 85% compared to control values at the 3 and 15 mg/kg/day body weight doses, respectively (Breslin et al. 1996). The dams exposed to 15 mg/kg/day chlorpyrifos also exhibited classic signs of organophosphate poisoning during the dosing period, including excessive salivation, tremors, and decreased plasma cholinesterase activity. In the same study, no neurological effects were seen at 0.1 mg/kg/day. Female CF-1 mice (40-51 per group) were exposed by gavage to 1, 10, or 25 mg/kg/day/day Dursban F® (96.8% chlorpyrifos) as a solution in cottonseed oil on day 6, days 6-10, or Gd 6-15 (Deacon et al. 1980). Plasma and erythrocyte cholinesterase levels were significantly decreased from control values among mice given 10 or 25 mg/kg/day chlorpyrifos on day 6 (plasma, 95 and 97% decrease, respectively; erythrocyte, 20 and 40%, respectively) and, days 6-10 (plasma, 97 and 99%, respectively; erythrocyte, 43 and 71%, respectively), or days 6-15 (plasma, 96 and 98%, respectively; erythrocyte, 43 and 57%, respectively). Plasma cholinesterase levels were significantly reduced among mice given 1 mg/kg/day chlorpyrifos during the same time intervals (69, 78, and 85%, respectively). Erythrocyte cholinesterase levels were also reduced (43%) after 1 mg/kg/day chlorpyrifos, but only after exposure on Gd 6-10 (Deacon et al.1980). In a concurrent study of cholinesterase inhibition using dosages of 0.1, 1, and 10 mg/kg/day, Deacon et al. (1980) determined a no-effect level of 0.1 mg/kg/day for erythrocyte and plasma cholinesterase inhibition. Similar effects on erythrocyte and plasma cholinesterase activities were noted in a multigeneration study in rats (Breslin et al. 1996). Significantly decreased erythrocyte and plasma cholinesterase levels were seen in first and second generation male and female Sprague-Dawley rats exposed to 1 mg/kg/day Dursban F® in feed. In males, erythrocyte cholinesterase was decreased 65-69%, while plasma cholinesterase was decreased 4344%. In females, erythrocyte cholinesterase was decreased 67%, while plasma cholinesterase was decreased 49-55%. These effects were not observed in rats fed diets containing 0.1 mg/kg/day Dursban F® (Breslin et al. 1996).

In one human suicide attempt, acute-duration oral exposure to approximately 300 mg/kg of a commercial formulation of chlorpyrifos caused transient distal polyneuropathy that resolved approximately 90 days after exposure (Lotti et al. 1986). Acute-duration oral exposure to un-determined amounts of chlorpyrifos produced clinical findings in a 3-year-old boy that were consistent with proximal polyneuropathy (Aiuto et al. 1993). Eleven days following exposure, the boy was areflexic, and electromyography demonstrated the absence of voluntary motor units on the 18th

day of hospitalization. Nerve conduction studies revealed a lack of F latencies. The patient was fully recovered by day 52 of his hospital stay.

In the chicken, the species of choice for the evaluation of the OPIDN (Johnson 1982), a single oral exposure to 150 or 300 mg/kg chlorpyrifos (with atropine prophylaxis to prevent death from acute cholinergic effects) caused a 3880% inhibition of neurotoxic esterase (NTE) 4 days after exposure (Capodicasa et al. 1991; Richardson et al. 1993a). NTE inhibition is believed by some to be directly related to the onset of OPIDN (Johnson 1982). Mild ataxia (indicating OPIDN) was observed in 4 of 7 chickens receiving 5 daily doses of 90 mg/kg/day chlorpyrifos (with atropine prophylaxis) and observed for a further 2 weeks (Capodicasa et al. 1991). A repeated-dose study showed that 20 daily doses of 10 mg/kg/day/day chlorpyrifos in corn oil (the maximally tolerated dose that did not require atropine prophylaxis) followed by a 4-week recovery produced signs of toxicity, including a significant decrease in body weight and brain and blood AChE (Richardson et al. 1993a). It also produced a maximum 18% inhibition of brain NTE, with no significant inhibition of lymphocyte NTE or clinical signs of OPIDN.

In the chicken, brain AChE has also been shown to be inhibited by acute-duration oral exposure to chlorpyrifos. Exposure to 150 or 300 mg/kg caused brain AChE inhibition of >80% 4 days after exposure (Richardson et al. 1993a). Intermediate-duration exposure to 10 mg/kg/day chlorpyrifos inhibited brain AChE 58-70% during days 4-20 of exposure (Richardson et al. 1993b). Similar effects on brain AChE were observed in male Long-Evans rats exposed to 75 mg/kg/day chlorpyrifos in corn oil via gavage for 24 weeks. Brain AChE was decreased 85, 91, 86, and 73% in the whole brain, forebrain, hippocampus, and cerebellum, respectively. Additionally, brain immunoreactive AChE was increased 56, 29, 26, and 26% in the whole brain, forebrain, hippocampus, and cerebellum, indicating increased synthesis of AChE or inhibited degradation to compensate for the effects of chlorpyrifos (Chiappa et al. 1995). In a study to examine the potential for intermediate-duration chlorpyrifos exposure to produce OPIDN (Francis et al. 1985), 2 hens were exposed to 10 mg/kg/day chlorpyrifos for 90 days. Physical deterioration began 30 days after exposure, and extreme debilitation, weakness, and lethargy occurred between 35 and 60 days of dosing. The report indicates that both hens recovered from the chlorpyrifos-induced neurotoxicity after the cessation of dosing, but the time to recovery was not given. The time-course of toxicity and the eventual resolution of neurological symptoms following the exposure indicate that chlorpyrifos did not cause the classic OPIDN, from which recovery would not be expected, in this study. In fact, work by Richardson et al.

(1993a) indicates that chlorpyrifos-related OPIDN would only be expected at doses that would cause death without aggressive therapy.

Other neurological effects were also noted in acute- and intermediate-duration studies of humans and animals (Aiuto et al. 1993; Dow 1993; Joubert et al. 1984; Lotti et al. 1986; Moser 1995; Selden and Curry 1987). Acute-duration exposure to unspecified amounts of chlorpyrifos in children (a 3-year-old boy [Aiuto et al. 19931 and a 5-year-old girl [Selden and Curry 19871) and a 23-year-old woman (Joubert et al. 1984) caused miosis. Miosis was also observed in a man who ingested an estimated 300 mg/kg chlorpyrifos in a suicide attempt (Lotti et al. 1986). Decreased motor activity was noted in male Long-Evans rats 3.5 hours after a single gavage exposure to 20, 50, or 100 mg/kg technical-grade chlorpyrifos (99%) in corn oil. At 24 hours post-dosing, decreased motor activity was still present in the 100 mg/kg group, but these effects were no longer evident at 72 hours post-dosing (Moser 1995). Male and female Sprague-Dawley rats exposed to 1.5 mg/kg/day Dursban F® in feed for 13 weeks displayed a transient decrease in motor activity at the fourth week of dosing (Dow 1993). Chronicduration oral exposure to chlorpyrifos in feed also caused neurological effects in rats and dogs (McCollister et al. 1974). Brain acetylcholinesterase AChE activity was depressed at all sampling times in rats fed 3 mg/kg/day chlorpyrifos for up to 2 years, with overall means averaging 56% of control value for males and 57% for females. There was no overall reduction in brain AChE activity at study termination in rats dosed with 1 mg/kg/day, although there were individually significant differences at some of the sampling times. Rat plasma cholinesterase (ChE) and red blood cell (RBC) AChE activities were significantly depressed for both male and female rats dosed with 1 and 3 mgfkglday chlorpyrifos. For example, at 1 mg/kg/day, plasma ChE activity was decreased 20-53% while RBC AChE activity was decreased 65-70%. At 0.1 mg/kg/day, the AChE activity of the RBCs for females was significantly different from controls at 2 of the 6 sampling periods only. Otherwise, doses of 0.1 mg/kg/day and below had no effect on either plasma or RBC activity. Cholinesterase activities in plasma, RBC, and brain returned to normal levels in males and females in all dose groups maintained on control diets for 7-8 weeks (McCollister et al. 1974). In Beagle dogs, similar effects were observed in males exposed to 1 mg/kg/day chlorpyrifos in feed for 1 or 2 years or-females receiving that same daily dose for 2 years. However, this effect was not seen in females exposed to as much as 3 mg/kg/day chlorpyrifos in feed for 1 year (McCollister et al. 1974), suggesting that there may be a cumulative effect of chlorpyrifos exposure.

Any sex-dependent toxicity of chlorpyrifos may be due to an increased rate of extrahepatic detoxification of the pesticide in males. A complete discussion of this phenomenon may be found in Section 2.3, Toxicokinetics, of this profile.

The highest NOAEL value and all LOAEL values for neurological effects in each reliable study for each species and duration category are shown in Table 2-2 and Figure 2-2.

2.2.2.5 Reproductive Effects

No information was found concerning reproductive effects in humans following oral acute-, intermediate-, or chronic-duration exposure to chlorpyrifos.

Pregnant CF-1 mice were exposed on Gd 6, Gd 6-10 or Gd 6-15, to 0, 1, 10, or 25 mg/kg/day chlorpyrifos (Deacon et al. 1980). Four of 47 dams exposed to 25 mg/kg/day chlorpyrifos died. That dose also caused a significant decrease in body weight gain during Gd lo-15 (33%) and Gd 6-17 (14%). Despite the deficits in weight gain, overall body weight at study termination was not affected at that dose. Thirty-two of 47 mice exposed to 25 mg/kg/day chlorpyrifos exhibited symptoms (excessive salivation, tremors, urine-soaked coat, ataxia, and lethargy) of cholinergic overstimulation; similar clinical signs were seen in 5 of 44 dams dosed with 10 mg/kg/day/day chlorpyrifos. Food and water intake were also significantly decreased at that dose. Despite the maternal toxicity, chlorpyrifos did not affect the ability of the surviving dams to maintain pregnancy. No overt neurological symptoms were observed at the lower chlorpyrifos doses (1 or 10 mg/kg/day). In a concurrent study, pregnant mice were orally administered 0, 0.1, 1, or 10 mg/kg/day chlorpyrifos. No significant clinical signs of maternal toxicity were noted at any dose of chlorpyrifos. In pregnant Fischer 344 rats exposed by gavage to 0, 0.1, 3, or 15 mg/kg/day technical-grade chlorpyrifos as Dursban F®, on Gd 6-15, vaginal bleeding was observed in dams exposed to 15 mg/kg/day chlorpyrifos, but no other reproductive organ effects were noted (Breslin et al. 1996). No reproductive effects were seen in rats exposed to 0.1 or 3 mg/kg/day. No adverse effects on fertility, mating, or gestation indices were observed in multigeneration studies conducted using Sprague-Dawley rats (30/sex/group) dosed with 0.1-5 mg/kg/day Dursban® feed (Breslin et al. 1996; Dow 1983b). No effects on testes weight or reproductive organ histology were observed in male and female Sherman rats or Beagle dogs exposed to as high as 3 mg/kg/day chlorpyrifos in feed for l-2 years (McCollister et al. 1974).

The highest NOAEL values for reproductive effects in each reliable study for each species and duration category are shown in Table 2-2 and Figure 2-2.

2.2.2.6 Developmental Effects

No information was found concerning developmental effects in humans following oral acute-, intermediate-, or chronic-duration exposure to chlorpyrifos.

The potential for chlorpyrifos to cause developmental toxicity was assessed in CF-1 mice exposed to 0, 1, 10, or 25 mg/kg/day chlorpyrifos on Gd 6-15 (Deacon et al. 1980). On Gd 18, all fetuses were weighed, sexed, examined for external malformations and cleft palate, and had their crown-rump length determined. One-third of the fetuses of each litter were also examined for evidence of softtissue alterations. There was no biologically significant effect of treatment on the number of live fetuses per litter, the number of dead fetuses per litter, the number of resorptions per litter, the average fetal body weight, or average crown-rump length. However, significant increases in skeletal variations were observed in litters exposed to 25 mg/kg/day chlorpyrifos. Increases were seen for the number of fetuses with delayed ossification of the skull bones (6.8-fold increase), delayed ossification of the stemebrae (2.1-fold increase), and unfused stemebrae (4-fold increase). These effects, however, may have been due, in part, to maternal toxicity as opposed to a direct effect of chlorpyrifos on the developing offspring. In the same study, 10 and 25 mg/kg/day significantly decreased whole fetal homogenate cholinesterase activity by 35 and 65%, respectively. Similar exposure in rats, however, caused no developmental effects (Breslin et al. 1996). Pregnant Fischer 344 rats exposed to 0.1, 3, or 15 mg/kg/day technical-grade chlorpyrifos Dursban F® in corn oil administered via gavage on Gd 6-15 showed no effect on pregnancy rate, number of implantations, preimplantation loss, resorption, number of dead fetuses, litter size, fetal body weight, crown-rump length, or sex ratio in any treatment group. Increased fetal body weight was observed in the 3 and 15 mg/kg groups, but was not considered treatment-related. There were no treatment-related effects on fetal malformations or variations at any exposure level (Breslin et al. 1996).

Few developmental effects have been seen following intermediate-duration oral exposure to chlorpyrifos. No adverse effects on gestation indices; gestation survival indices; total number of live pups per litter on day 1 of lactation; pup survival indices on days 1, 4, 7, 14, and 21 of lactation; sex ratio of pups at day 21; or incidence of external alterations in first and second generation offspring

between birth and 21 days of age were observed in a multigeneration study conducted using Sprague-Dawley rats (30/sex/dose group) fed the equivalent of 0.5, 0.8, or 1.2 mg/kg/day Dursban® (Dow 1983b). However, a 10-l1% decrease in pup body weight was observed in first generation pups in a multigeneration study of male and female Sprague-Dawley rats fed diets containing 5 mg/kg/day Dursban F® (Breslin et al. 1996). Using a similar study design and numbers of animals, Breslin et al.(1996) did not report offspring body weight deficits in animals fed 1 mg/kg/day or less chlorpyrifos. No data were located for developmental effects in animals following chronic-duration oral exposure to chlorpyrifos.

The LOAEL values for developmental effects in each reliable study for each species and duration category are shown in Table 2-2 and Figure 2-2.

2.2.2.7 Genotoxic Effects

No information was found concerning the potential genotoxic effects in humans following oral acute-, intermediate-, or chronic-duration exposure to chlorpyrifos.

Chlorpyrifos was tested for its ability to induce complete and partial chromosome losses in *D. melanogaster* males (Woodruff et al. 1983). Initial attempts were made to identify an approximate LD_{30} dose prior to treatment, with toxicity defined as the number of dead flies out of the total number treated over a 3-day period. Mortality was recorded at 24, 48, and 72 hours. At 72 hours, males were removed and mated with mus-302 repair-defective females, and F_1 male progeny were screened for complete and partial chromosome loss. Treated and control males that had a ring-X chromosome and a doubly-marked Y chromosome were used in a screen for ring-chromosome loss and for loss of Y-chromosome markers. A significant increase in complete chromosome loss was induced by 0.05 mg/kg chlorpyrifos, but no effect on partial chromosome loss was observed.

The mutagenic potential of an unspecified dose of Durmet® (20% chlorpyrifos) was assessed using the Drosophila wing mosaic and sex-linked recessive lethal tests (Patnaik and Tripathy 1992). In the wing mosaic test, second- and third-instar larvae that were trans-heterozygous for the recessive marker mutations multiple wing hair (mwh) and flare-3 (flr3) were obtained from a cross of mwh females and flr3/TM3 Ser males. They were exposed to various concentrations of Durmet®, and the frequency of the mutant mosaic spot induction on the wings noted. The Basc technique was used to evaluate the

induction of sex-linked lethals. Because of an increase in the frequency of induction of mosaic wing spots and sex-linked recessive lethals, Durmet® was considered to be genotoxic to *Drosophila* somatic and germ cells.

Intermediate-duration oral exposure to chlorpyrifos (as Dursban®) has been shown to increase the incidence of erythroblast chromosomal aberrations (Amer and Fahmy 1982). In that study, mice received rat chow containing either 0, 80, or 240 ppm Dursban® for 24 hours, 7 days, 14 days, or 14 days with a 7-day recovery period. Doses of 1.39 or 4.18 mg/kg/day Dursban® were estimated from those concentrations. Dursban® at 4.18 mg/kg/day caused a statistically significant increase in the percentage of polychromatic erythrocytes (PE) and PE with micronuclei after 24 hours (70 and 176% increases, respectively) and 7 days (25 and 257% increases, respectively) of exposure. PE with micronuclei were also significantly increased at 14 days of treatment with 4.18 mg/kg/day (458% increase). These increases were transient, and percentages of PE and PE with micronuclei were normal seven days after the end of the dosing period. These results indicate that during exposure, chlorpyrifos increased the incidence of erythroblast chromosomal aberrations. Similar transient increases in PE and PE with micronuclei were found after mice were dose-fed 2.09 mg/kg/day Dursban® for 10 weeks (Amer and Fahmy 1982). No data were located for genotoxic effects in animals following chronic-duration oral exposure to chlorpyrifos. Genotoxicity studies are also discussed in Section 2.5.

2.2.2.8 Cancer

No information was located concerning carcinogenic effects of chlorpyrifos in humans following oral acute-, intermediate-, or chronic-duration exposures.

No studies were located concerning carcinogenic effects of chlorpyrifos in animals following acute- or intermediate-duration exposure. Chronic-duration exposure studies have shown no carcinogenicity. Male and female Sherman rats and Beagle dogs exposed to up to 3 mg/kg/day chlorpyrifos in feed for l-2 years had no increased incidence of tumors compared to controls (McCollister et al. 1974).

2.2.3 Dermal Exposure

2.2.3.1 Death

No information was found concerning death in humans following acute-, intermediate-, or chronicduration dermal exposure to chlorpyrifos.

Acute-duration dermal exposure LD_{50} for chlorpyrifos was determined to be 202 mg/kg in Sherman rats (Gaines 1969). Survival times of 46 hours to 13 days were reported. Acute-duration dermal exposure of 185 young (9-52 months of age) bulls to an undetermined dose of Dursban 44® to control lice killed 7 of the animals (Everett 1982). Additionally, age-related death was observed in newborn piglets sprayed with an undetermined amount of chlorpyrifos at various times after birth (Long et al.1986). Mortality was 4 of 4 in piglets treated 0-3 hours after birth, 3 of 3 in piglets treated l-3 hours after birth, 3 of 5 in piglets treated 24-30 hours after birth, and 0 of 3 in piglets treated 30-36 hours after birth. The results indicate that newborn piglets are more susceptible to the chlorpyrifos toxicity. In hens, intermediate-duration dermal exposure to 20 mg/kg/day killed 2 of 3 hens after 30 and 38 days of exposure, respectively (Francis et al. 1985). No data were located concerning death in animals following chronic-duration dermal exposure to chlorpyrifos.

The LD_{50} value for mortality in rats in shown in Table 2-3.

2.2.3.2 Systemic Effects

No studies were located concerning the potential cardiovascular, endocrine, body weight, or metabolic effects of chlorpyrifos in humans or animals following acute-, intermediate-, or chronic-duration dermal exposure to chlorpyrifos.

Respiratory Effects. No information was found concerning respiratory effects in humans following intermediate-duration dermal exposure to chlorpyrifos.

The effects of presumed acute-duration dermal exposure to chlorpyrifos were reported for 12 persons exposed to chlorpyrifos primarily in the home or workplace following professional application of the pesticide (Thrasher et al. 1993). The route of exposure was not reported; however, dermal in addition

Table 2-3. Levels of Significant Exposure to Chlorpyrifos - Dermal

Species/ (Strain)	Exposure/ Duration/ Frequency/ (Specific Route)	System	NOAEL (mg/kg/day)	LOAEL		Reference
				Less Serious (mg/kg/day)	Serious (mg/kg/day)	
ACUTE EXPOSURE						
Death						
Rat (Sherman)	once				202 M (LD_{50})	Gaines 1969

LOAEL = lowest-observable-adverse-effect level; LD_{50} = lowest dose, 50% kill; M = male; NOAEL = no-observable-adverse-effect level; NS = not specified; wk = week(s)

to inhalation exposure was likely. The approximate dose received and the length of time between exposure and the onset of symptoms was not known for any of the patients. The pesticide-exposed persons reported an increase in flu-like symptoms and upper and lower respiratory problems when compared to 60 (28 male and 32 female) control subjects. In a chronic-duration exposure study by Brenner et al. (1984) the prevalence of selected illnesses and symptoms in 175 employees involved in the production of chlorpyrifos was compared with 335 matched controls with no history of exposure to organophosphorus chemicals. Employees were further subdivided for dose-response testing into three exposure intensity groups on the basis of job title and air-monitoring data. There were no statistically significant differences in the prevalence of respiratory illness or other respiratory symptoms in the exposed groups compared to matched controls. Exposure was assumed to be via both inhalation and dermal routes.

Piglets acutely exposed (by spraying) to an undetermined amount of chlorpyrifos at 0-3, 1-3, 24-30, or 30-36 hours after birth were observed for clinical signs of toxicity, and various tissues were taken for histopathological evaluations (Long et al. 1986). Mortality was 4 of 4, 3 of 3, 3 of 5, and 0 of 3 in piglets treated 0-3, 1-3, 24-30, and 30-36 hours after birth, respectively. Dyspnea, resulting from cholinergic over-stimulation, was observed in the pigs that eventually died. However, microscopic evaluation of the lung tissues from the treated piglets did not reveal any abnormalities. No data were located for respiratory effects in animals following intermediate- or chronic-duration dermal exposure to chlorpyrifos.

Gastrointestinal Effects. Gastrointestinal effects have been observed in humans following acute-, intermediate-, and chronic-duration exposures (Kaplan et al. 1993; Thrasher et al. 1993). Nonspecific gastrointestinal disturbances were reported by individuals acutely exposed to unknown quantities of chlorpyrifos. The exact number of individuals experiencing gastrointestinal disturbances, however, was not reported. Additionally, the approximate dose received and the length of time between exposure and the onset of symptoms was not known for any of the patients (Thrasher et al. 1993). Intermediate-duration exposure to chlorpyrifos also causes gastrointestinal distress in humans. Diarrhea developed in a 40-year-old male exterminator who was repeatedly exposed to an unknown concentration of Dursban® in a closed environment over a 6-month interval (Kaplan et al. 1993). Exposure -was assumed to be via both inhalation and dermal routes. Erythrocyte cholinesterase levels determined at the onset of symptoms were reported to be initially low (value not given). The diarrhea probably resulted from stimulation of parasympathetic nervous system-dependent physiological

processes as a consequence of cholinesterase inhibition. Stimulation of the parasympathetic nervous system increases gastrointestinal motility, thereby decreasing food transit times. The net result is that there is less time for water to be absorbed by the intestinal system and diarrhea results. In a chronicduration exposure study by Brenner et al. (1984), the prevalence of selected illnesses and symptoms in 175 employees involved in the production of chlorpyrifos was compared with 335 matched controls with no history of exposure to organophosphorus chemicals. Employees were further subdivided for dose-response testing into three exposure intensity groups on the basis of job title and air-monitoring data. There were no statistically significant differences in the prevalence of digestive system illnesses or symptoms between the exposed groups and matched controls. Exposure was assumed to be via both inhalation and dermal routes.

Piglets acutely exposed by spraying an undetermined amount of chlorpyrifos at 0-3, 1-3, 24-30, or 30-36 hours after birth were observed for clinical signs of toxicosis, and various tissues were taken for histopathological evaluations (Long et al. 1986). Mortality was 4 of 4, 3 of 3, 3 of 5, and 0 of 3 in piglets treated 0-3, 1-3, 24-30, and 30-36 hours after birth. Diarrhea resulting from cholinergic overstimulation was observed in the pigs that eventually died. Necropsy of the piglets revealed increased fluid in the intestines of some, but only in those piglets exposed l-3 hours after birth. Two of 4 bulls treated with 1 g testosterone for 86 days, then dermally exposed to 0.33 mL/kg of a chlorpyrifos solution (equivalent to approximately 0.04 mg/kg) 28 and 58 days after the start of the testosterone treatment, had to be killed because of severe diarrhea (Haas et al. 1983). No data were located for gastrointestinal effects in animals following intermediate- or chronic-duration dermal exposure to chlorpyrifos.

Hematological Effects. No hematological effects were observed in a 40-year-old male exterminator who was repeatedly exposed to an unknown concentration of Dursban ® in a closed environment over a 6-month interval (Kaplan et al. 1993). Exposure was assumed to be via inhalation and dermal routes. No information was found concerning hematological effects in humans following acute- or intermediate-duration dermal exposure to chlorpyrifos.

Acute-duration dermal exposure to 0.33 mL/kg of a chlorpyrifos solution (equivalent to approximately 0.04 mg/kg) caused no hematological effects in groups of 4 Holstein bulls and steers (Haas et al. 1983). No information was found concerning hematological effects in animals following intermediateor chronic-duration dermal exposure to chlorpyrifos.

Musculoskeletal Effects. Musculoskeletal effects have been observed in humans following acuteand intermediate-duration exposure to chlorpyrifos (Brenner et al. 1984; Kaplan et al. 1993; Thrasher et al. 1993). In humans, acute-duration exposure to undetermined amounts of chlorpyrifos was reported to produce unspecified muscle pain (Thrasher et al. 1993) and muscle cramps (Kaplan et al. 1993). A family became ill and complained of muscle cramps after their house was sprayed with Dursban® (Kaplan et al. 1993). The time from exposure to the onset of symptoms and exposure-level data were not reported. Intermediate-duration exposure to chlorpyrifos also causes musculoskeletal effects in humans. Muscle twitching was reported by a 40-year-old exterminator exposed to unspecified amounts of chlorpyrifos over a 6-month period (Kaplan et al. 1993). In the Kaplan et al. (1993) case reports, exposure was assumed to be via inhalation and dermal routes. It should be noted that in the Kaplan et al. (1993) and Thrasher et al. (1993) studies, chlorpyrifos exposure could not be conclusively determined for each case report. Also, in the Thrasher et al. (1993) study, the approximate dose received and the length of time between exposure and the onset of symptoms was not known for any of the patients.

In a chronic-duration exposure study by Brenner et al. (1984), the prevalence of selected illnesses and symptoms in 175 employees involved in the production of chlorpyrifos was compared with 335 matched controls with no history of exposure to organophosphorus chemicals. Employees were further subdivided for dose-response testing into three exposure intensity groups on the basis of job title and air-monitoring data. There were no statistically significant differences in the prevalence of musculoskeletal illnesses or symptoms between the exposed groups and matched controls. Exposure was assumed to be via both inhalation and dermal routes.

In animals, musculoskeletal effects have been observed following intermediate-duration exposure (Jaggy and Oliver 1992). Creatine kinase activity increased an undetermined amount in a female cat exposed to an unspecified amount of chlorpyrifos during apartment spraying every third day for 18 days (Jaggy and Oliver 1992). It was assumed that some of the exposure was dermal. No information was found concerning musculoskeletal effects in animals following acute- or chronicduration dermal exposure to chlorpyrifos.

Hepatic Effects. In a chronic-duration exposure study by Brenner et al. (1984), the prevalence of selected illnesses and symptoms in 175 employees involved in the production of chlorpyrifos was compared with 335 matched controls with no history of exposure to organophosphorus chemicals.

Employees were further subdivided for dose-response testing into three exposure intensity groups on the basis of job title and air-monitoring data. There were no statistically significant differences in the prevalence of hepatic illnesses or symptoms between the exposed groups and matched controls. Exposure was assumed to be via both inhalation and dermal routes. No information was found concerning hepatic effects in humans following acute- or intermediate-duration dermal exposure to chlorpyrifos.

In animals, hepatic effects have been observed following intermediate-duration exposure (Jaggy and Oliver 1992). Increased serum total protein and albumin levels were observed in a female domestic short-hair cat exposed to an unspecified amount of chlorpyrifos in an apartment that was sprayed with chlorpyrifos every third day for 18 days (Jaggy and Oliver 1992). It is assumed that some of the exposure was via the oral route as a result of grooming. No information was found concerning hepatic effects in animals following acute- or chronic-duration dermal exposure to chlorpyrifos.

Renal Effects. No information was found concerning renal effects in humans following acute duration dermal exposure to chlorpyrifos.

The effects of intermediate-duration exposure to undetermined amounts of chlorpyrifos in humans were assessed in a survey of pesticide applicators working in a variety of settings (Ames et al. 1989). Exposure was assumed to be via inhalation and dermal routes. Those applicators reported an unspecified decrease in urinary frequency. This information is also presented in Section 2.2.1 of this profile because the route of exposure is not specified in the Ames et al. (1989) report, and it is probable that exposure occurred by multiple routes. In a chronic-duration exposure study by Brenner et al. (1984) the prevalence of selected illnesses and symptoms in 175 employees involved in the production of chlorpyrifos was compared with 335 matched controls with no history of exposure to organophosphorus chemicals. Employees were further subdivided for dose-response testing into three exposure intensity groups on the basis of job title and air-monitoring data. There were no statistically significant differences in the prevalence of renal illnesses or symptoms between the exposed groups and matched controls. Exposure was assumed to be via both inhalation and dermal routes. No information was found concerning renal effects in humans following acute- or intermediate-duration dermal exposure to chlorpyrifos. Exposure was assumed to be via inhalation and dermal routes.

In animals, renal effects have been observed following intermediate-duration exposure (Jaggy and Oliver 1992). Urea nitrogen, alkaline phosphatase, and alanine aminotransferase levels increased in a female cat exposed to an unspecified amount of chlorpyrifos during apartment spraying every third day for 18 days (Jaggy and Oliver 1992). It was assumed that at least some of the exposure was dermal. No information was found concerning hepatic effects in animals following acute- or chronic-duration dermal exposure to chlorpyrifos. No data were located for renal effects in animals following acute- or chronic-duration dermal exposure to chlorpyrifos.

Dermal Effects. No information was found concerning dermal effects in humans following acuteduration dermal exposure to chlorpyrifos.

The effects of intermediate-duration exposure to undetermined amounts of chlorpyrifos in humans were assessed in a survey of pesticide applicators working in a variety of settings (Ames et al. 1989). Exposure was assumed to be via inhalation and dermal routes. Those applicators reported an unspecified increase in skin flushing. This effect may be related to a disruption of autonomic function. This information is also presented in Section 2.2.1 of this profile, because the route of exposure is not specified in the Ames et al. (1989) report, and it is probable that exposure occurred by multiple routes. Additionally, prolonged dermal contact with chlorpyrifos may produce irritation; dermal sensitization may also occur (HSDB 1995). In a chronic-duration exposure study by Brenner et al. (1984), the prevalence of selected illnesses and symptoms in 175 employees involved in the production of chlorpyrifos was compared with 335 matched controls with no history of exposure to organophosphorus chemicals. Employees were further subdivided for dose-response testing into three exposure intensity groups on the basis of job title and air-monitoring data. There were no statistically significant differences in the prevalence of dermal illnesses or symptoms between the exposed groups and matched controls. Exposure was assumed to be via both inhalation and dermal routes. No information was found concerning dermal effects in humans following acute- or intermediate-duration dermal exposure to chlorpyrifos. Exposure was assumed to be via inhalation and dermal routes.

No data were located for dermal effects in animals following acute-, intermediate-, or chronic-duration dermal exposure to chlorpyrifos.

Ocular Effects. No information was found concerning ocular effects in humans following acuteor chronic-duration dermal exposure to chlorpyrifos.

Intermediate-duration exposure to an undetermined amount of chlorpyrifos caused an unspecified increase in tearing in a 40-year-old male exterminator repeatedly exposed to Dursban® over a 6-month period (Kaplan et al. 1993). Exposure was assumed to be via inhalation and dermal routes. Additionally, the effects of intermediate-duration exposure to undetermined amounts of chlorpyrifos in humans were assessed in a survey of pesticide applicators working in a variety of settings (Ames et al. 1989). Exposure was assumed to be via inhalation and dermal routes. Those applicators reported an unspecified increase in blurred vision. This information is also presented in Section 2.2.1 of this profile, because the route of exposure is not specified in the Ames et al. (1989) report, and it is probable that exposure occurred by multiple routes.

No data were located for ocular effects in other animals following acute-, intermediate-, or chronic-duration dermal exposure to chlorpyrifos.

2.2.3.3 Immunological and Lymphoreticular Effects

No information was located concerning the potential immunological and lymphoreticular effects of chlorpyrifos in humans following intermediate- or chronic-duration dermal exposure, or in other animals following acute-, intermediate-, or chronic-duration dermal exposure.

The effects of acute-duration dermal exposure to chlorpyrifos were reported for 12 persons exposed to chlorpyrifos primarily in the home or work place following professional application of the pesticide (Thrasher et al. 1993). The route of exposure for any of the exposed persons was not given. The approximate dose received and the length of time following exposure were not known for any of the patients. It is assumed that exposure occurred primarily by inhalation, but dermal exposure was also possible. Examination of blood taken from the chlorpyrifos-exposed persons indicated that there were changes in some lymphocyte subtypes when compared to 60 (28 male and 32 female) control subjects. The presence of autoantibodies to smooth muscle, parietal cells, intestinal brush border, mitochondria, or nuclei was also determined. Analysis of the blood revealed a 300% increase in the mean absolute counts of CD26 cells and a decrease in the relative percentages of CD5 (11%) and CD4 (7%) lymphocytes. Additionally, 83% of the chlorpyrifos-exposed individuals had increased levels (300-1,200%) of circulating autoantibodies to at least one of the cell types or organelles (except mitochondria) listed above, and 25% of the chlorpyrifos-exposed patients had elevated autoantibodies to three or more of the cell types or organelles, compared to 0-3.7% in the control group. The authors

suggested that the increase in autoantibodies was due to chlorpyrifos-induced tissue damage (Thrasher et al. 1993). However, the causality of these effects must be interpreted with caution. This study was a retrospective case study where the symptoms arose 14.5 years post-exposure to chlorpyrifos. No exposure data were presented and there were no objective data or methods for ruling out confounding chemical exposures. Ten of the patients had a history of some type of atopy or drug sensitivity, while one patient had been diagnosed with systemic lupus erythematous and another had a lupus-like syndrome. From the results of this study, it may be concluded that the patients had some immunological abnormalities, but it is difficult to attribute the effects to chlorpyrifos exposure (Richardson 1995). Additionally, although CD26 is a surface marker whose expression is increased on the surface of activated T cells, it has not been validated as a diagnostic indicator of immunotoxicity in either animal or human studies. Of primary importance is the fact that the following are not known: how the expression of the CD26 marker varies in a normal human population; what kinds of conditions can cause changes in the expression of CD26, especially regarding studies of potential drug/chemical-induced changes in its expression; the functional significance of changes in CD26 expression; and how much the expression of CD26 must change to be causally associated with changes in immune function. Finally, although it is true that elevations in autoantibodies to a number of self-antigens can be caused by exposure to a variety of drugs and chemicals, the presence of autoantibodies can also be measured in normal healthy human populations. Thus, the biological significance of these findings is unclear.

In spite of the widespread use of insecticides containing chlorpyrifos, there are no definitive reports that it sensitizes human skin. A study, which assessed a number of pesticides via patch tests in California nursery workers, reported no positive responses with chlorpyrifos in 38 out of the 39 exposed workers who were tested (O'Malley et al. 1995). The duration of exposure to any of the 6 pesticide formulations to which exposure occurred was not specified in this paper. Although none of the 21 control subjects were positive for chlorpyrifos, there were positive responses to other pesticides noted in the controls. Therefore, the biological significance of the positive response to chlorpyrifos in the single exposed worker could not be determined

2.2.3.4 Neurological Effects

The accidental application of an unspecified amount chlorpyrifos into the eye of a 42-year-old woman caused unilateral miosis presenting as anisocoria (Flach and Donahue 1994). Unilateral effects were

probably due to the unilateral application of the pesticide. In a review of the physical, neurotoxic, and respiratory problems suffered by 41 people exposed to organophosphate pesticidal products, symptoms of moderate to severe organophosphate poisoning were reported. In men and women exposed to unspecified amounts of only chlorpyrifos at home or at work, these symptoms included: seizures; peripheral and central nervous system disturbances; headaches; dizziness; nausea/vomiting; chest problems; heart problems; ear, nose, and throat problems; eye problems; skin problems; diarrhea; incoordination of the bowel/bladder; multiple chemical sensitivity; arthritis; fatigue; bladder symptoms; nightmares; sleep disturbances; joint problems; abnormal limbic system responses; thyroid problems; and weakness (Sherman 1995). However, in the Sherman (1995) report, no exposure-level data were presented. Additionally, the effects were reported by patients in uncontrolled studies. The cognitive complaints were nonspecific, nonquantitative, and could be attributable to a wide variety of possible causes.

Intermediate-duration dermal exposure to chlorpyrifos has been associated with neurological effects (Kaplan et al. 1993). Memory impairment and sensory loss were observed in a 42-year-old female exposed to Dursban ®that had been applied in her basement 8 times over 3 weeks (Kaplan et al. 1993). Muscle twitching, paresthesia, numbness, sensory loss, mild distal weakness, areflexia of lower extremities, and nerve conduction and quantitative sensory threshold abnormalities were observed in a 40-year-old male exterminator repeatedly exposed to Dursban®over a 6-month period (Kaplan et al. 1993). Exposure in this study was assumed to be via inhalation and dermal routes. In a chronicduration exposure study by Brenner et al. (1984), the prevalence of selected illnesses and symptoms in 175 employees involved in the production of chlorpyrifos was compared with 335 matched controls with no history of exposure to organophosphorus chemicals were. Employees were further subdivided for dose-response testing into three exposure intensity groups on the basis of job title and airmonitoring data. There were no statistically significant differences in the prevalence of central and peripheral nervous system illnesses or symptoms between the exposed groups and matched controls. Exposure was assumed to be via both inhalation and dermal routes.

Piglets acutely exposed by spraying an undetermined amount of chlorpyrifos at 0-3, 1-3, 24-30, or 30-36 hours after birth were observed for clinical signs of toxicity (Long et al. 1986). Mortality was 4 of 4, 3 of 3, 3 of 5, and 0 of 3 in piglets treated 0-3, 1-3, 24-30, and 30-36 hours, respectively, after birth. Weakness, trembling, ataxia, miosis, and lateral recumbency were observed in the piglets that eventually died. Additionally, determinations of brain cholinesterase activity in piglets exposed

l-3 hours after births showed a 55--67% inhibition in activity. Blood acetylcholinesterase activity determined in piglets 12-17 hours after exposure displayed 8l-99% decreases in activity in piglets exposed up to 30 hours after birth. Intermediate-duration dermal exposure to 20 mg/kg/day chlorpyrifos applied to the ventral wing surface at the humerus for at least 28 days produced debilitation and paralysis in 2 of 3 exposed hens after 20-28 days of dosing (Francis et al. 1985). No data were located for neurological effects in animals following chronic-duration dermal exposure to chlorpyrifos.

2.2.3.5 Reproductive Effects

No information was found concerning reproductive effects in humans following acute-, intermediate-, or chronic-duration dermal exposure to chlorpyrifos.

An unspecified amount of Dursban 44® was applied once to 185 young bulls (9-52 months of age) for lice control. Semen output was analyzed from historical samples collected from 583 control animals to establish normal production (Everett 1982). Following exposure, semen production and sperm viability were determined in frozen samples. The bulls were divided into 2 post-exposure groups (6-month and 7-12-month) in order to assess the short- and long-term effects of the treatment, respectively. Six months post-exposure, the treated bulls were reported to have an unspecified increase in nonmotile sperm upon thawing of samples. Sperm motility and ejaculate volume were decreased, and the number of post-thaw nonmotile sperm increased in those bulls that became ill after treatment and required veterinary interventions. No adverse effects on bull sperm were observed 7-12 months postexposure. No data were located for reproductive effects in animals following intermediate- or chronic-duration dermal exposure to chlorpyrifos.

2.2.3.6 Developmental Effects

No information was located concerning the potential developmental effects of chlorpyrifes in humans or animals following acute-, intermediate-, or chronic-duration dermal exposure.

2.2.3.7 Genotoxic Effects

No information was located concerning the potential genotoxic effects of chlorpyrifos in humans following acute-, intermediate-, or chronic-duration dermal exposure.

The effect of intermediate-duration dermal exposure to chlorpyrifos was assessed in Swiss mice (Amer and Fahmy 1982). Dursban® (99 mg/kg) was applied as a solution in 0.1 mL dimethyl sulfoxide (DMSO) to the backs of mice for 24 hours, 7 days, or 14 days, and the percentage of polychromatic erythrocytes (PE) determined. The applications were performed twice weekly for the 7- and 14-day exposures. Additionally, some animals exposed for 14 days were allowed to recover 1 or 2 weeks before having the percentage of PE determined. Controls received DMSO only. After 1 and 14 days of exposure, the percentage of PE increased 17 and 82%, respectively. However, no effect on PE was observed for the 7-day-exposure group. As a result, the authors concluded that the effect seen after one day of exposure was probably spurious. The percentage of PE was still elevated in the 14-day exposure group 7 days after termination of exposure. However, normal percentages of PE were found in the 14-day-exposure group after 14 days of recovery. Additionally, there was no induction of micronuclei in any of the treatment groups. The results indicate that chlorpyrifos has the potential to cause transient increases in the incidence of erythroblast chromosomal aberrations. No data were located for genotoxic effects in animals following acute- or chronic-duration dermal exposure to chlorpyrifos.

Other genotoxicity studies are discussed in Section 2.5.

2.2.3.8 Cancer

No information was located concerning the potential carcinogenic effects of chlorpyrifos in humans or other animals following acute-, intermediate-, or chronic-duration dermal exposure.

2 . 3 TOXICOKINETICS

Most of the toxicokinetic data on chlorpyrifos were collected following oral or dermal administration. Limited inhalation exposure data are available. Studies in humans and other animals indicate that orally administered chlorpyrifos is well absorbed, with 70-90% of the administered dose being

absorbed within 48 hours after exposure. In humans, only 3% of a the dermally applied dose is absorbed. In animals, the skin did not appear to provide an effective barrier to absorption. This seems unexpected based on the human data. However, those animal studies are confounded by the fact that dermal irritation, which may have decreased skin integrity, accompanied the dermal dosing, thereby increasing absorption. Animal studies indicate that orally and dermally administered chlorpyrifos rapidly distributes to all the major organs. Chlorpyrifos metabolism is similar in both humans and other animals. Chlorpyrifos is bioactivated to chlorpyrifos oxon in the liver via cytochrome P-450-dependent desulfuration. The oxon is hydrolyzed by A-esterase to diethylphosphate and 3,5,6-trichloro-2-pyridinol (TCP), the major metabolite detected in humans and other animals. The tissue elimination of chlorpyrifos is organ-dependent, with the slowest elimination occurring from fat (half-life 62 hours). Chlorpyrifos is primarily excreted in the urine in the form of TCP conjugates.

2.3.1 Absorption

2.3.1.1 Inhalation Exposure

The absorption of chlorpyrifos following acute-duration inhalation exposure has been demonstrated in humans (Aprea et al. 1994). Determination of chlorpyrifos metabolites in the urine from 1 man and 11 women exposed to chlorpyrifos in an orchard previously sprayed with chlorpyrifos indicated that significantly higher levels of urinary excretion of alkylphosphates were found in all exposure groups than in unexposed controls. There was a high correlation between quantities of the active ingredients on the hands and urinary excretion of total dimethylated alkylphosphates and of dimethylthiophosphates and dimethylphosphate. Respiratory absorption appears to have been significant in view of the difference in urinary excretion of dimethylated alkylphosphates found between subjects with and without face masks. No toxicokinetic information was located concerning the absorption of chlorpyrifos following inhalation exposure in other animals.

2.3.1.2 Oral Exposure

The absorption of chlorpyrifos following acute-duration oral exposure has been investigated in humans and other animals. In humans, determination of chlorpyrifos metabolites in the urine from 6 adult males orally exposed to chlorpyrifos administered orally in dipropylene glycol methyl ether indicated an average of 70% of the administered dose was absorbed within 48 hours (Nolan et al. 1984). In rats

(Bakke et al. 1976; Smith et al. 1967) and mice (Ahdaya et al. 19Sl), nearly 90% of the administered dose of ^{14}C-labeled chlorpyrifos in an acute-duration oral exposure was absorbed 48-60 hours after dosing, as assessed by the amount of radioactivity recovered in the feces and urine.

2.3.1.3 Dermal Exposure

The absorption of chlorpyrifos following dermal exposure has been investigated in humans and other animals. In humans, determination of chlorpyrifos metabolites in the urine from 6 adult males dermally exposed to chlorpyrifos indicated that an average of 3% of a dose administered in dipropylene glycol methyl ether was absorbed within 48 hours, compared to 70% of an oral dose (Nolan et al. 1984). In goats, 80-96% of a 22 mg/kg dermal dose (vehicle not specified) was absorbed 12-16 hours after dosing (Cheng et al. 1989). In female Fischer 344 rats, the percentage of chlorpyrifos dissolved in acetone absorbed through the skin during a 72-hour period was dosedependent, with relatively more absorption occurring at higher doses (Shah et al. 1987). In that study, approximately 99% of a 21.03 mg/kg dose was absorbed, compared with 46% of a 4.21 mg/kg dose. However, considerably more irritation and blistering accompanied the high dose, compromising the integrity of the skin and increasing the possibility of absorption. Thus, the dose-dependent absorption of chlorpyrifos may have been enhanced by the destruction of the epidermis. In that same study, Shah et al. (1987) also assessed the effect of age on dermal penetration of chlorpyrifos. On average, 23% more chlorpyrifos was absorbed by young (33-day-old) than by adult (82-day-old) rats. The possible age-dependence of the dermal absorption of chlorpyrifos was also investigated in a study in which piglets of varying ages were sprayed with a solution containing an unspecified concentration of chlorpyrifos (Long et al. 1986). In that study, the toxicity of chlorpyrifos decreased with increasing time following birth.

2.3.2 Distribution

2.3.2.1 Inhalation Exposure

No toxicokinetic information was located concerning the distribution of chlorpyrifos following inhalation exposure in humans or other animals.

2.3.2.2 Oral Exposure

The distribution of ^{14}C-labeled chlorpyrifos following oral exposure has been investigated using male Wistar rats (Smith et al. 1967) and Hereford crossbred heifers (Dishburger et al. 1977). The results of the Smith et al. (1967) study indicate that a single dose of 50 mg/kg chlorpyrifos administered via gavage readily distributes to all organs of the body, but that it accumulates in the fat and is liberated slowly ($t_{1/2}$, 62 hours) compared to elimination from other tissues ($t_{1/2}$, for elimination from liver, kidney, and heart is about l0-16 hours). Similar distribution was seen in Hereford crossbred heifers exposed to 0, 3, 10, 30, or 100 ppm chlorpyrifos for 30 days (Dishburger et al. 1977). In keeping with the results of the Smith et al. (1967) study, chlorpyrifos residues were found predominantly in fatty tissues and averaged 0.02 (<0.0l-0.05 ppm) and 3.28 ppm (2.28-4.7 ppm) in the fat of cattle fed 3 and 100 ppm chlorpyrifos, respectively, for 30 days with no withdrawal.

2.3.2.3 Dermal Exposure

The distribution of dermally applied ^{14}C-labeled chlorpyrifos has been investigated using goats (Cheng et al. 1989), mice (Shah et al. 1981), and bovines (Claborn et al. 1968; Ivey et al. 1972). The results from those studies indicate that chlorpyrifos readily distributes to all organs of the body, with relatively higher concentrations being found in the blood, liver, and fat than in other organs (e.g., heart, gastrointestinal tract, skeletal muscle). Radioanalysis of the blood and selected tissues (liver, kidney, heart, fat and muscle) of 2 male weanling goats receiving a single dose of 22 mg/kg radiolabeled chlorpyrifos indicated very low tissue radioactivity levels equivalent to 0.04 ppm (chlorpyrifos equivalents) in muscle to 0.90 ppm in omental fat (Cheng et al. 1989). Eight hours after a single dermal application of 1 mg/kg radiolabeled chlorpyrifos to female ICR mice, the amount of radioactivity recovered was highest in the excretory products (38.4%) followed by the carcass (24.1%); blood (2.7%); intestine (1.9%); liver (1.8%); kidney (0.8%); stomach and ear (0.5% each); lungs, brain, bladder, and fat (0.2% each); heart, bone marrow, and muscle (0.1% each); and spleen (<0.1%). In 11 Hereford cattle dipped once in a 0.05% emulsion of Dursban® and in 1 Holstein-cross calf sprayed with 8.75 mL/kg of a 25% emulsion of Dursban®, chlorpyrifos residues were highest in fat (Clabom et al. 1968). Similarly, in 57 beef cattle dipped up to 6 times in a 0.023-0.027% solution of chlorpyrifos, the residues of chlorpyrifos were found mostly in the fatty tissues. The low residues found in other tissues (muscle, kidneys, and liver) could be attributed to the small amount of fat present in those tissues. The highest residues in fat occurred 1 week after the second and third

dippings (0.726-1.24 and 0.937-2.01 ppm, respectively), and were eliminated at 10 weeks or reduced to an insignificant level (Ivey et al. 1972).

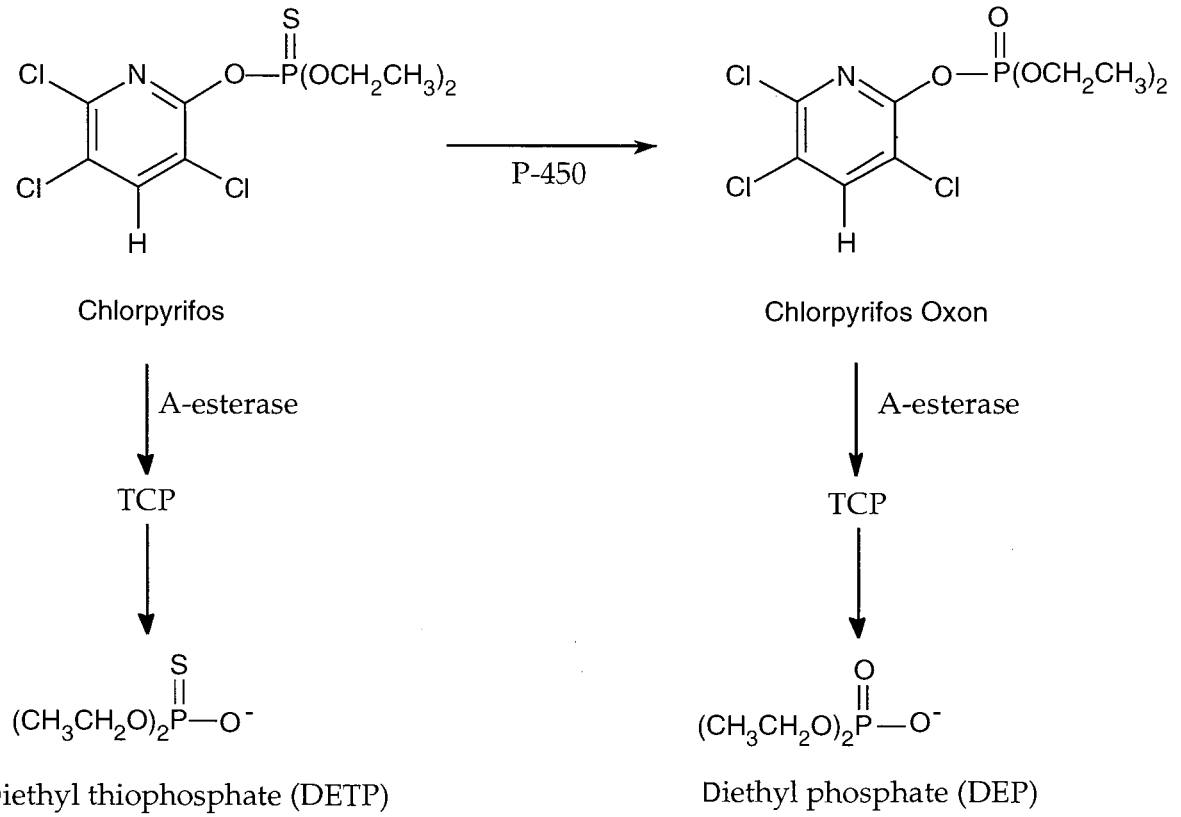
2.3.3 Metabolism

An adaptation of the scheme for the metabolism of organophosphate compounds analyzed in serum and urine of persons poisoned by chlorpyrifos (Drevenkar et al. 1993) is presented in Figure 2-3.

In the rat and mouse, chlorpyrifos is bioactivated in the liver to chlorpyrifos oxon via cytochrome P-450-dependent desulfuration (Ma and Chambers 1994; Sultatos and Murphy 1983a). The oxon is rapidly hydrolyzed to TCP, probably by A-esterase (Sultatos and Murphy 1983a, 1983b). Studies using liver perfusion have shown that both bioactivation and detoxification of chlorpyrifos occur very rapidly, since only TCP can be detected in the hepatic effluent once steady-state conditions are reached (Sultatos and Murphy 1983a, 1983b). Hydrolysis of the chlorpyrifos oxon by A-esterase is probably the more common route of detoxification, since TCP or a conjugate of TCP is the major metabolite of chlorpyrifos in humans (Nolan et al. 1984) and rodents (Bakke et al. 1976; Smith et al. 1967; Sultatos and Murphy 1983a, 1983b; Sultatos et al. 1985).

The relative rates of desulfuration and detoxification are gender-dependent and may account for the increased toxicity of chlorpyrifos in female rats (Chambers and Chambers 1989; Sultatos 1991). The results of the above studies indicate that although the rates of bioactivation (desulfuration) and detoxification (dearylation) are higher in males than females, the ratio of the rates of bioactivation to detoxification is 2-3-fold higher for females. Those studies suggest that females may be at increased risk to chlorpyrifos-induced toxicity. However, bulls with high levels of testosterone were more sensitive than steers (castrated bulls) to the toxic effects of chlorpyrifos (Haas et al. 1983). Although no metabolism data were present in that study, it suggests that for bovines, the male may be more susceptible than the female.

Figure 2-3. Organophosphorus Compounds in Serum and Urine of Persons Poisoned by Chlorpyrifos



Adapted from Drevenkar et al. 1993

2.3.4 Elimination and Excretion

2.3.4.1 Inhalation Exposure

Examination of urine samples from pesticide applicators presumably exposed to chlorpyrifos by inhalation revealed the presence of TCP (Jitsunari et al. 1989). Examination of urine samples from 1 man and 11 women exposed to chlorpyrifos in an orchard previously sprayed with chlorpyrifos indicated that significantly higher levels of urinary excretion of alkylphosphates were found in all exposure groups than in unexposed controls. There was a high correlation between quantities of the active ingredients on the hands and urinary excretion of total dimethylated alkylphosphates and of dimethylthiophosphates and dimethylphosphate. Respiratory absorption appears significant in view of the difference in urinary excretion of dimethylated alkylphosphates found between subjects with and without face masks (Aprea et al. 1994).

2.3.4.2 Oral Exposure

Male rats exposed to ^{14}C-labeled chlorpyrifos had their urine and feces collected every 12 hours for 48 hours (Bakke et al. 1976). The combined urine from all 4 samples contained approximately 88% of the administered radiolabel, and it separated into at least 6 chlorpyrifos metabolites. Three of these metabolites were identified as the glucuronide of TCP, a glycoside of TCP, and TCP, comprising 80, 4, and 12% of the total metabolites, respectively. In a similar study, 90% of the radiolabel was found in the urine, and 10% was recovered in the feces (Smith et al. 1967). Additionally, the elimination half-life was estimated for several compartments. Chlorpyrifos was eliminated slowly from fat (halflife 62 hours) and relatively rapidly from liver, heart, and kidney (half-life 10-16 hours) (Smith et al. 1967). In humans, an elimination half-life of 27 hours has been estimated following oral or dermal exposure (Nolan et al. 1984).

2.3.4.3 Dermal Exposure

A half-life of 21 hours has been estimated for the urinary elimination and fecal excretion of chlorpyrifos following dermal exposure in mice (Shah et al. 1981). For humans, an elimination half-life of 27 hours has been estimated following oral or dermal exposure (Nolan et al. 1984). As with

oral exposure, the majority of dermally absorbed chlorpyrifos is eliminated in the urine, based upon the quantity of radioactivity in the urine (Shah et al. 1981).

2.3.5 Physiologically Based Pharmacokinetic (PBPK)/Pharmacodynamic (PD) Models

Physiologically based pharmacokinetic (PBPK) models use mathematical descriptions of the uptake and disposition of chemical substances to quantitatively describe the relationships among critical biological processes (Krishnan et al. 1994). PBPK models are also called biologically based tissue dosimetry models. PBPK models are increasingly used in risk assessments, primarily to predict the concentration of potentially toxic moieties of a chemical that will be delivered to any given target tissue following various combinations of route, dose level, and test species (Clewell and Andersen 1985). Physiologically based pharmacodynamic (PBPD) models use mathematical descriptions of the dose-response function to quantitatively describe the relationship between target tissue dose and toxic end points.

PBPK/PD models refine our understanding of complex quantitative dose behaviors by helping to delineate and characterize the relationships between: (1) the external/exposure concentration and target tissue dose of the toxic moiety, and (2) the target tissue dose and observed responses (Andersen and Krishnan 1994; Andersen et al. 1987). These models are biologically and mechanistically based and can be used to extrapolate the pharmacokinetic behavior of chemical substances from high to low dose, from route to route, between species, and between subpopulations within a species. The biological basis of PBPK models results in more meaningful extrapolations than those generated with the more conventional use of uncertainty factors.

The PBPK model for a chemical substance is developed in four interconnected steps: (1) model representation, (2) model parametrization, (3) model simulation, and (4) model validation (Krishnan and Andersen 1994). In the early 1990s, validated PBPK models were developed for a number of toxicologically important chemical substances, both volatile and nonvolatile (Krishnan and Andersen 1994; Leung 1993). PBPK models for a particular substance require estimates of t he chemical substance-specific physicochemical parameters, and species-specific physiological and biological parameters. The numerical estimates of these model parameters are incorporated within a set of differential and algebraic equations that describe the pharmacokinetic processes. Solving these

differential and algebraic equations provides the predictions of tissue dose. Computers then provide process simulations based on these solutions.

The structure and mathematical expressions used in PBPK models significantly simplify the true complexities of biological systems. If the uptake and disposition of the chemical substance(s) is adequately described, however, this simplification is desirable because data are often unavailable for many biological processes. A simplified scheme reduces the magnitude of cumulative uncertainty. The adequacy of the model is, therefore, of great importance, and model validation is essential to the use of PBPK models in risk assessment.

PBPK models improve the pharmacokinetic extrapolations used in risk assessments that identify the maximal (i.e., the safe) levels for human exposure to chemical substances (Andersen and Krishnan 1994). PBPK models provide a scientifically sound means to predict the target tissue dose of chemicals in humans who are exposed to environmental levels (for example, levels that might occur at hazardous waste sites) based on the results of studies where doses were higher or were administered in different species. Figure 2-4 shows a conceptualized representation of a PBPK model.

If PBPK models for chlorpyrifos exist, the overall results and individual models are discussed in this section in terms of their use in risk assessment, tissue dosimetry, and dose, route, and species extrapolations.

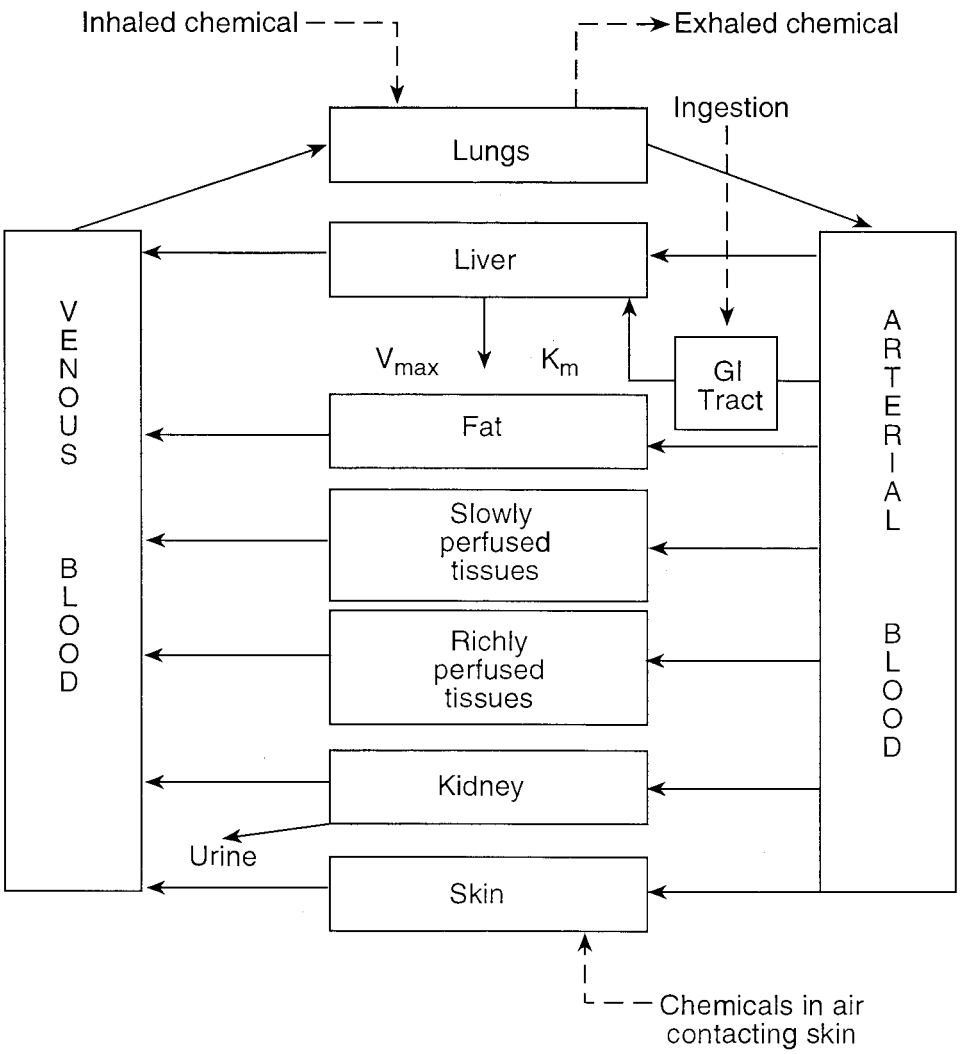
No PBPK information was found for chlorpyrifos.

2.4 MECHANISMS OF ACTION

2.4.1 Pharmacokinetic Mechanisms

Chlorpyrifos is well absorbed through the gut and lungs, but dermal absorption is considerably less effective. The skin presents a reasonably effective barrier to penetration, unless the pesticide is mixed with a carrier or the skin is compromised. However, since all commercial chlorpyrifos products, with the exception of granular forms, contain solvents or emulsifiers, human exposure to chlorpyrifos that is not mixed with a carrier is unlikely. Oral and dermal absorption of chlorpyrifos was assessed in six adult male humans (Nolan et al. 1984). On average, 70% of the oral dose was absorbed, compared to

Figure 2-4. Conceptual Representation of a Physiologically Based Pharmacokinetic (PBPK) Model for a Hypothetical Chemical Substance



Source: adapted from Krishnan et al. 1992

Note: This is a conceptual representation of a physiologically based pharmacokinetic (PBPK) model for a hypothetical chemical substance. The chemical substance is shown to be absorbed via the skin, by inhalation, or by ingestion, metabolized in the liver, and excreted in the urine or by exhalation.

only 3% of the dermal dose. Once chlorpyrifos has been absorbed, it rapidly distributes to all organs (Shah et al. 1981; Smith et al. 1967). The half-life for elimination of chlorpyrifos from the various organs in rats is comparable (10-16 hours), except for elimination from fat, which was estimated to be 62 hours (Smith et al. 1967). The elimination half-life in humans has been estimated to be 27 hours (Nolan et al. 1984).

The major site of chlorpyrifos metabolism is the liver, where it is rapidly bioactivated (desulfurated) by a P-450-dependent monooxygenase to chlorpyrifos oxon (Ma and Chambers 1994; Sultatos and Murphy 1983a). The oxon is 300-400 times more potent at inhibiting rat brain acetylcholinesterase than the parent compound (Huff et al. 1994). The rate of detoxification of the oxon is also rapid (Sultatos and Murphy 1983a, 1983b). Thus, it is rare to find either the parent compound or the oxon in body fluid samples (Nolan et al. 1984; Sultatos and Murphy 1983a), except in very high exposures. What is found in the general circulation is the major oxon metabolite TCP (Bakke et al. 1976; Nolan et al. 1984; Smith et al. 1967). TCP is a relatively unique metabolite of chlorpyrifos, and it (or one of its conjugates) is almost exclusively (90%) excreted in the urine (Bakke et al. 1976; Smith et al. 1967). Kinetic studies using rats indicate that following a single-dose exposure, most (>90%) of the chlorpyrifos is eliminated within 48 hours (Bakke et al. 1976; Smith et al. 1967). Thus, urine TCP can be used as a qualitative biomarker for chlorpyrifos exposure, provided the testing is performed within 48 hours after exposure. It should be noted that the relative rate of detoxification of chlorpyrifos is lower in female rats (i.e., ratio of bioactivation to detoxification), and it is postulated that this may account for the increased toxicity of chlorpyrifos in those animals (Chambers and Chambers 1989; Chambers et al. 1994; Sultatos 1991).

The dose of chlorpyrifos is important in predicting the potential toxicity. Further, factors such as age, health, and possibly gender may significantly lower the threshold for toxic effects. While acuteduration, high-dose intoxication has been demonstrated in a variety of species, including humans, the effects of longer-term, low-level exposure are less clear. Small-scale attempts to quantify chlorpyrifos related toxicity in pesticide applicators suggest that intermediate-duration exposure to low levels of chlorpyrifos may adversely affect health (Ames et al. 1989); but whether the effects may be related to cumulative direct target insult or simply to cholinesterase inhibition is less clear. Low levels of exposure are assumed for that study, because pesticide applicators are usually presumed to wear protective clothing and respirators when spraying the pesticide. However, neither the dose nor the length of exposure could be estimated.

2.4.2 Mechanisms of Toxicity

Chlorpyrifos-induced toxicity results almost entirely from inhibition of neural acetylcholinesterase by chlorpyrifos and its bioactivation product, chlorpyrifos oxon (Namba et al. 1971). Acetylcholinesterase (true cholinesterase) belongs to a class of choline ester hydrolases which includes butyrylcholinesterase, or pseudocholinesterase (Ballantyne and Marts 1992). Acetylcholinesterase is found postsynaptically in central and peripheral cholinergic synapses, including the preganglionic autonomic synapses and postganglionic parasympathetic synapses (Palmer 1980). It is also found at the motor end plate in the neuromuscular junction and is further associated with erythrocytes (red blood cells) (Ballantyne and Marrs 1992). Butyrylcholinesterase can be found in the plasma, and also in nonneuronal tissues such as the liver and fat (Ballantyne and Marrs 1992). Butyrylcholinesterase levels can be affected by health, age, genetic factors, and gender, with or without exposure to cholinesterase inhibiting substance (Ballantyne and Marts 1992). Inhibition of butyrylcholinesterase can be used as an indicator of exposure to cholinesterase-inhibiting substances, but is not, in and of itself, considered to constitute an adverse health effect.

Organophosphorus insecticides, such as chlorpyrifos and its oxon, may cause irreversible cholinesterase inhibition by forming a stable covalent bond at the active site (Goodman et al. 1990). Stability of the bond is further enhanced by a process called aging, which occurs when one of the alkyl groups of the diethylester is lost (Goodman et al. 1990). Aging of the cholinesterase enzyme is an important factor in determining the effectiveness of oximes, such as pyridine-2-aldoxime methyl chloride (2-PAM or pralidoxime), to reactivate the enzyme through nucleophilic attack on the phosphorus. Once aging has occurred, 2-PAM can no longer reactivate the enzyme. Thus, in the absence of oximes, recovery of enzyme activity often depends heavily on the synthesis of new cholinesterase enzyme. The result of cholinesterase inhibition is cholinergic overstimulation. The resulting effects can be reversed by administration of the cholinergic blocking agent, atropine.

2.4.3 Animal-to-Human Extrapolations

Extrapolating from laboratory animals to humans may be done in the case of chlorpyrifos because the mechanism of action of the pesticide is the same in all species examined, and the metabolism and excretion of the pesticide are similar, if not identical, in humans and common laboratory animals.

2.5 RELEVANCE TO PUBLIC HEALTH

Overview

The most likely mode of exposure to chlorpyrifos at a hazardous waste site is through the skin. The most significant effect of acute-duration exposure to chlorpyrifos is cholinergic over-stimulation resulting from cholinesterase inhibition. Clinical signs associated with parasympathetic stimulation include headache, diaphoresis, nausea, vomiting, diarrhea, epigastric cramping, bradycardia, blurred vision, miosis, bronchoconstriction and excess mucous secretions, pulmonary edema, dyspnea, muscle fasciculations, salivation, lacrimation, and urination (Ballantyne and Marrs 1992). Exposure to high doses can also produce a profound tachycardia, pulmonary edema, loss of bowel control, convulsions, coma. and death.

The actual symptoms seen in patients poisoned with cholinesterase-inhibiting pesticides result from actions at both nerve synapses and neuromuscular junctions. Cholinesterase inhibition in skeletal muscle can cause muscle weakness, fasciculations, and tremors. Central nervous system effects may include anxiety, headaches, drowsiness, confusion, tremor, ataxia, abnormal gait, hypotension, respiratory depression, convulsions, and coma (Ballantyne and Marrs 1992). Reversible peripheral neuropathies and polyneuritis have also been observed in humans and other animals following acuteduration, high-dose exposures.

Transient memory impairment following acute-duration exposure to chlorpyrifos has been observed in humans. Acute-duration exposure to high levels of chlorpyrifos in laboratory animals has been shown to cause long-term down-regulation of central muscarinic receptors (Bushnell et al. 1993). Chlorpyrifos has not been shown to affect reproduction in laboratory animals, but sperm production was decreased in bulls dermally exposed to chlorpyrifos. Limited information for rodents suggests that in utero exposure to chlorpyrifos may increase the incidence of skeletal variations and be developmentally neurotoxic to offspring. Additionally, data collected from mice and Drosophila indicate that chlorpyrifos may be genotoxic.

Following acute-duration exposure in humans or animals, chlorpyrifos is rapidly eliminated from the body; only trace amounts of chlorpyrifos metabolites can usually be found in the blood or urine 48 hours after a single exposure. However, in humans (Lotti et al. 1986), bulls (Haas et al. 1983), and

cats (Jaggy and Oliver 1992), clinical signs of toxicity may be evident for weeks following exposure, long after the chlorpyrifos should have been eliminated. There is no evidence to suggest that chlorpyrifos is bioaccumulated. Little information is available concerning the effects of intermediateduration exposure of humans or animals to chlorpyrifos, and no information was located regarding the effects of chronic-duration exposure.

Measurement of erythrocyte and plasma cholinesterase activity is usually performed if organophosphate poisoning is suspected. However, erythrocyte cholinesterase inhibition by itself is not always associated with the presence of cholinergic symptoms, and plasma (pseudo-) cholinesterase inhibition is generally considered only an index of exposure. Brain acetylcholinesterase inhibition, where available, and erythrocyte acetylcholinesterase inhibition are commonly used to correlate cholinesterase inhibition with a threshold for toxic manifestations associated with inhibition of the cholinesterase enzyme. In the case of chlorpyrifos, this particular insecticide is considered a selective pseudocholinesterase inhibitor (HSDB 1995). The course of inhibition of the respective acetyl- and butyrylcholinesterase enzymes have different times of onset after a single exposure, with acetylcholinesterase inhibition following the drop in butyrylcholinesterase activity (Ballantyne and Marrs 1992). Thus, both plasma and erythrocyte cholinesterase activities should be measured if chlorpyrifos exposure is suspected. It should be noted that the degree of erythrocyte cholinesterase inhibition does not always correlate with toxicity; this is especially true in children. In some cases, children have been highly symptomatic after chlorpyrifos exposure at a time when only plasma cholinesterase levels have been reduced, or when all cholinesterase levels were within normal ranges. Thus, measuring cholinesterase activity in children may have little practical value except to confirm exposure to chlorpyrifos.

There are many populations at potentially greater risk to chlorpyrifos-induced toxicity. Populations at risk include the elderly, persons with pre-existing medical conditions, infants and children, and women (especially pregnant women). The elderly are considered at risk for increased toxicity because of the general decline in health that accompanies aging. Persons with chronic respiratory ailments such as asthma, emphysema, and bronchitis would be at greater risk for respiratory distress following chlorpyrifos exposure. Additionally, approximately 5% of the population are succinylcholine (diacetylcholine) sensitive and would be at greater risk following chlorpyrifos exposure because they have a genetically based deficiency in pseudocholinesterase. Research using rats indicates that females are more susceptible to the toxic effects of chlorpyrifos, possibly because they detoxify chlorpyrifos at

a slower rate than males. However, in bovines, bulls have been shown to be at increased risk to some aspects of chlorpyrifos toxicosis. It is not known if gender differences in chlorpyrifos metabolism or susceptibility exist in humans. Additionally, the doses of chlorpyrifos needed to cause death in pregnant mice are approximately six times lower than those need to cause death in nonpregnant mice, suggesting that pregnancy may increase the risk of chlorpyrifos-induced toxicity.

It is difficult to determine whether the increased susceptibility of children to chlorpyrifos toxicity is due to physiological or behavioral characteristics. Results from an animal study conducted in piglets suggest that chlorpyrifos more easily penetrates the skin of young animals, compared to adults. Very young children and infants also have a decreased metabolic capacity to eliminate toxicants and are more susceptible to central nervous system toxicants, thus lowering the exposure levels needed to cause chlorpyrifos toxicity in that population. Chlorpyrifos may also affect neurological development after birth. Studies in rat neonates indicate that 2 mg/kg chlorpyrifos inhibits brain DNA synthesis (Whitney et al. 1995). However, studies in pregnant rats suggest that high levels of chlorpyrifos exposure during gestation are needed to adversely affect offspring mortality, reduce birth weight, and alter offspring behavior (Breslin et al. 1996; Deacon et al. 1980), and studies in preweanling rats found that the neurobehavioral toxicity of chlorpyrifos was less severe and of shorter duration than in adult rats (Stanton et al. 1994).

Minimal Risk Levels for Chlorpyrifos

Inhalation MRLs

No MRLs have been derived for this route of exposure because of the lack of suitable information for any exposure durations.

Oral MRLs

- An MRL of 0.003 mg/kg/day has been derived for both acute (14 days or less) and intermediate (15-364 days) oral exposure to chlorpyrifos. The combination of the length of exposure period and the critical effect in this study enable it to be used for the derivation of both acute- and intermediate-duration oral exposure MRLs.

These MRLs are based upon a study by Coulston et al. (1972) in which 16 human adult male volunteers (4 per dose group) were administered chlorpyrifos in doses of 0, 0.014, 0.03, or 0.1 mg/kg once daily in a tablet with breakfast for up to 28 days. The low- and mid-dose groups were dosed for 28 and 21 days, respectively, but the high-dose treatment was discontinued after 9 days due to one individual in this group experiencing a runny nose, blurred vision, and a feeling of faintness. Twice each week, blood samples were obtained from each volunteer for determination of cholinesterase activity. Mean plasma and RBC cholinesterase levels were ascertained for all groups and compared with pretreatment values, and comparison was also made between treated and control groups. At weekly intervals, additional blood samples were obtained for hematology and routine serum chemistry determinations. Urinalyses were also performed on a weekly basis. Throughout the course of the experiment, no treatment-related effects were found among any of the parameters examined in the urinalyses, hematological, or serum chemistry tests. In the high-dose group, mean plasma cholinesterase (ChE) was depressed by 66% of average baseline levels after 9 days of treatment. In the group receiving 0.03 mg/kg/day, plasma ChE levels were reduced by an average of 30% from baseline levels; however, when compared with control group levels on a day-to-day basis, plasma ChE was reduced by only 13% of concurrent control values. Statistical analysis of this treatment group revealed the decrease was not different from controls. There was no statistically significant effect on plasma ChE activity during the four-week experiment in the low-dose group. No effect on RBC ChE activity was apparent at any dose, and the plasma ChE levels in all high-dose volunteers had returned to baseline levels within four weeks.

Although the authors of the Coulston et al. (1972) study indicated that the individual with the runny nose, blurred vision, and faint feeling was treated for a cold and was asymptomatic by the end of the day (day 9), they neither provided further comment indicating that the symptoms were unrelated to treatment nor explained why the high-dose treatments were discontinued after 9 days. Therefore, the highest dose that can be unequivocally stated to be a NOAEL in this study is the 0.03 mg/kg/day dosage. While plasma cholinesterase activity was depressed by approximately 65% in the high-dose group, plasma (pseudo-) cholinesterase activity is considered by ATSDR to be only an indicator of exposure to a cholinesterase-inhibiting substance or substances, and does not, in and of itself, constitute an adverse health effect.

The MRLs derived from the Coulston et al. (1972) study are closely supported by the Deacon et al.(1980) study, in which pregnant adult CF-1 mice (40-47 per group) were bred and administered daily

gavage chlorpyrifos dosages of 1, 10, or 25 mg/kg/day in cottonseed oil on Gd 6-15. A group of 51 female control animals was given an equivalent volume of cottonseed oil without the test material. Since the high dose resulted in severe maternal toxicity, additional mice (35-41 per dosage group) were bred and administered chlorpyrifos at doses of 0.1, 1, or 10 mg/kg/day on Gd 6-15, inclusively, to further evaluate the teratogenic potential of chlorpyrifos. Animals were observed daily (from day 6 on) for signs of toxicity. Maternal body weights were recorded for Gd 6-15. Maternal body weight, liver weight, and weight of the gravid uterus (including ovaries) were recorded at the time of cesarean section on Gd 18. After sacrifice (with CO_2), the number and position of live, dead, and resorbed fetuses were noted. Fetuses were weighed, their crown-rump length measured, and then examined for external alterations and cleft palate. In addition, 1 in 3 of the fetuses from each litter were examined for evidence of soft-tissue alterations by dissections under a stereomicroscope. To determine the degree of plasma and erythrocyte cholinesterase depression, groups of 4-10 bred mice were given 0, 1, 10, or 25 mg/kg/day on Gd 6, Gd 6-10, or Gd 6-15. Subsequently, groups of 5-15 mice were given 0.1, 1, or 10 mg/kg/day of chlorpyrifos concurrently with the animals for the teratologic study on Gd 6, Gd 6-10, or Gd 6-15. Five hours after the final dosing for each period, blood was obtained by cardiac puncture. A homogenate of fetuses from the litters of mice sacrificed on Gd 15 was prepared to measure total fetal cholinesterase levels.

In the 25 mg/kg/day group, severe maternal toxicity (4 deaths; clinical symptoms indicating “severe cholinesterase inhibition”) was observed in 32 of 47 mice. Cholinergic symptoms included excessive salivation, tremors, urine-soaked coat, ataxia, and lethargy. Mean body weight was significantly decreased in this group on day 16, and the mean value for total body weight gain was also significantly decreased, as were food and water consumption at this dosage. Plasma and RBC ChE levels were significantly decreased from controls at Gd 6, Gd 6-10, and Gd 6-15, and fetal homogenate ChE levels were also significantly decreased. While there was no significant effect on the incidence of pregnancy, average number of implantations, live fetuses, or resorptions (at this or any experimental dosage), there was a significant decrease in fetal body weight and crown-rump length at the high dose. There were also significant increases in the occurrence of several minor skeletal variants, including delayed ossification of the skull bones, delayed ossification of the stemebrae, and unfused stemebrae at 25 mg/kg/day. By contrast, the 10 mg/kg/day groups showed only occasional mild to moderate symptoms of ChE inhibition in 9 of 44 treated animals, with both plasma and RBC ChE levels significantly decreased from controls at Gd 6, Gd 6-10, and Gd 6-15; fetal ChE levels significantly decreased in this group as well. In the 1 mg/kg/day groups, only a single animal showed

any cholinergic symptom (excess salivation on day 7). In the two 1 mg/kg/day treatment groups, plasma (but not RBC) levels were significantly reduced from controls at Gd 6 and Gd 6-15; both plasma and RBC levels were significantly reduced in mice treated from Gd 6 through 10 in the primary study; and both plasma and RBC ChE levels were significantly decreased on days 6-10 and 6-15 in the second (concurrent) phase of this study. There was also a significantly increased incidence of exencephaly at this dosage, but this effect was not seen at either of the higher dosages, making this finding questionable and of indeterminable significance. An increase in the incidence of unfused stemebrae and an decreased incidence of fused stemebrae were also observed at this treatment level. The 0.1 mg/kg/day dosage is considered to be the NOAEL for both fetotoxicity and acetylcholinesterase inhibition for this study.

With the application of appropriate uncertainty factors to account for extrapolation of animal experimental data to humans and for intraspecies variability (100 total uncertainty factor), an acute MRL of 0.001 mg/kg/day could be calculated from this study alone. However, the human data from the Coulston et al. (1972) study is considered to be more appropriate for use in MRL derivation, and the calculated MRL of 0.003 mg/kg/day is considered adequate to afford protection from all adverse health effects that have been associated experimentally as well as clinically with acute- and intermediate-duration exposure to chlorpyrifos.

- An MRL of 0.001 mg/kg/day has been derived for chronic (365 days or more) oral exposure to chlorpyrifos.

The chronic-duration exposure MRL was derived from a study by McCollister et al. (1974). In that study, Sherman rats were fed chlorpyrifos at levels corresponding to 0, 0.01, 0.03, 0.1, 1, or 3 mg/kg/day for 2 years, beginning at 7 weeks of age. Additional groups of 5-7 rats of each sex at each dose level were set up to provide interim pathological examination and acetylcholinesterase (AChE) determinations. Red blood cell AChE activity was depressed in both male and female rats dosed with diets containing 1 and 3 mg/kg/day chlorpyrifos. Doses of 0.1 mg/kg/day and below had no effect on RBC ChE. Based on the NOAEL of 0.1 mg/kg/day for cholinesterase inhibition, an MRL of 0.001 mg/kg/day was calculated, using uncertainty factors of 10 for interspecies extrapolation and 10 for intraspecies variability in susceptibility.

Death. The LD_{50} for acute-duration inhalation exposure to chlorpyrifos was determined for mice and female rats (Berteau and Deen 1978). In mice, an LD_{50} of 94 mg/kg was determined after whole-

body inhalation exposure to 6,700-7,900 mg/m^3 chlorpyrifos in 65% xylene. In that study, the dose range was achieved by varying the length of exposure from 27 to 50 minutes. Virgin female Sprague-Dawley rats were similarly exposed to 5,900-7,500 mg/m^3 chlorpyrifos in 65% xylene, and an acuteduration exposure inhalation LD_{50} of 78 mg/kg was determined by varying the exposure duration from 48 to 61 minutes. The acute-duration oral exposure LD_{50} in female rats ranges between 82 mg/kg (Gaines 1969) to 135 mg/kg (McCollister et al. 1974) and 122 mg/kg (Gaines 1969) to 163 mg/kg (McCollister) for male rats. Approximately 9% mortality was seen in pregnant mice orally dosed with 25 mg/kg/day chlorpyrifos on Gd 6-15 (Deacon et al. 1980). The LD_{50} for male Leghorn chicken has been reported by Miyazaki and Hodgson (1972) and McCollister et al. (1974) to be 34.8 and 32 mg/kg chlorpyrifos, respectively.

Systemic Effects

Respiratory Effects. Acute-duration exposure to chlorpyrifos in humans has been shown to cause respiratory distress, probably due to acetylcholinesterase inhibition (Aiuto et al. 1993; Lotti et al. 1986; Selden and Curry 1987). In piglets, acute-duration dermal exposure to chlorpyrifos causes dyspnea, also a result of acetylcholinesterase inhibition (Long et al. 1986).

Cardiovascular Effects. In humans, acute-duration oral exposure to chlorpyrifos initially causes bradycardia, then tachycardia (Aiuto et al. 1993; Selden and Curry 1987). However, the progression to tachycardia is a dose-dependent effect.

Gastrointestinal Effects. Gastrointestinal distress, including nausea and diarrhea, has been observed in humans following acute- (Kaplan et al. 1993) or intermediate-duration (Kaplan et al. 1993) inhalation exposure or acute-duration dermal exposure (Thrasher et al. 1993) to chlorpyrifos. In bulls, acuteduration dermal exposure caused severe diarrhea and rumen atony (Haas et al. 1983).

Hematological Effects. Acute-duration inhalation exposure to chlorpyrifos in humans has not been shown to affect blood chemistry (Kaplan et al. 1993).

Musculoskeletal Effects. In humans, muscle pain (Thrasher et al. 1993) and muscle cramps (Kaplan et al. 1993) have been reported following acute-duration dermal and inhalation exposure, respectively, to chlorpyrifos. Increased muscle tone (Joubert et al. 1984) and vocal cord paralysis (Aiuto et al.

1993) were observed in humans following acute-duration oral exposure. Muscle twitching and fasciculations, hyper- or hyporeflexia, and coreo-athetotic motions have also been observed following acute-duration chlorpyrifos exposure (Aiuto et al. 1993; Joubert et al. 1984; Lotti et al. 1986; Selden and Curry 1987).

Hepatic Effects. In pregnant mice, acute-duration oral exposure to 25 mg/kg/day chlorpyrifos did not affect absolute or relative liver weight (Deacon et al. 1980).

Endocrine Effects. No information was found associating endocrine effects with chlorpyrifos exposure in humans or animals.

Renal Effects. An increase in urinary frequency was observed in adult male humans acutely exposed by inhalation to chlorpyrifos (Kaplan et al. 1993). However, unspecified decreases in urinary frequency were observed in humans following intermediate-duration inhalation or dermal exposure to undetermined amounts of chlorpyrifos (Ames et al. 1989).

Dermal Effects. In humans, intermediate-duration (3 months) inhalation or dermal exposure to undetermined amounts of chlorpyrifos resulted in an unspecified increase in skin flushing (Ames et al. 1989).

Ocular Effects. Acute-duration exposure in children (Aiuto et al. 1993; Selden and Curry 1987) and adults (Joubert et al. 1984) can cause miosis. In humans, intermediate-duration (3 months) inhalation or dermal exposure to undetermined amounts of chlorpyrifos resulted in an unspecified increase in blurred vision (Ames et al. 1989).

Body Weight Effects. The effects of Dursban® on body weight and body weight gain were assessed in pregnant mice following acute-duration oral exposure to doses as high as 25 mg/kg/day chlorpyrifos from Gd 6-15 (Deacon et al. 1980). A statistically significant decrease in mean body weight gain for Gd lo-15 (33.3%) and overall (Gd 6-17, 14%) was observed in animals exposed to 25 mg/kg/day chlorpyrifos. In the same study, the body weight gains of dams exposed to 1 or 10 mg/kg/day chlorpyrifos were comparable to controls. Additionally, body weights determined on Gd 18 for all the treatment groups were similar to control values.

Immunological and Lymphoreticular Effects. A study by Brenner et al. (1984) compared the prevalence of selected illnesses and symptoms in 175 employees involved in the production of chlorpyrifos and 335 matched controls with no history of exposure to organophosphorus chemicals. The employees were further subdivided for dose-response testing into three exposure intensity groups on the basis of job title and air-monitoring data. There were no statistically significant differences in illness or prevalence of symptoms between the exposed and unexposed groups, or among the three exposure subgroups. Exposure was assumed to be via inhalation and dermal routes. Although the objective of this study was not to specifically address whether exposure to chlorpyrifos causes any changes in immune function in humans, the results offered no evidence to suggest that chlorpyrifos suppresses human immunocompetence.

In spite of the widespread use of insecticides containing chlorpyrifos, there are no definitive reports that it sensitizes human skin. A study, which assessed a number of pesticides via patch tests in California nursery workers, observed no positive responses to chlorpyrifos in 38 out of the 39 exposed workers who were tested (O'Malley et al. 1995). The duration of exposure to any of the pesticides was not specified in this paper. Although none of the 21 control subjects were positive for chlorpyrifos, positive responses to other pesticides were noted in the controls.

The effects of acute-duration dermal exposure to chlorpyrifos were reported for 12 persons exposed to chlorpyrifos primarily in the home or workplace following professional application of the pesticide (Thrasher et al. 1993). The approximate dose received and the length of time following exposure were not known for any of the patients. Examination of blood taken from the chlorpyrifos-exposed persons indicated that there were changes in some lymphocyte subtypes when compared to 60 (28 male and 32 female) control subjects.

Analysis of the blood revealed a 300% increase in the mean absolute counts of CD26 cells and a decrease in the relative percentages of CD5 (11%) and CD4 (7%) lymphocytes. Additionally, 83% of the chlorpyrifos-exposed individuals had increased levels (300-l ,200%) of circulating autoantibodies to at least one of the following cell types or organelles: smooth muscle, parietal cells, brush boarder, and nuclei. Twenty-five percent of the chlorpyrifos-exposed patients had elevated autoantibodies to 3 or more of the cell types or organelles compared to 0-3.7% in the control group. The authors suggested that the increase in auto antibodies was due to chlorpyrifos-induced tissue damage. However, the causality of these effects must be interpreted with caution. This study was a retrospective case study

in which the symptoms arose l-4.5 years post-exposure to chlorpyrifos. No exposure data were presented and there were no objective data or methods for ruling out confounding chemical exposures. Ten of the patients had a history of some type of atopy or drug sensitivity while one patient had been diagnosed with systemic lupus erythematous and another had a lupus-like syndrome. From the results of this study, it may be concluded that the patients had some immunological abnormalities, but it is difficult to attribute the effects to chlorpyrifos exposure (Richardson 1995).

Neurological Effects. The most common effect in humans and other animals following acuteduration chlorpyrifos exposure is inhibition of cholinesterase activity (Berteau and Deen 1978; Deacon et al. 1980; Hooser et al. 1988; Joubert et al. 1984; Kaplan et al. 1993; Long et al. 1986; Selden and Curry 1987). In humans, acute-duration exposure to unspecified amounts of chlorpyrifos is associated with a variety of symptoms, including headache, excessive salivation, lacrimation, diaphoresis, bradycardia, tachycardia, excessive respiratory tract secretions, bronchoconstriction, paresthesia, lightheadedness, memory impairment, stupor (Joubert et al. 1984), seizure-like motor activity, and coma (Aiuto et al. 1993; Kaplan et al. 1993; Lotti et al. 1986; Selden and Curry 1987). Motor symptoms such as muscle twitching, fasciculations, and coreo-athetotic movements have also been observed following acute-duration oral exposure to chlorpyrifos (Aiuto et al. 1993; Joubert et al. 1984; Lotti et al. 1986; Selden and Curry 1987). Transient, delayed polyneuropathy has been noted in humans following acute- (Aiuto et al. 1993; Lotti et al. 1986) or intermediate-duration (Kaplan et al.1993) exposure to chlorpyrifos.

Neurotoxic effects similar to the ones described above have also been observed in laboratory animals following acute-duration exposure (Capodicasa et al. 1991; Deacon et al. 1980; Hooser et al. 1988). In the Deacon et al. (1980) study, erythrocyte acetylcholinesterase activity was significantly inhibited at dosages of 10 and 1 mg/kg/day, but not at 0.1 mg/kg/day. Muscle weakness and abnormal gait were observed in hens orally dosed with 10 mg/kg/day chlorpyrifos for 90 days. The symptoms subsided by 60 days after the end of the dosing period. These symptoms differed from the classical OPIDN in the apparent reversibility of ataxia in the hens which survived (Francis et al. 1985). No-symptoms of classical OPIDN were observed in hens exposed to 10 mg/kg/day chlorpyrifos for 20 days (Richardson et al. 1993b).

Reproductive Effects. No effects on reproduction were observed in mice following acuteduration oral exposure to chlorpyrifos during pregnancy (Deacon et al. 1980). However, decreased

sperm production was observed in bulls to which an undetermined amount of chlorpyrifos had been dermally applied (Everett 1982).

Developmental Effects. The potential for chlorpyrifos to be developmentally toxic was assessed in mice exposed to 0, 1, 10, or 25 mg/kg/day chlorpyrifos on Gd 6-15 (Deacon et al. 1980). On Gd 18, all fetuses were weighed, sexed, examined for external malformations and cleft palate, and had their crown-rump length determined. One-third of the fetuses of each litter were also examined for evidence of soft-tissue alterations. There was no biologically significant effect of treatment on the number of live fetuses per litter, the number of dead fetuses per litter, the number of resorptions per litter, the average fetal body weight, or average crown-rump length. However, significant increases in skeletal variations were observed in litters exposed to 25 mg/kg/day chlorpyrifos, a level also causing significant maternal toxicity. Increases were seen in the number of fetuses with delayed ossification of the skull bones (6.8-fold increase), delayed ossification of the stemebrae (2.1-fold increase), and unfused stemebrae (4-fold increase) at the same dosage. In the same study, total fetal homogenate cholinesterase levels were decreased by 19, 35, and 65% in the litters of mice given 1, 10, or 25 mg/kg/day chlorpyrifos, respectively, on Gd 6-15 (Deacon et al. 1980). The decreases in cholinesterase activity were significantly different from controls at the 10 and 25 mg/kg/day doses.

Genotoxic Effects. Results of studies conducted with rodent and insect cell lines suggest that chlorpyrifos may be genotoxic (Amer and Fahmy 1982; Patnaik and Tripathy 1992; Sobti et al. 1982; Woodruff et al. 1983). A dose-response effect of chlorpyrifos on the induction of micronuclei in bone marrow has been observed (Amer and Fahmy 1982). A dose-response relationship for chlorpyrifosinduced cytotoxic cytogenetic effects in human lymphoid cells has also been demonstrated. Chlorpyrifos has been shown to produce significant increases in sister chromatid exchanges (Sobti et al. 1982). It has also been reported that chlorpyrifos causes X chromosome loss (Woodruff et al.1983). Spindle poisoning and induction of micronuclei and polyploidy have also been reported following chlorpyrifos exposure (Rao et al. 1988). Sex-linked recessive lethals have also been produced by chlorpyrifos exposure, indicating that chlorpyrifos is genotoxic to both somatic and germ cells (Patnaik and Tripathy 1992). Finally, chlorpyrifos at a concentration of 0.05 µg/mL caused induction of chromosomal aberrations and sister chromatid exchanges in spleen cells. Chromosomal aberrations included chromatic and chromosomal gaps and fragments. Additionally, some polyploid metaphases were observed (Amer and Aly 1992). The results of these studies are summarized in Tables 2-4 and 2-5.

Table 2-4. Genotoxicity of Chlorpyrifos *In Vivo*

Species (test system)	End point	Results	Reference
Fly *(Drosophila melanogaster)* germ cells	Complete chromosome loss	+	Woodruff et al. 1983
Fly *(Drosophila melanogaster)* germ cells	Partial chromosome loss	–	Woodruff et al. 1983
Fly *(Drosophila)* somatic and germ cells	Induction of mosaic wing spots	+	Patnaik and Tripathy 1992
Fly *(Drosophila)* somatic and germ cells	Induction of sex-linked recessive lethals	+	Patnaik and Tripathy 1992
Mouse (Swiss) bone marrow	Polychromatic erythrocytes (PE) and PE with micronuclei	+	Amer and Fahmy 1982

– = negative; + = positive

Table 2-5. Genotoxicity of Chlorpyrifos *In Vitro*

Species (test system)	End point	Result		Reference
		With activation	Without activation	
Human peripheral blood	Sister chromatid exchange		–	Nelson et al. 1990
Mouse (Swiss) bone marrow	Polychromatic erythrocytes (PE)		+	Amer and Fahmy 1982
Mouse (Swiss) bone marrow	Induction of micronuclei		–	Amer and Fahmy 1982
Mouse (Swiss) spleen cells	Cytotoxicity		+	Amer and Aly 1992
Mouse (Swiss) spleen cells	Chromosomal aberrations		+	Amer and Aly 1992

– = negative results; + = positive

Cancer Effects. Research in rats and dogs (McCollister et al. 1974) found that chlorpyrifos did not increase the incidence of cancer, but the data from this study are not sufficient to assess any human cancer risk to chlorpyrifos exposure. The EPA has not classified chlorpyrifos for carcinogenicity (Class D).

2.6 BIOMARKERS OF EXPOSURE AND EFFECT

Biomarkers are broadly defined as indicators signaling events in biological systems or samples. They have been classified as markers of exposure, markers of effect and markers of susceptibility (NAS/NRC 1989).

Due to a nascent understanding of the use and interpretation of biomarkers, implementation of biomarkers as tools of exposure in the general population is very limited. A biomarker of exposure is a xenobiotic substance or its metabolitets), or the product of an interaction between a xenobiotic agent and some target molecule(s) or cell(s) that is measured within a compartment of an organism (NAS/NRC 1989). The preferred biomarkers of exposure are generally the substance itself or substance-specific metabolites in readily obtainable body fluid(s) or excreta. However, several factors can confound the use and interpretation of biomarkers of exposure. The body burden of a substance may be the result of exposures from more than one source. The substance being measured may be a metabolite of another xenobiotic substance (e.g., high urinary levels of phenol can result from exposure to several different aromatic compounds). Depending on the properties of the substance (e.g., biologic half-life) and environmental conditions (e.g., duration and route of exposure), the substance and all of its metabolites may have left the body by the time samples can be taken. It may be difficult to identify individuals exposed to hazardous substances that are commonly found in body tissues and fluids (e.g., essential mineral nutrients such as copper, zinc, and selenium). Biomarkers of exposure to chlorpyrifos are discussed in Section 2.6.1.

Biomarkers of effect are defined as any measurable biochemical, physiologic, or other alteration within an organism that, depending on magnitude, can be recognized as an established or potential health impairment or disease (NAS/NRC 1989). This definition encompasses biochemical or cellular signals of tissue dysfunction (e.g., increased liver enzyme activity or pathologic changes in female genital epithelial cells), as well as physiologic signs of dysfunction such as increased blood pressure or decreased lung capacity. Note that these markers are not often substance specific. They also may not

be directly adverse, but can indicate potential health impairment (e.g., DNA adducts). Biomarkers of effects caused by chlorpyrifos are discussed in Section 2.6.2.

A biomarker of susceptibility is an indicator of an inherent or acquired limitation of an organism's ability to respond to the challenge of exposure to a specific xenobiotic substance. It can be an intrinsic genetic or other characteristic or a preexisting disease that results in an increase in absorbed dose, a decrease in the biologically effective dose, or a target tissue response. If biomarkers of susceptibility exist, they are discussed in Section 2.8, Populations That Are Unusually Susceptible.

2.6.1 Biomarkers Used to Identify or Quantify Exposure to Chlorpyrifos

Measurement of erythrocyte or plasma cholinesterase activity is usually performed if organophosphate poisoning is suspected. Erythrocyte cholinesterase activity may be used as both an index of exposure and as a harbinger of potential toxicity. Butyrylcholinesterase activity may also be used as an indicator of exposure to a cholinesterase-inhibiting agent, but due to its lack of substrate specificity, it may not, by itself, be used as a reliable index of toxicity.

Chlorpyrifos is known to inhibit acetylcholinesterase activity, but the degree of inhibition does not correlate well with the onset of toxicity or the amount of exposure. Moreover, acetylcholinesterase inhibition may occur after exposure to a wide variety of organophosphate and carbamate pesticides. Thus, acetylcholinesterase activity is not a specific marker for chlorpyrifos exposure. However, unlike many pesticides, chlorpyrifos metabolism yields some relatively unique compounds. The major metabolite of chlorpyrifos is TCP. TCP can be found in the general circulation and in the urine, its principal route of excretion. Moreover, TCP levels correlate well with the degree of exposure to chlorpyrifos, and current analytic methods can detect TCP in the nanomolar range. The results of metabolism studies conducted in animals indicate that >90% of absorbed chlorpyrifos is eliminated from the body within 48 hours. Therefore, urine TCP can be used as a qualitative biomarker for chlorpyrifos exposure, providing the testing is performed within 48 hours after exposure, It should be noted that clinical signs of chlorpyrifos-induced toxicity may persist for several weeks after exposure, or longer in the case of extremely high exposures.

2.6.2 Biomarkers Used to Characterize Effects Caused by Chlorpyrifos

There are no specific biomarkers that may be used to characterize the effects caused by chlorpyrifos. All the signs and symptoms (weakness, headache, dizziness, visual disturbances, increased salivation, increased lacrimation, nausea, vomiting, lack of appetite, stomachache, restlessness or increased excitement, myosis, bronchial spasms, diarrhea, miosis, sweating, bradycardia, hypertonia, facial muscle twitching, tremors, gait disturbances, feeling of fear, chest pain, difficult respiration, cyanosis of the mucous membrane, generalized convulsions, psychic disturbances, edema of lung, coma) of chlorpyrifos exposure relate directly to its inhibition of acetylcholinesterase, which may be caused by any organophosphate or carbamate insecticide.

For more information on biomarkers for renal and hepatic effects of chemicals, *see ATSDR/CDC Subcommittee Report on Biological Indicators of Organ Damage* (1990), and for information on biomarkers for neurological effects, see OTA (1990).

2.7 INTERACTIONS WITH OTHER CHEMICALS

The primary risk of interaction is with other compounds that also inhibit acetylcholinesterase. In those cases, the dose needed to produce chlorpyrifos-induced toxicity would be correspondingly lower. Additionally, it would be expected that concurrent exposure to other central nervous system toxicants such as solvents may exacerbate the chlorpyrifos-induced neurotoxicity or confound the diagnosis, depending on whether the toxicant has excitatory or depressant neurological effects. Additionally, chlorpyrifos toxicity in bovines appears to correlate with high circulating levels of testosterone, suggesting that sex steroids may lower the threshold for toxicity.

2.8 POPULATIONS THAT ARE UNUSUALLY SUSCEPTIBLE

A susceptible population may exhibit a different or enhanced response to chlorpyrifos than will most persons exposed to the same level of chlorpyrifos in the environment. Reasons may include genetic makeup, age, health and nutritional status, and concurrent exposure to some pharmaceuticals or other toxic substances. These parameters may result in reduced detoxification or excretion of chlorpyrifos, or compromised function of target organs affected by chlorpyrifos. Populations that are at greater risk

due to their unusually high exposure to chlorpyrifos are discussed in Section 5.6, Populations With Potentially High Exposure.

There are many populations at potentially greater risk to chlorpyrifos-induced toxicity. Populations at risk include the elderly, persons with pre-existing medical conditions, infants and children, and pregnant women. The elderly are considered at risk for increased toxicity because of the general decline in health that accompanies aging. Persons with chronic respiratory ailments such as asthma, emphysema, and bronchitis would be at greater risk for respiratory distress following chlorpyrifos exposure due to the insecticide's ability to cause bronchochronstriction and increase mucous secretions in the airways. Persons suffering from heart disease may also represent a group at particular risk due to both direct cardiac effects and restriction in airway diameter. Research using rats indicates that females are more susceptible to the toxic effects of chlorpyrifos, possibly because they detoxify chlorpyrifos at a lower rate than males. However, in bovines, bulls have been shown to be at increased risk to chlorpyrifos toxicity. It is not known if gender differences in chlorpyrifos metabolism or susceptibility exist in humans. Additionally, the doses of chlorpyrifos needed to cause death in pregnant mice are approximately six times lower than those need to cause death in nonpregnant mice, suggesting that pregnancy may increase the risk of chlorpyrifos-induced toxicity.

Infants and children may also be at increased risk for toxicity. Results from animal studies suggest that chlorpyrifos more easily penetrates the skin of young animals, compared to adults. Children also have a decreased metabolic capacity to eliminate toxicants and are more susceptible to central nervous system toxicants, thus lowering the exposure levels considered protective against the potential toxicity of chlorpyrifos in that population. Chlorpyrifos may also be developmentally toxic. Studies of pregnant rats suggest that low levels of chlorpyrifos exposure during gestation have the potential to increase offspring mortality, reduce birth weight, and alter offspring behavior.

2.9 METHODS FOR REDUCING TOXIC EFFECTS

This section will describe clinical practice and research concerning methods for reducing toxic effects of exposure to chlorpyrifos. However, because some of the treatments discussed may be experimental and unproven, this section should not be used as a guide for treatment of exposures to chlorpyrifos. When specific exposures have occurred, poison control centers and medical toxicologists should be

consulted for medical advice. The following texts provide specific information about treatment following exposures to chlorpyrifos:

- Cholinesterase inhibitor pesticides, in Handbook of Poisoning, 1987, Appleton and Lang, Norwalk; R.H. Dreisbach, 110-l 18.
- Organophosphates and other insecticides, in Clinical Management of Poisoning and Drug Overdose, 2nd. Edition, 1990, W.B. Saunders, Philadelphia; M. Haddad and J.F. Winchester, eds., 1105-l 119.
- Insecticides: organophosphates and carbamates, in Goldfrank's Toxicologic Emergencies, 5th edition, 1994, Norwalk; C.K. Aaron and M.A. Howland, 1076-1087.

2.9.1 Reducing Peak Absorption Following Exposure

Gastric lavage may be used to reduce peak absorption following oral exposure to chlorpyrifos (Aiuto et al. 1993; Namba et al. 1971). Additionally, the oral administration of activated charcoal with a saline cathartic given repeatedly interrupts the enterohepatic circulation of chlorpyrifos and its metabolites by blocking intestinal absorption and reducing residency time in the intestine. For dermal exposure, gently washing the exposed area with soap and water would be recommended; however, rough cleansing may damage the skin, leading to increased absorption of the pesticide.

2.9.2 Reducing Body Burden

Repeated oral administration of activated charcoal interrupts enterohepatic circulation and reduces body burden via hepatic excretion into the gastrointestinal tract.

2.9.3 Interfering with the Mechanism of Action for Toxic Effects

There are two commonly used procedures (antidotes) to interfere with the mechanism of chlorpyrifos. One is to administer pralidoxime (2-PAM) intravenously to displace the chlorpyrifos or its oxon from the acetylcholinesterase enzyme and restore its activity (Namba et al. 1971). Since 2-PAM is itself a potent inhibitor of acetylcholinesterase, care should be taken not to use it in cases of concurrent exposure to carbamate insecticides, since this may exacerbate the toxicity of that group of pesticides. Additionally, 2-PAM cannot displace chlorpyrifos or its oxon from the aged form of the cholinesterase enzyme. However, 2-PAM may be given if clinical signs of toxicity are still observable. Since the

percentage of aged acetylcholinesterase increases with time after exposure, 2-PAM treatment should be given as soon as chlorpyrifos exposure has been determined. Chlorpyrifos toxicosis can also be reduced using muscarinic cholinergic receptor blockers such as atropine. Atropine blocks the predominantly parasympathetic effects caused by chlorpyrifos (Aiuto et al. 1993; Goodman et al. 1990; Namba et al. 1971). Both atropine and 2-PAM are toxic and should be used with care. In addition to the above treatments, diazepam may be used to reduce muscle fasciculations and seizure activity (Ballantyne and Marrs 1992).

2.10 ADEQUACY OF THE DATABASE

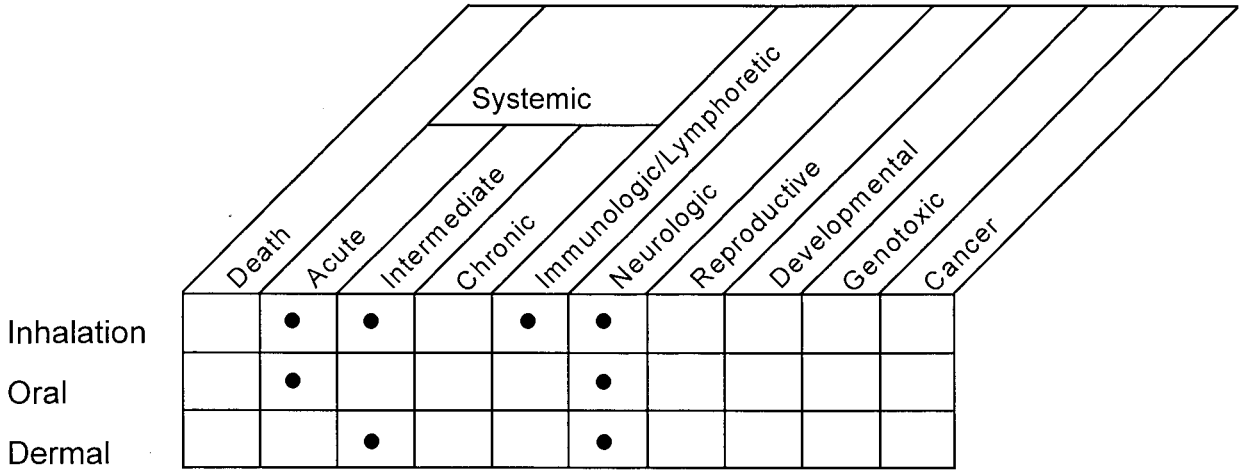
Section 104(i)(5) of CERCLA, as amended, directs the Administrator of ATSDR (in consultation with the Administrator of EPA and agencies and programs of the Public Health Service) to assess whether adequate information on the health effects of chlorpyrifos is available. Where adequate information is not available, ATSDR, in conjunction with the National Toxicology Program (NTP), is required to assure the initiation of a program of research designed to determine the health effects (and techniques for developing methods to determine such health effects) of chlorpyrifos.

The following categories of possible data needs have been identified by a joint team of scientists from ATSDR, NTP, and EPA. They are defined as substance-specific informational needs that if met would reduce the uncertainties of human health assessment. This definition should not be interpreted to mean that all data needs discussed in this section must be filled. In the future, the identified data needs will be evaluated and prioritized, and a substance-specific research agenda will be proposed.

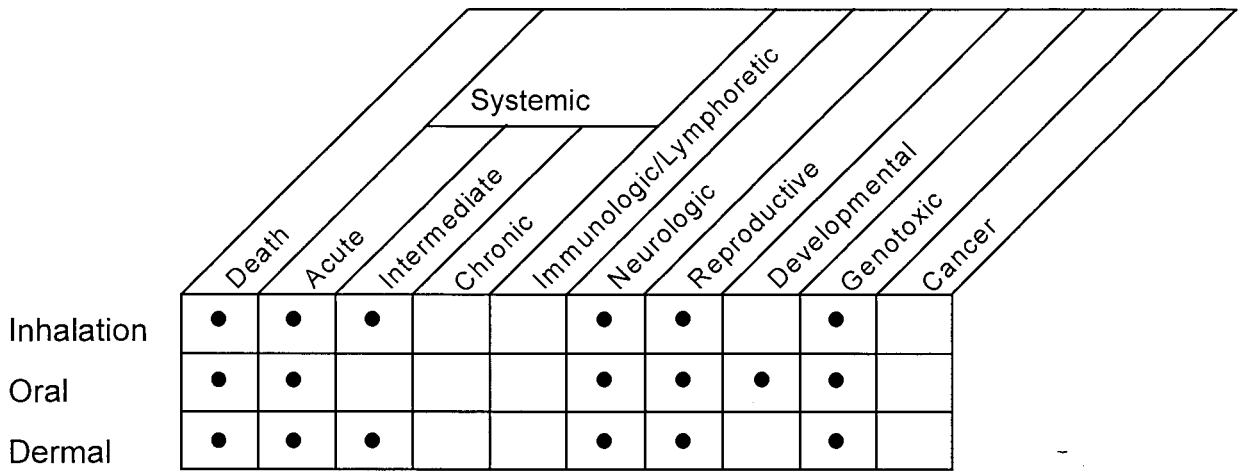
2.10.1 Existing Information on Health Effects of Chlorpyrifos

The existing data on health effects of inhalation, oral, and dermal exposure of humans and other animals to chlorpyrifos are summarized in Figure 2-5. The purpose of this figure is to illustrate the existing information concerning the health effects of chlorpyrifos. Each dot in the figure indicates that one or more studies provide information associated with that particular effect. The dot does not necessarily imply anything about the quality of the study or studies, nor should missing information in this figure be interpreted as a “data need.” A data need, as defined in ATSDR’s Decision Guide for Identifying Substance-Specific Data Needs Related to Toxicological Profiles (ATSDR 1989), is substance-specific information necessary to conduct comprehensive public health assessments.

Figure 2-5. Existing Information on Health Effects of Chlorpyrifos



Human



Animal

- ● Existing Studies

Generally, ATSDR defines a data gap more broadly as any substance-specific information missing from the scientific literature.

2.10.2 Identification of Data Needs

Acute-Duration Exposure. In general, acute-duration toxicity of chlorpyrifos has been well characterized in humans and other animals. The most common effect in humans and other animals following acute-duration chlorpyrifos exposure is inhibition of cholinesterase activity (Berteau and Deen 1978; Deacon et al. 1980; Hooser et al. 1988; Joubert et al. 1984; Kaplan et al. 1993; Long et al. 1986; Selden and Curry 1987). In humans, acute-duration exposure to chlorpyrifos is associated with a variety of symptoms, including headache, excessive salivation and lacrimation, diaphoresis, bradycardia, tachycardia, excessive respiratory tract secretions, bronchoconstriction, paresthesia, lightheadedness, memory impairment, stupor (Joubert et al. 1984), seizure-like motor activity, and coma (Aiuto et al. 1993; Kaplan et al. 1993; Lotti et al. 1986; Selden and Curry 1987). Motor symptoms such as muscle twitching, fasciculations, and coreo-athetotic movements have also been observed following acute-duration oral exposure to chlorpyrifos (Aiuto et al. 1993; Joubert et al. 1984; Lotti et al. 1986; Selden and Curry 1987). Transient, delayed polyneuropathy has been noted in humans following acute- (Aiuto et al. 1993; Lotti et al. 1986) or intermediate-duration (Kaplan et al. 1993) exposure to chlorpyrifos. Neurotoxic effects similar to the ones described above have also been observed in laboratory animals following acute-duration exposure (Capodicasa et al. 1991; Deacon et al. 1980; Hooser et al. 1988). These data indicate that the database is adequate for this exposure duration and sufficient to derive an acute-duration exposure MRL. Although the symptoms associated with chlorpyrifos exposure are well characterized, the correlation between cholinesterase inhibition and the severity of the symptoms is not. Increased reporting in the biomedical literature of human chlorpyrifos exposures, and animal studies designed to examine the correlation between cholinesterase inhibition and toxicity are needed. Acute-duration exposure toxicity in bovines appears to be associated with high levels of testosterone. The nature of the chlorpyrifos-testosterone interaction needs to be evaluated to determine if gender-related susceptibility to chlorpyrifos toxicity exists.

Intermediate-Duration Exposure. The toxic effects of chlorpyrifos following intermediate-duration exposure are expected to be similar to the cholinergic effects seen after acute-duration exposure. For example, blurred vision and skin flushing have been reported following occupational exposure to chlorpyrifos by multiple routes (Ames et al. 1989). Sufficient oral exposure data exist to

calculate an MRL for this exposure route. However, toxicological data for dermal and inhalation exposure are sparse. Since chlorpyrifos is rapidly absorbed through the lungs, inhalation exposure may represent a significant health risk. Limited attempts to identify chlorpyrifos-related toxicity in pesticide applicators suggest that intermediate-duration exposure to low levels of chlorpyrifos may adversely affect health (Ames et al. 1989); but whether the effects may be related to cumulative direct target insult or simply to cholinesterase inhibition is less clear. Low-level inhalation or dermal exposures are assumed for the Ames et al. (1989) study because pesticide applicators are usually presumed to wear protective clothing and respirators when spraying the pesticide. However, neither the dose nor the length of exposure could be estimated. Thus, toxicity-based dose-response information is needed following inhalation and dermal exposure to chlorpyrifos. Based on the Ames et al. (1989) study, it would be particularly relevant to assess the toxic effects of low-level intermediate-duration exposure on human health. Intermediate-duration exposure neurotoxicity studies conducted in animals are recommended. Better quantification of the toxicity caused by intermediateduration occupational exposure would help in assessing the health risks posed by chlorpyrifos.

Chronic-Duration Exposure and Cancer. There is limited information regarding the potential toxic and carcinogenic effects of chronic, low-level exposure to chlorpyrifos (Brenner et al. 1984; McCollister et al. 1974; Miyazaki and Hodgson 1972). Of particular concern are the potential systemic effects of chronic-exposure to low levels of the pesticide by the oral, dermal, and inhalation routes, because of its widespread use in industry, the home, and agriculture.

Genotoxicity. Results of studies conducted with rodent and insect cell lines indicate that chlorpyrifos may be genotoxic (Amer and Fahmy 1982; Patnaik and Tripathy 1992; Sobti et al. 1982; Woodruff et al. 1983). A dose response effect of chlorpyrifos on the induction of micronuclei in bone marrow has been observed (Amer and Fahmy 1982). A dose response relationship of cytotoxic cytogenetic effects to chlorpyrifos exposure has also been demonstrated in human lymphoid cells. Chlorpyrifos has been shown to produce significant increases in sister chromatid exchanges, with the percentage of M3 metaphases showing a dose response decrease (Sobti et al. 1982). It has also been reported that chlorpyrifos causes X chromosome loss (Woodruff et al. 1983). Spindle poisoning and induction of micronuclei have also been reported following chlorpyrifos exposure (Rao et al. 1988). In addition, some polyploid metaphases were observed (Amer and Aly 1992). Sex-linked recessivelethals have also been produced by chlorpyrifos exposure, indicating that chlorpyrifos is genotoxic in both somatic and germ cells (Patnaik and Tripathy 1992). Finally, chlorpyrifos at concentrations of

0.05 µg/rnL caused induction of chromosomal aberrations and sister chromatic exchanges in spleen cells. Chromosomal aberrations included chromatic and chromosomal gaps, and fragments. Thus, sufficient data exist to identify chlorpyrifos as genotoxic. Epidemiological studies are recommended to investigate whether the effects observed may also occur in humans.

Reproductive Toxicity. Chlorpyrifos administered orally at 25 mg/kg/day from Gd 6 to 15 caused severe maternal toxicity (Deacon et al. 1980). The toxicity was characterized by symptoms of profound cholinergic stimulation and death. Despite the maternal toxicity, the surviving dams gave birth to normal numbers of offspring. No effects on reproduction were observed in mice receiving lower doses of chlorpyrifos. Decreased sperm production was observed in bulls to which an undetermined amount of chlorpyrifos had been dermally applied (Everett 1982). The data are not sufficient to evaluate the reproductive health risk of chlorpyrifos, especially in light of its genotoxic potential. Since chlorpyrifos may affect sperm production and viability, and because the effects of intermediate or long-term exposure are not known, a two-generation reproductive toxicity assessment is recommended. This type of study would be useful because it would address the effects of chlorpyrifos on both male and female reproduction.

Developmental Toxicity. The acute oral administration of 25 mg/kg/day chlorpyrifos from Gd 615 decreased average fetal weight and crown-rump length (Deacon et al. 1980). Chlorpyrifos also inhibits fetal cholinesterase activity (Deacon et al. 1980). However, the fetal effects in that study occurred in tandem with severe maternal toxicity. Thus, it is not certain if the reduction in fetal growth was secondary to maternal toxicity. More information is needed in this area, especially as it relates to the effect of chlorpyrifos on the developing nervous system, because of the potential for chlorpyrifos to affect cholinergic systems. Developmental toxicity and neurotoxicity studies are recommended. Dosing in the neurotoxicity studies should extend from gestation through weaning in order to expose brain regions that develop primarily postnatally.

Immunotoxicity. Work by Brenner et al. (1984) failed to identify immunotoxicity in a comparison of 175 employees involved in the production of chlorpyrifos and 335 matched controls with no history of exposure to organophosphorus chemicals. Exposure in this study was assumed to be via inhalation and dermal routes. A study which assessed a number of pesticides via patch tests in California nursery workers observed no positive responses with chlorpyrifos in 38 out of the 39 exposed workers who were tested (O'Malley et al. 1995). In contrast, work by Thrasher et al. (1993) raises the

possibility that certain aspects of human immune function may be altered by chlorpyrifos exposure. It should be noted that while the Thrasher et al. (1993) had several flaws, it nevertheless suggests that certain components of the immunological system may be affected by chlorpyrifos. Because of the lack of a definitive immunotoxicity study, this area must be considered a data gap. Thus, an assessment of a validated immune functional test battery following intermediate- and chronic-duration exposure by inhalation and dermal exposure to low levels (levels not causing overt toxicity) of chlorpyrifos is recommended.

Neurotoxicity. Acute-duration exposure to chlorpyrifos has been shown to cause transient delayed peripheral neuropathy in humans and hens. Limited epidemiological studies in humans failed to reveal motor effects of intermediate-duration chlorpyrifos exposure beyond those seen in acute-exposure scenarios. However, acute-duration oral exposure to chlorpyrifos in humans and other animals has been reported to cause transient memory impairment. Information is lacking regarding the potential for inhaled or dermally absorbed chlorpyrifos to cause similar cognitive deficits. Thus, data are needed regarding the potential development of neuropathies and neurobehavioral toxicity associated with intermediate- or chronic-duration oral, inhalation, and dermal exposure to chlorpyrifos. Epidemiological research is also needed to identify levels of cholinergic inhibition associated with the onset of cholinergic symptoms in people exposed to chlorpyrifos, and to determine if susceptible or sensitized individuals can be identified.

Epidemiological and Human Dosimetry Studies. Epidemiological/occupational studies are needed because of the large population that is potentially at risk to chlorpyrifos exposure, both in the work place and the home.

Biomarkers of Exposure and Effect. No additional information is needed in this area. Chlorpyrifos has a unique metabolite, TCP, that has been well characterized and for which sensitive analytic methods exist.

Exposure. Although chlorpyrifos inhibits acetylcholinesterase, the degree of inhibition does not correlate well with toxicity or the amount of exposure. Moreover, acetylcholinesterase inhibition may occur after exposure to a wide variety of organophosphate and carbamate pesticides. Thus, acetylcholinesterase activity is not a specific marker for chlorpyrifos exposure, though total blood cholinesterase is a good indicator in animals. However, unlike many pesticides, chlorpyrifos

metabolism yields some unique compounds. The major and unique metabolite of chlorpyrifos is TCP. TCP can be found in the general circulation and in the urine, its principal route of excretion. Moreover, TCP levels correlate well with the degree of exposure to chlorpyrifos, and analytic methods can detect TCP in the nanomolar range. Thus, TCP is a specific and sensitive marker for chlorpyrifos exposure.

Effect. There are no specific biomarkers that may be used to characterize the effects caused by chlorpyrifos. All clinical signs and symptoms of chlorpyrifos exposure relate directly to its inhibition of acetylcholinesterase, which may be caused by any organophosphate or carbamate insecticide.

Absorption, Distribution, Metabolism, and Excretion. In general, the absorption, distribution, metabolism, and excretion of chlorpyrifos have been well characterized in humans and other animals. However, female rats and bulls with high circulating testosterone levels appear to more susceptible to chlorpyrifos toxicity. Thus, toxicokinetic data is needed in rats and bovines to determine whether there are gender-related differences in chlorpyrifos metabolism which could be used to identify a specific population at risk. Additionally, clinical signs of chlorpyrifos toxicity may persist long after it has been eliminated form the body. Information is needed to determine if this is due to a metabolite or to long-term changes in organ responsiveness resulting from the exposure.

Comparative Toxicokinetics. Adequate data exist for this area.

Methods for Reducing Toxic Effects. The methods for reducing the toxic effects of chlorpyrifos are well established. Any improvements in management of organophosphate poisoning would be expected to be relevant to chlorpyrifos.

2.10.3 Ongoing Studies

No ongoing studies for chlorpyrifos were found.

3. CHEMICAL AND PHYSICAL INFORMATION

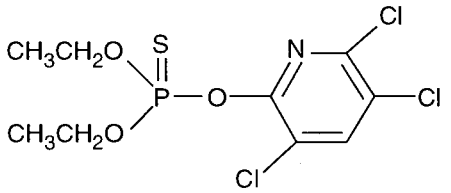
3.1 CHEMICAL IDENTITY

Information regarding the chemical identity of chlorpyrifos is located in Table 3-l.

3.2 PHYSICAL AND CHEMICAL PROPERTIES

Information regarding the physical and chemical properties of chlorpyrifos is located in Table 3-2.

Table 3-1. Chemical Identity of Chlorpyrifos

Characteristic	Information	Reference
Chemical name	O,O-diethyl O-(3,5,6-trichloro-2-pyridyl) phosphorothioate	Merck 1989
Synonym(s)	Phosphorothioic acid O,O-diethyl O-(3,5,6-trichloro-2-pyridinyl) ester; chlorpyrifos-ethyl; chlorpyriphos	Merck 1989
Registered trade name(s)	Dowco 179; ENT 27311; Dursban; Lorsban; Pyrinex; DMS-0971	Merck 1989
Chemical formula	$C_9H_{11}Cl_3NO_3PS$	Merck 1989
Chemical structure		Merck 1989
Identification numbers:		
CAS Registry	2921–88–2	Merck 1989
NIOSH RTECS	TF6300000	HSDB 1994
EPA Hazardous Waste	059101	HSDB 1994
OHM/TADS	7800025	HSDB 1994
DOT/UN/NA/IMCO	NA 2783 Chlorpyrifos	HSDB 1994
HSDB	389	HSDB 1994
NCI	No data	

CAS = Chemical Abstracts Services; DOT/UN/NA/IMCO = Department of Transportation/United Nations/North America/International Maritime Dangerous Goods Code; EPA = Environmental Protection Agency; HSDB = Hazardous Substance Data Bank; NCI = National Cancer Institute; NIOSH = National Institute for Occupational Safety and Health; OHM/TADS = Oil and Hazardous Materials/Technical Assistance Data System; RTECS = Registry of Toxic Effects of Chemical Substances

Table 3-2. Physical and Chemical Properties of Chlorpyrifos

Property	Information	Reference
Molecular weight	350.57	Merck 1989
Color	White granular crystals White to tan Amber solid cake with amber oil Colorless crystals	Merck 1989 EPA 1988 Verschueren 1983 Worthing 1987
Physical state	Crystalline solid	EPA 1988
Melting point	41–42 °C	Merck 1989
Boiling point	Decomposes at approximately 160 °C	Verschueren 1983
Density at 43.5 °C	1.398 g/cm^3	Verschueren 1983
Odor	Mild mercaptan	EPA 1988
Odor threshold: Water Air	 No data No data	
Solubility: Water at 20 °C Water at 25 °C	 0.7 mg/L 2 mg/L	 Bowman 1983 Merck 1989
Organic solvent(s)	79% w/w in isooctane 43% w/w in methanol Readily soluble in other organic solvents	Merck 1989
Partition coefficients: Log K_{ow} Log K_{oc}	 4.82 3.73	 McCall et al. 1980
Vapor pressure at 20 °C Vapor pressure at 25 °C	1.87x10^{-5} mm Hg 1.87x10^{-5} mm Hg	Verschueren 1983 Merck 1989
Henry's law constant: at 25 °C	1.23x10^{-5} atm-m^3/mol	HSDB 1995
Autoignition temperature	No data	
Flashpoint	None	EPA 1988b
Flammability limits at 25 °C	No data	
Conversion factors (25 °C)	1 ppm=14.3 mg/m^3 1 mg/m^3=0.070 ppm	
Explosive limits	No data	

CAS = Chemical Abstracts Services; DOT/UN/NA/IMCO = Department of Transportation/United Nations/North America/International Maritime Dangerous Goods Code; EPA = Environmental Protection Agency; HSDB = Hazardous Substance Data Bank; NCI = National Cancer Institute; NIOSH = National Institute for Occupational Safety and Health; OHM/TADS = Oil and Hazardous Materials/Technical Assistance Data System; RTECS = Registry of Toxic Effects of Chemical Substances

4. PRODUCTION, IMPORT/EXPORT, USE, AND DISPOSAL

4.1 PRODUCTION

Chlorpyrifos is prepared commercially by several methods (Rigterink 1966). In a preferred method, the final step in the synthesis is reacting 3,5,6-trichloro-2-pyridinol (TCP) and O,O-diethylphosphorochloridothioate under basic conditions in dimethylformamide (Sittig 1985). Chlorpyrifos was introduced in 1965 by Dow Chemical Company under the protection of U.S. Patent 3,244,586. It is produced under many trade names including Brodan®, Detmol UA®Dowco 179®, Dursban®, Empire®, Equity®, Eradex®, Lentrek®, Lock-On®, Lorsbanv®, Pageant®, Piridane®, and Stipend® Producers of chlorpyrifos in the United States are DowElanco in Midland, Michigan and Lafayette, Indiana, and SureCo, Inc. in Fort Valley, Georgia (SRI 1994). Production volumes have not been located.

No information is available in the Toxics Release Inventory (TRI) database on total environmental releases of chlorpyrifos from production facilities, because chlorpyrifos is not included under SARA, Title III, and, therefore, is not one of the chemicals that facilities are required to report (EPA 1993c).

4.2 IMPORT/EXPORT

Information on import/export volumes was not located.

4.3 USE

Chlorpyrifos is a broad spectrum organophosphate insecticide/acaricide which is used to control a variety of insects. First introduced into the non-crop specialty market, it was marketed in the late 1960s to control pests in turfgrass and omamentals, and to control indoor pests. Chlorpyrifos was first registered for termiticide use in the United States in 1980 (Racke 1993). Products are available for both professional pest control workers and homeowners. Agricultural commercial products were introduced in the mid-1970s. As a foliar pesticide for alfalfa and cotton, it is used to control aphids, armyworms, pillbugs, chinch bugs, common stalk borers, corn borers, corn earworm, corn rootworm adults, cutworms, flea beetle adults, grasshoppers, and lesser cornstalk borers. It also controls peach tree borer and overwinter scale on dormant fruit trees and is used as a slurry seed treatment for seed

corn maggot. It has additional uses as a foliar and soil applicant on sorghum, soybeans, sugarbeets, and sunflowers, and as a soil applicant for peanuts. Dursban® is used to control fire ants, ornamental plant insects, stored-product insects, and turf- and wood-destroying insects. Lorsban® is used as a soil insecticide for pillbugs, corn rootworms, cutworms, flea beetle larvae, grubs, lesser cornstalk. borer, seed corn beetle, seed corn maggot, symphylan, and wireworm on corn (Farm Chemicals Handbook 1994). At one time, it was used to kill mosquitoes in the immature, larval stage of development, a use that involved application of formulated product directly to bodies of water, but hlorpyrifos is no longer registered for this purpose (EPA 1986). Other discontinued uses are spray-dip or pour-on applications of chlorpyrifos for cattle and sheep (Racke 1993).

Formulations for chlorpyrifos include emulsifiable concentrate, dust, flowable, granular wettable powder, microcapsule, pellet, and spray. Chlorpyrifos acts on pests primarily as a contact poison, with some action as a stomach poison. It is a nonsystemic contact chemical, meaning that it acts only where it comes into direct contact with plant tissues, and is not transported to other plant parts. It interferes with the activity of acetylcholinesterase, an enzyme that is essential for the proper working of the nervous systems of both humans and insects.

There is currently no federal requirement to report sales or use of pesticides; consequently, the only figures available are estimates (Felsot 1991). From data collected from usage surveys conducted by USDA, EPA, and the Department of Food and Agriculture of the State of California, the usage of chlorpyrifos is estimated to be 7,023,190 pounds active ingredient per year (Gianessi 1986). Agricultural uses account for most of its applications. In 1982, total agricultural use of chlorpyrifos was estimated at 2.2-3.2 million kg (4.8-7.0 million pounds), and industrial uses ranged between 0.68 and 1.04 million kg (1.5-2.3 million pounds) (EPA 1982). The State of Ohio Agricultural Extension Service estimates that 36.33 metric tons (80,093 pounds) of chlorpyrifos were used in the Lake Erie Basin in 1986 (Baker and Richards 1988). In 1984, about 0.15 million kg (0.33 million pounds) of chlorpyrifos was applied to about 600,000 hectares (1.48 million acres) of wetlands in the United States for mosquito control (Odenkirchen and Eisler 1988); this use has since been discontinued.

Chlorpyrifos is used significantly in urban settings, where it has replaced chlordane and other chlorinated cyclodiene termiticides. Therefore, its use can be estimated based on former chlordane use; the annual application of chlorpyrifos for termite control is estimated at approximately 1.7 million

pounds of active ingredient (Cink and Coats 1993). Each year, the pesticides used to control structural pests account for about 15% of California's nonagricultural use of conventional pesticides. Structural pest control encompasses treatment of private residences, office buildings, schools, hotels, hospitals, restaurants, and other publicly used buildings. In 1990, 604,713 pounds of chlorpyrifos were used as structural pesticides in California, and 693,354 pounds were used in 1991 (Robinson et al. 1994). Pesticides for commercial landscape maintenance account for about 2% of nonagricultural use in California. The landscaping use figures for chlorpyrifos in 1990 and 1991 were 45,267 pounds and 32,118 pounds, respectively. Nationally, chlorpyrifos is ranked twelfth in frequency of indoor pesticide applications and fifth in frequency of outdoor pesticide applications (Robinson et al. 1994).

4.4 DISPOSAL

The recommended treatment and disposal methods for chlorpyrifos are incineration, adsorption, and landfilling (IRPTC 1989). For small amounts, the recommended disposal is adsorption onto materials such as sand and burying in locations away from domestic water supplies. For the decontamination of containers, the triple rinse and drain procedure is recommended. The use of a caustic soda-methanol or caustic soda-detergent rinse solution is also effective in decontaminating the container, but the rinse solutions must be disposed of either by incineration or burial in an area away from water supplies (IRPTC 1989).

Small-scale farm operators have a pressing need for methods to dispose of unused concentrated and dilute formulated chlorpyrifos suspensions or solutions such as rinsate. The use of solid state fermentation techniques to dispose of pesticide waste may be a viable alternative to other disposalmethods that are either too expensive or technically too sophisticated. Chlorpyrifos was evaluated in bioreactors by Berry et al. (1993), who reported that chlorpyrifos levels were reduced to 0.6% (by solvent extraction) in 290 days in wheat straw/horse manure reactors, and that leachability studies showed that of the 28 µg chlorpyrifos in the soil column, only 72 ng leached.

While not strictly a disposal method, it is worth pointing out that NaOH-methanol and sodium hypochlorite can be used to degrade (but not necessarily detoxify) chlorpyrifos. For example, on exposed surfaces, the use of caustic soda-methanol or caustic soda-detergent rinse solution can also be effective in decontaminating containers used to store chlorpyrifos, but these rinse solutions must be

disposed of either by incineration or proper burial (Dillon 1981). A full discussion of regulations regarding disposal of chlorpyrifos is given in Chapter 7.

5. POTENTIAL FOR HUMAN EXPOSURE

5.1 OVERVIEW

Chlorpyrifos enters the environment as the result of its use as a broad spectrum insecticide/acaricide for treatment of crops, lawns, ornamental plants, domestic animals, and a variety of building structures. Unintentional releases to the environment include improper indoor application, redeposition of air residues, spills, and the disposal of chlorpyrifos wastes. Indoor use by unlicensed or untrained applicators has occasionally resulted in excessive human exposure. EPA (1997) reported that most of the more serious chlorpyrifos poisonings appear to involve either the misuse or inappropriate use of the pesticide by pest control operators.

The important physical and chemical characteristics which influence the fate and transport of chlorpyrifos in the environment are its low solubility, volatility, and strong affinity for colloidal matter. Abiotic hydrolysis, photodegradation, and biodegradation are all important processes for the transformation and degradation of chlorpyrifos. Chlorpyrifos bioconcentrates to only a limited extent, and has little mobility in most soils. Chlorpyrifos exists in the atmosphere primarily in the vapor phase, but can partition to particulates. Chlorpyrifos is not persistent in water, due to volatilization and strong adsorption to particulate matter.

Indoor air, food, and soil are the environmental media with the highest degree of chlorpyrifos contamination; ambient air, groundwater, and surface water have lesser degrees of contamination. Although a large amount of chlorpyrifos is used in various environments (see Chapter 4), levels of general exposure are mediated by its limited mobility and persistence, and by environmental degradation processes.

Several subpopulations are at higher risk of exposure: workers in industries that manufacture and formulate chlorpyrifos, those who apply the insecticide, and farm workers who enter treated fields after the insecticide has been applied. Among the general population, people who use the insecticide in homes and gardens and people who ingest food exposed to chlorpyrifos are at higher risks of exposure.

Chlorpyrifos has been identified in at least 7 of the 1,428 current or former EPA National Priorities List (NPL) hazardous waste sites (HazDat 1996). However, the number of sites evaluated for chlorpyrifos is not known. The frequency of these sites within the United States can be seen in Figure 5- 1.

5.2 RELEASES TO THE ENVIRONMENT

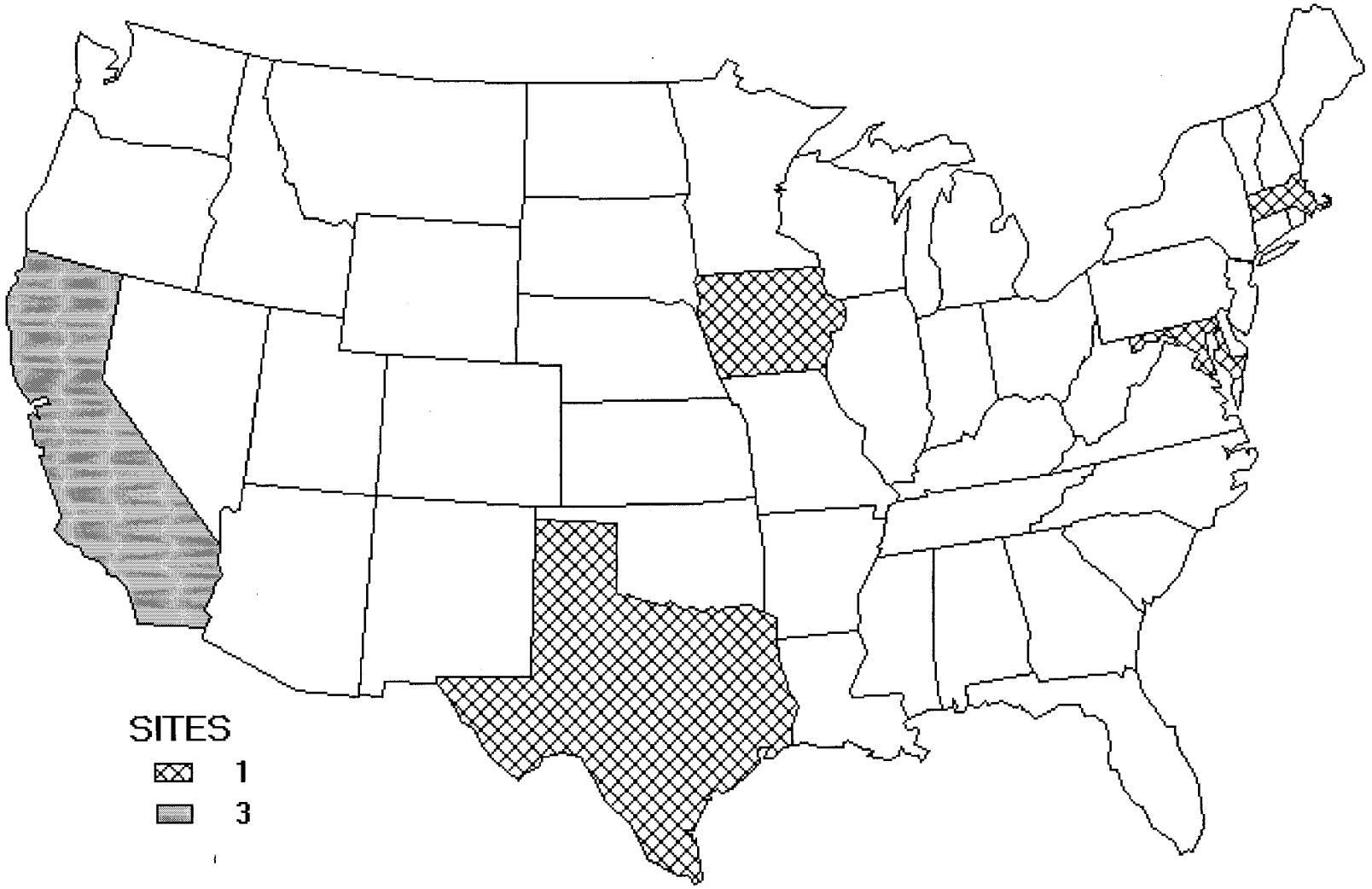
5.2.1 Air

Chlorpyrifos enters the atmosphere as a result of its use as an insecticide/acaricide. Chlorpyrifos is released to the atmosphere by volatilization during foliage or soil application by ground or air broadcast equipment (Racke 1993). Air emissions from chlorpyrifos production have been reported to be 0.5 kg per 1,000 kg (one metric ton) produced (Sittig 1980). The Toxics Release Inventory in 1992 did not require reporting of chlorpyrifos releases to air (EPA 1993c). No information was found on detections of chlorpyrifos in air at NPL hazardous waste sites (HazDat 199).

5.2.2 Water

Chlorpyrifos is released to water during foliage or soil application as an insecticide/acaricide by ground or air broadcast equipment and during subsequent runoff or leaching (Racke 1993). Leaching and runoff from treated fields, pesticide disposal pits, or hazardous waste sites may inadvertently contaminate both groundwater and surface water with chlorpyrifos. Entry into water can also occur from accidental spills, redeposition of atmospheric chlorpyrifos, and discharge of waste water from chlorpyrifos manufacturing, formulation, and packaging facilities (HSDB 1996; Racke 1993). In the past, chlorpyrifos was aerially applied to water over swamps for mosquito abatement; however, it is no longer registered for this use. No other uses are known which result in direct application to water (EPA 1986). The Toxics Release Inventory in 1992 did not require reporting of chlorpyrifos releases to water (EPA 1993c). There is also a potential for release of chlorpyrifos to water from hazardous waste sites. Chlorpyrifos has been detected in surface water samples collected at 4 of the 7 NPL sites and in groundwater samples collected at 1 of the 7 NPL sites where chlorpyrifos has been detected in some environmental medium (HazDat 1996). The HazDat information used includes data from NPL sites only.

Figure 5-1. Frequency of NPL Sites with Chlorpyrifos Contamination



Derived from HazDat 1996

5.2.3 Soil

Chlorpyrifos is released in agricultural, home, and garden soil during direct soil or foliar treatment, and from disposal of chlorpyrifos-containing wastes in hazardous waste sites (HSDB 1994). Much of the chlorpyrifos (or its metabolites) applied to foliage eventually reaches soil (Racke 1993). Soil in waste disposal sites may include manufacturing wastes containing chlorpyrifos. A primary method for disposing of liquid pesticide wastes has been the dumping of liquid materials into soil evaporation pits, ditches, and ponds. Topsoil from such discharge areas is expected to be contaminated with pesticides; the soil from one discharge pit contained chlorpyrifos at concentrations of 1,012-3,193 mg/L in the top 7.5 cm (Winterlin et al. 1989). Soil from tail water pits used for collecting irrigation runoff may also be a source of chlorpyrifos if the soil is treated with this insecticide (Kadoum and Mock 1978). Chlorpyrifos may also enter soil by redeposition of atmospheric chlorpyrifos (Racke 1992). Entry may also occur from spills during storage, transport, or equipment loading and cleaning, although the sophistication of contemporary management practices limits this amount. The Toxics Release Inventory in 1992 did not require reporting of chlorpyrifos releases to soils (EPA 1993c). Chlorpyrifos also can be released to soils and sediments from hazardous waste sites. Chlorpyrifos has been detected in soil samples collected at 3 of the 7 NPL sites and in sediment samples collected at 1 of the 7 NPL sites where chlorpyrifos has been detected in some environmental medium (HazDat 1996). The HazDat information used includes data from NPL sites only.

5.3 ENVIRONMENTAL FATE

5.3.1 Transport and Partitioning

The vapor pressure of chlorpyrifos is 1.9×10^{-5} mm Hg at 25 °C (2.5×10^{-8} atm) (Racke 1993). This suggests that while chlorpyrifos is in the atmosphere, it will exist primarily in the vapor phase but will also partition to available airborne particulate (Eisenreich et al. 1981). Experimental evidence during fog events (Glotfelty et al. 1990) supports this hypothesis. The removal rate by dry deposition is low for such compounds (Schroeder and Lane 1988); therefore, depending on its reactivity characteristics and the amount of available airborne particulate, chlorpyrifos may travel long distances in the air. The low solubility of chlorpyrifos at 1.12 mg/L at 24 °C (Felsot and Dahm 1979) indicates that dry deposition is a more important process than wet deposition.

The transport of chlorpyrifos from water to air can occur due to volatilization. Compounds with a Henry's law constant (H) of $<10^{-5}$ atm-m^3/mol may volatilize slowly from water (Lyman et al. 1990). Therefore, chlorpyrifos, with an H value of $6.6x10^{-6}$ atm-m3/mol at 25 °C (Downey 1987) may volatilize slowly from water. The dimensionless Henry's law constant (H′) or air/water partition coefficient for chlorpyrifos, as calculated from vapor pressure and solubility data, has been reported to be $5x10^{-4}$ (Glotfelty et al. 1987), $7.3x10^{-4}$ (Suntio et al. 1987), and $1.7 \pm 0.3x10^{-4}$ (Fendinger and Glotfelty 1990). Using these data, the estimated volatilization half-life from a river 1 meter deep flowing 1 m/set with a wind velocity of 3 m/sec is estimated to be 9 days (Lyman et al. 1982).

The amount of chlorpyrifos available to be volatilized from surface water is reduced by sediment adsorption. Chlorpyrifos has a strong affinity for soil colloids, as evidenced by its measured range of organic carbon-adjusted soil sorption coefficient (K_{oc}) of 973-31,000 (Felsot and Dahm 1979; Kenaga 1980; McCall et al. 1980; Racke 1993). This suggests that chlorpyrifos in natural water ecosystems adsorbs strongly to suspended solids and sediments, and that this process may transport considerable amounts of chlorpyrifos from water to particulate matter. Several studies have reported very low concentrations of chlorpyrifos in surface waters (see Section 5.4.2).

In macrophyte-dominated freshwater model ecosystems, *Elodea nutalli* vegetation adsorbed a large proportion of the dose of chlorpyrifos applied and hampered mixing of the insecticide in the water column (Brock et al. 1992). Only a relatively small proportion of the applied dose became incorporated in the sediment. In open-water model ecosystems, however, mixing was rapid and the sediment compartment, particularly its upper layer, was a sink for chlorpyrifos.

Aquatic bioconcentration factors (BCF) ranging from 1 to 5,100 for chlorpyrifos and metabolites have been determined extensively from laboratory and field studies (ASTER 1996; Cid Montafies et al. 1995; Macek et al. 1972; Mulla et al. 1973; Odenkirchen and Eisler 1988; Racke 1993). These studies suggest that chlorpyrifos bioconcentrates to varying degrees in different organisms, and with different doses and durations of exposure. It has been suggested that the BCF values determined-during short duration single-dose exposure studies may not be indicative of long-term exposure due to nonattainment of equilibrium conditions (Racke 1993). It has been observed that 5-9 days are necessary for steady-state conditions (Hedlund 1973; Welling and deVries 1992).

5. POTENTIAL FOR HUMAN EXPOSURE

The transport processes that may move chlorpyrifos from soil to other media are volatilization, leaching, runoff, and biotransfer by plants. Post-application volatilization of chlorpyrifos applied as an agricultural insecticide and subsequent atmospheric transport is thought to be a primary means by which chlorpyrifos is dispersed throughout the environment. Volatilization is affected by soil cultivation practices. Cumulative losses of chlorpyrifos by volatilization from no-till (NT) and from conventionally tilled (CT) plots were measured by Whang et al. (1993). The NT/CT flux ratio increased from a factor of about 3 on days 1 and 2 to a factor of 12 by day 26. Soil dryness did not often limit volatilization, and differences in soil moisture resulting from different tillage practices were not usually a major reason for differences between fluxes.

Volatilization rates, which result from the complex interplay between chlorpyrifos sorbed to soil, dissolved in the soil pore water, and present in the soil air spaces, can be quite variable. Chlorpyrifos (applied to the soil at 11 μg/cm^2) was captured from 3 moist soils (0.3 bar soil moisture tension, 25 °C) by blowing an airstream of 1 km/hour over the soils. The calculated flux rate ranged from 80-290 g/hectare/day during the first 3 days, with 62-89% of applied chlorpyrifos remaining after 36 hours (McCall et al. 1985). Racke et al. (1991) observed significantly less volatility over a longer exposure period with ranges of 3-39 g/hectare/day, and >90% of the applied chlorpyrifos remaining after 30 days. When applied as a foliar spray, chlorpyrifos volatilized from corn leaves rapidly. In the laboratory, 80% volatilized within 48 hours at 30 °C with a simulated wind speed of 0.8 km/hour (McCall et al. 1985). A field study confirmed the fairly rapid rate of volatilization, with an observed half-life of about 1.5 days on corn and soybean foliage (McCall et al. 1984).

Leaching studies have shown chlorpyrifos to have little mobility in soil. Laboratory leaching studies revealed that all the surface-applied residues of chlorpyrifos were confined to the upper 5 cm of several soils after elution with 20 cm of water (Harris et al. 1988; McCall et al. 1985). Field studies have confirmed this lack of mobility, with chlorpyrifos residues being confined to the upper 12 inches of soils in several trials (Fontaine and Teeter 1987; Oliver et al. 1987). The leaching and dissipation of the applied ^{14}C-chlorpyrifos in sandy soil under simulated field precipitation, drainage and temperature was less than 0.2% (Fermanich and Daniel 1991). Amounts of chlorpyrifos lethal to termites moved to a depth of at least 30 cm in decomposed granite soil from the Santa Ana River bed in Colton, California, after it was applied at 500 ppm to the top 7.62 cm of soil in a long column of 34 mm diameter and ≈130 mL of water was dripped through (Smith and Rust 1992).

5. POTENTIAL FOR HUMAN EXPOSURE

Studies indicate that runoff of chlorpyrifos is of minor environmental significance. In a study conducted in an Iowa cornfield, approximately 0.003% of 3 applications of chlorpyrifos was transported via runoff to a pond within the watershed (McCall et al. 1984). Information from irrigated environments (e.g., turf) indicates that because of the lack of erosion of soil particles, strongly sorbed chlorpyrifos is not transported via runoff (Watschke and Mumma 1989). Even during a simulated l00-year rainfall event (13.6 cm) occurring less than a week after application, only between 0.10 and 0.29% of the applied chlorpyrifos was present in runoff. In another study of runoff from turfgrass treated at 1.12 kg/hectare with irrigation applied at 150 mm/hour, no residue of chlorpyrifos was detected at 5 μg/L (minimum detection level) (Harrison et al. 1992). The movement of chlorpyrifos was studied from 1985 to 1987 in a small agricultural Saskatchewan watershed (Waite et al. 1992). In 1985-86, 3-4 million hectares of farmland were treated with insecticides at application rates as high as 1 kg/hectare to control grasshopper infestations. The frequency of occurrence and concentrations of chlorpyrifos in groundwater, surface water and runoff from spring snow melt were measured. No chlorpyrifos was found in any of the samples at detection limits of 1 ppb in 1985 and 0.1 ppb in 1986.

Spills are an important way that chlorpyrifos enters surface waters. A spill of chlorpyrifos into a marine bay resulted in initial water concentrations of up to 300 μg/L, but because of sediment sorption, dissipation, and dilution, the concentration had dropped to below detectable levels within 17 days (Cowgill et al. 1991).

Some research has shown that only very small levels of chlorpyrifos are taken up by plant roots, translocated, or metabolized by plant tissues (Kenaga et al. 1965; Smith et al. 1967). Cranberry bean plants were hydroponically grown in nutrient solutions containing 50 ppm of chlorpyrifos emulsifiable concentration. After 72 hours, only 0.07-0.1% of the radioactivity present, composed of TCP and other degradation products, had been translocated to the plant tops. In another experiment (Smith et al. 1967), one leaf of the cranberry bean plant was treated foliarly with 1 mg of chlorpyrifos. After 7 days, <1% of the chlorpyrifos applied was found in nontreated areas of the plant.

However, other researchers have found that soil-applied doses of chlorpyrifos are transported to foliage (Rouchaud et al. 1991). Cauliflower and brussels sprouts were treated with chlorpyrifos by pouring it onto soil around the stem of the plant for protection against the root fly. During plant growth, chlorpyrifos and its soil metabolites were transported from soil into the plant foliage, where it could give a secondary plant protection against the foliage insects. The foliage concentrations of the

nonsystemic chlorpyrifos was ≥1 mg/kg fresh weight during a period of about 44 days after soil treatment in brussels sprouts crops and a period of 3.5 days in cauliflower crops.

5.3.2 Transformation and Degradation

Chlorpyrifos undergoes a number of different transformation and degradation reactions in the environment as discussed in the following sections. The resulting environmental transformation products are shown in Figure 5-2.

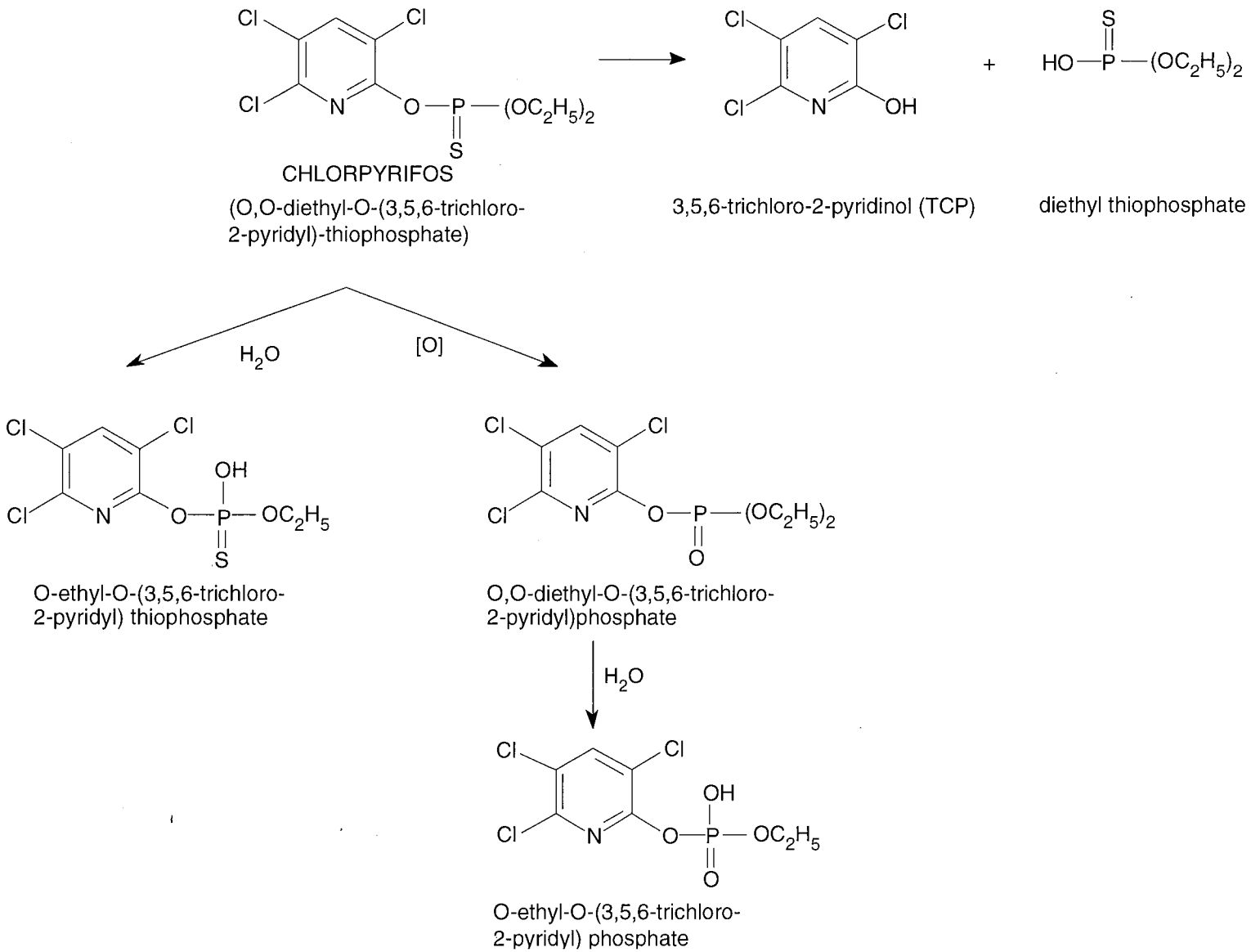
5.3.2. 1 Air

Both chlorpyrifos and its degradation product, TCP, have ultraviolet (UV) absorbencies above 295 nm, indicating their susceptibility to photodegradation by sunlight. The photodegradation half-life of chlorpyrifos in the laboratory is approximately 2.6 days (Fontaine and Teeter 1987). While in the atmosphere, chlorpyrifos will react with photochemically induced hydroxyl radicals. Its estimated halflife is 6.34 hours (Atkinson 1987).

5.3.2.2 Water

The processes primarily responsible for the transformation and degradation of chlorpyrifos in water are abiotic hydrolysis and photosensitized oxidation. Neutral hydrolysis is favored below pH 9, whereas alkaline hydrolysis dominates above pH 9 (Macalady and Wolfe 1983). Thus, both the disappearance half-life and the products are pH-dependent. Neutral hydrolysis yields O-ethyl-O-3,5,6-trichloro-2-pyridyl phosphorothioate, while alkaline hydrolysis occurs by base-catalyzed cleavage at the phosphate ester linkage to produce TCP and phosphorthioic acid. Neutral hydrolysis is pseudo-first-order kinetics, while alkaline hydrolysis is second-order kinetics (Wolfe 1988). Keeping the temperature at 25 °C, the half-life of chlorpyrifos in distilled water was 89.14 days at pH 1, and 0.01 days at pH 12.9 (Macalady and Wolfe 1983). At 20 °C, it has a half-life of 120 days at pH 6.1 and 53 days at pH 7.4 (Freed et al. 1979). The activation energy for the hydrolysis of chlorpyrifos at pH 7.4 is 14 kcal/mol, indicating its sensitivity to temperature change. Laboratory studies on the interaction of chlorpyrifos with Cu^{2+} have demonstrated metal-catalyzed hydrolysis and have provided rate constants for this pathway (Blanchet and St. George 1982).

Figure 5-2. Environmental Degradation Pathways of Chlorpyrifos



Photodegradation in water is possible since chlorpyrifos absorbs in the UV region at >295 nm; however, its relative importance as a dissipative force in the environment is unclear. Laboratory studies from artificial light sources may not be very useful for predicting environmental photodegradation kinetics (Miller and Zepp 1983). For example, chlorpyrifos in natural waters is usually very strongly sorbed to suspended particulate and bottom sediment, and thus less readily available to photolytic forces than chlorpyrifos in clear distilled water in the laboratory.

Brock et al. (1992) performed experiments using macrophyte-dominated freshwater ecosystems and open-water model ecosystems. In both systems, 50% of the chlorpyrifos dose applied had disappeared on day 8 post-treatment. In the long run, loss of chlorpyrifos was more rapid in the macrophytedominated ecosystems than in the open-water ecosystems.

Under field conditions, chlorpyrifos exhibits very short persistence in the water compartment of aquatic ecosystems, and half-lives as short as several hours have been observed. This is due to its considerable volatility from water (arising from low solubility and moderate vapor pressure) and its high association with sediment. The rate of disappearance of chlorpyrifos from river and well waters in a pH range of 8-8.5 was studied in the laboratory at a range of temperatures and under conditions of light and dark (Frank et al. 1991). The half-life for the disappearance of chlorpyrifos was 4.8 days at 21 °C and 27 days at 4 °C, indicating that temperature plays a major role in the degradation of chlorpyrifos in water. The half-life for disappearance of chlorpyrifos was 56 days in the dark and 46 days in the light at 21 °C, indicating that sunlight photolysis is not a major route of chlorpyrifos degradation in water.

The persistence of chlorpyrifos in surface water was studied (Hughes et al. 1980) by application of 10 ppb chlorpyrifos to polyethylene-lined ponds and a single natural pond inoculated with leaf litter. In early post-treatment, there was rapid partitioning to adsorption on bottom sediments and polyethylene; 30-60% disappeared from the water within 24 hours. The time for the concentration of chlorpyrifos to decline to 0.01 ppb in the polyethylene-lined pond was estimated to be 40 to >200 days compared to 18 days for the natural pond. The desorption from sediments was considerably slower from organic matter than from polyethylene. Desorption from the polyethylene contributed to residual concentrations in the water of artificial ponds for up to 18 months. Similar results were noted in an artificial lake treated with chlorpyrifos: lake water concentrations peaked 1 day after treatment at 0.9 μg/L and leveled near 0.2 μg/L after 3 weeks (Mulla et al. 1973).

First-order degradation rate constants of chlorpyrifos were determined in estuarine water and sediment/water slurry systems (Walker et al. 1988). Half-lives of chlorpyrifos in sediment/slurry systems calculated from these rate constants ranged from 12 to 30 days for the non-sterile system, and 16-51 days for the sterile system. Half-lives for the seawater-only systems ranged from 13 to 41 days for the non-sterile systems and 3.5-24 days for the sterile systems. The half-life of chlorpyrifos in seawater was 24 days in a sediment-seawater slurry (Schimmel et al. 1983). These data indicate that abiotic processes predominate in estuarine systems.

5.3.2.3 Sediment and Soil

Chlorpyrifos may undergo degradation on the surface of soils by photo-induced reactions. Laboratory photodegradation of chlorpyrifos on soil surfaces with UV light (254 nm from mercury lamps) demonstrated that three different photochemical processes (hydrolysis, dechlorination, and oxidation) take place simultaneously (Walia et al. 1988). The oxidative and dehalogenated products formed during photo-irradiation of soil undergo further photolysis to form chloropyridinols and O,O-diethyl phosphorothioic acid. The oxon is unstable; it tends to hydrolyze more rapidly than chlorpyrifos and does not accumulate in the soil. With the passage of time, the percentage of chlorinated pyridinols also decreased, suggesting that these products are mineralized in the soil under UV-photo-irradiation conditions. Under simulated sunlight conditions, the rate of photodegradation of chlorpyrifos on a leaf surface was slow. Chlorpyrifos was stable up to 10 days; then the oxon (1.5%) and the hydrolytic product, TCP (2.5%), were detected. Dehalogenated analogs of chlorpyrifos could be detected only after 15 days of constant irradiation. Under these conditions, the photo-oxidation process was more predominant than the photohydrolytic or dehalogenation process. Formation of such photoproducts on an irradiated soil surface was very fast, but the rates in the laboratory will differ from those found under environmental conditions.

Chlorpyrifos undergoes transformation in soil by the processes of abiotic hydrolysis and microbial degradation. A few studies have attempted to separate abiotic chemical hydrolysis from-microbial processes and to determine their relative importance (Miles et al. 1979, 1983). The half-lives of chlorpyrifos in muck (48% organic matter [OM]) and loam (2.7% OM) were determined in sterilized and natural soils at 3 temperatures (3, 15, and 28 °C). The results indicate that in sterile soils, chlorpyrifos is progressively more degraded by abiotic hydrolysis as the temperature increases, and that it degrades faster in sandy loam than in muck (after 24 weeks, 38 versus 68% remaining at the

highest temperature). An explanation for the soil difference may lie in the pH. The sterile loam had a pH of 6.5, whereas the sterile muck had a pH of 5.9, indicating that increasing pH increases degradation. The degradation study of chlorpyrifos in natural soil gave the same progression for increasing temperature, and it continued to degrade faster in the loam than in the muck (half-lives of 16, 6, and 2.5 weeks versus >24, 15, and 6 weeks at the respective temperatures). All half-lives were shorter in the natural soils as opposed to the sterile soils, however, indicating microbial degradation in addition to abiotic chemical hydrolysis.

Some researchers have concluded that chlorpyrifos is not catabolized (Racke and Coats 1988, 1990) because it is resistant to enhanced degradation by microbes. When chlorpyrifos is applied to fields with a soil history of chlorpyrifos use, the breakdown of chlorpyrifos is not enhanced, and is often delayed (Racke and Coats 1988; Somasundaram et al. 1989). The biotic process at work is probably co-metabolism. Patterns of persistence were observed in a variety of agricultural soils after treatment with ^{14}C-chlorpyrifos and its hydrolysis product, TCP (Racke et al. 1988). In soils with no previous history of chlorpyrifos use, significant quantities of TCP and soil-bound residues were produced, but little $^{14}CO_2$. In soils with a history of chlorpyrifos use, neither TCP nor soil-bound residues accumulated, but large quantities of $^{14}C0_2$ were produced. Direct treatment of fresh samples of each of these soils with ^{14}C-TCP resulted in rapid mineralization of TCP to $^{14}CO_2$ only in those soils with a history of prior chlorpyrifos use. The rapid mineralization of TCP in these soils was microbially mediated. It is unclear if catabolic or co-metabolic processes are predominant (Racke and Robbins 1990) in the degradation of TCP. TCP exhibited sorption (K_d) coefficients of between 0.3 and 20.3 mL/g (mean of 3.1) and calculated mean Koc coefficients for the neutral and anionic forms of 3,344 and 54 mL/g, respectively.

In a study of persistence of chlorpyrifos in a silt loam soil, the disappearance rate was fast in the first 15 days, but slowed after that. The pseudo-first-order rate constants were 0.041 day^{-1} and 0.044 day^{-1}, for the band treatment at seeding, and 0.04 day^{-1} for the drench at seeding. The calculated half-lives ranged from 15.8 to 17.3 days (Szeto et al. 1988).

5.4 LEVELS MONITORED OR ESTIMATED IN THE ENVIRONMENT

Reliable evaluation of the potential for human exposure to chlorpyrifos depends, in part, on the reliability of supporting analytical data from environmental samples and biological specimens. In

reviewing data on chlorpyrifos levels monitored in the environment, it should also be noted that the amount of chemical identified analytically is not necessarily equivalent to the amount that is bioavailable.

5.4.1 Air

Chlorpyrifos has been detected in both outdoor and indoor air; of special concern are levels in fogwater and environments receiving broadcast pesticide application, and in selected indoor environments such as poorly ventilated and artificially lit environments and the infant breathing zone (25 cm above the carpet). Selected studies documenting chlorpyrifos concentration and persistence in these environments include Anderson and Hites (1988); Fenske et al. (1990); Jackson and Lewis (1981); Leidy et al. (1992); Lewis et al. (1988); Moye and Malagodi (1987); Vaccarro (1993); and Wright et al. (1991, 1994). Special issues in these environments are discussed below.

Substantially higher chlorpyrifos concentrations were measured in the infant breathing zone than in the adult breathing zone, implying a vertical gradient with the treated carpet serving as a source of volatilized chlorpyrifos (Fenske et al. 1990). All concentrations in the infant breathing zone exceeded the National Academy of Sciences interim guideline of 10 $\mu g/m^3$. This study also indicated that broadcast applications appear to produce average levels 5-10 times higher and peak levels l-2 orders of magnitude greater than other application procedures, with peak concentrations occurring 3-7 hours after application. Following treatment in the crawl spaces, significantly more chlorpyrifos was present in the air of houses built over sand than in the air of houses built over clay soils. However, no differences were found between rooms or construction types (slab, crawl, crawl-slab) (Wright et al.1988). The air of storage rooms in commercial pest control buildings was found to have a higher concentration (220 ng/m^3) of chlorpyrifos than office rooms (126 ng/m^3). The same study detected levels of chlorpyrifos from 20 to 1,488 ng/m^3 in the air of 6 food preparation serving areas following application of a 0.5% emulsion spray into cracks and crevices, although concentrations dropped considerably over 24 hours in all areas. Chlorpyrifos was detected in homes and pest control offices and vehicles, with residues ranging from 0.1 to 5 $\mu g/m^3$ (Leidy et al. 1992). Air concentrations in commercial pest control vehicles ranged from 9 to 221 ng/m^3 (Wright and Leidy 1980).

High fogwater concentrations (320-6,500 ng/L) were reported at Parlier, Corcoran, and Lodi, California, relative to air concentrations (0.6-14.7 ng/L), with enrichment factors of 160-260 (Plimmer

1992). Other researchers have found similar enrichment factors (Glotfelty et al. 1987, 1990). Enrichment was attributed to the effect of temperature correction, colloidal organic matter, and adsorption. The enrichment factor has also been correlated to hydrophobicity, as indicated by K_{ow} (Valsaraj et al. 1993).

There is less evidence of general contamination of ambient air, although residues have been detected. Ambient air monitoring at 10 U.S. locations in 1980 resulted in 14 detections from 123 samples, with a maximum of 100 ng/m^3 and an arithmetic mean of 2.1 ng/m^3 (Carey and Kutz 1985). This same study reported 2 detections of chlorpyrifos from 11 air samples in Pekin, Illinois, in 1980. Ambient air and wet-deposition monitoring of chlorpyrifos in California indicated that atmospheric transport is occurring from the Central Valley, where chlorpyrifos is used agronomically, to the Sierra Nevada Mountains; concentrations decrease with distance from the source area and elevation (Zabik and Seiber 1993). A maximum concentration of 6.5 ng/m^3 was recorded in the valley; the maximum value midslope was 0.083 ng/m^3. A loading rate of 0.8 μg/m^2 to Sierra National Park was calculated.

5.4.2 Water

Chlorpyrifos has been detected in groundwater and surface water, but only rarely, and generally well below levels of concern. Hallberg (1989) reported that chlorpyrifos was detected (concentrations unspecified) in 0.2% of 334 samples from groundwater used for public drinking water supply in Illinois, but was not detected in 15 Iowa samples. This same study detected chlorpyrifos in 45% of the wells in the vicinity of agrochemical dealers, and in 1.4% of farm water supply wells. In a survey of surface waters in southern Ontario from 1975-77, chlorpyrifos was detected in 3 of 949 samples from 11 agricultural watersheds (Braun and Frank 1980). Krill and Sonzogni (1986) reported no detections of chlorpyrifos in groundwater sampling of 358 wells in Wisconsin. In a study of 54 wells in California, Maddy et al. (1982) found no detectable levels of chlorpyrifos. Pionke et al. (1988) and Pionke and Glotfelty (1989) found no detectable levels of chlorpyrifos in a study of 21 wells and 2 springs (detection limit of 4 ng/L) in Pennsylvania. Maddy et al. (1982) found no detectable levels of chlorpyrifos in a study of 53 wells in California. In an intensive monitoring effort, Richards and Baker (1993) detected chlorpyrifos in 0-l .06% of 750 samples for each of 7 tributaries to Lake Erie from 1983 to 1991. A maximum chlorpyrifos concentration of 480 μg/kg in runoff from irrigated cropland in California was reported by Leonard (1990). Total seasonal losses as a percentage of application were 0.02-0.24, and were attributed to aerial application during irrigation. Chlorpyrifos

detections were not reported as part of the national surface water monitoring program for 1976-80 (Carey and Kutz 1985).

5.4.3 Sediment and Soil

Limited data on chlorpyrifos residues in soils or sediments were located. At a detection limit of 0.01 mg/kg, chlorpyrifos was not detected in sediment samples collected from Lakes Superior and Huron, including Georgian Bay, in 1974 (Gloschenko et al. 1976). Chlorpyrifos detections were not reported in sediments as part of the national surface water monitoring program for 1976-80 (Carey and Kutz 1985). Soil evaporation pits, ditches, and ponds have been used to dispose of liquid pesticide wastes in California (Winterlin et al. 1989). A core soil sample taken from one such pit in northern California contained detectable levels of chlorpyrifos to a depth of 67.5 cm (Winterlin et al.1989).

5.4.4 Other Environmental Media

The Food and Drug Administration (FDA) identified chlorpyrifos in four grain samples and in four samples of animal feed in 1975 (Duggan et al. 1983). The FDA's pesticide residue monitoring program for domestic and imported food commodities detected chlorpyrifos 33 times in 1,044 samples in unspecified foods at unspecified concentrations during fiscal years 1978-82 and 295 times from 3,744 samples during fiscal years 1982-86 (Yess et al. 1991a, 1991b). From October 1, 1981, to September 30, 1986, the FDA Los Angeles District Laboratory detected chlorpyrifos in 1,969 of 19,851 samples of domestic and imported food and feed commodities (Luke et al. 1988). Chlorpyrifos was detected in 440 of 4,916 samples analyzed as part of the FDA Total Diet Study between 1986 and 1991. As part of the FDA's Pesticide Monitoring Program for domestic and imported foods, chlorpyrifos residues have been detected during 1988-89, 1989-90, 1990-91, and 1991-92 (FDA 1990, 1991, 1992, 1993). Chlorpyrifos was detected in domestic feed, lavender, lettuce, cantaloupe, peanuts, bell peppers, summer squash, and cherry tomatoes; and in imported apples, green beans, cabbage, coriander, cucumbers, eggplant, feijoa, kiwi, green leaf lettuce, cantaloupe, honeydew, nectarine, Chinese peas, peaches, peppers, spinach, squash, tomatillos, and tomatoes (Hundley et al. 1988). In the FDA's Revised Market Basket Study (FDA 1995), ready-to-eat foods were analyzed for pesticides and industrial chemicals repetitively for 10 years (1982-91). During that period, 37 market baskets, each containing 234 food items, were collected. Chlorpyrifos was detected in 121 of the food

items a total of 718 times; the average concentration found was 0.0036 μg/g (ppm). Gartrell et al.(1986) found chlorpyrifos in meat, fish and poultry, grain and cereal products, garden fruits, oils and fats, and sugar. Chlorpyrifos was detected in 121 different domestic foods (0.9% of samples) in 1988 and 128 domestic foods (1% of samples) in 1989 by state regulatory monitoring (Minyard et al. 1991). In a study of processed foods imported into Hawaii from western Pacific rim countries, chlorpyrifos was detected in oriental-style noodle soup and roasted peas at concentrations of 4.7 ppb and 10.95 ppb, respectively (Gans et al. 1994). In a pesticide residue screening program conducted in 1989-91 in San Antonio, Texas, on 6,970 produce samples, chlorpyrifos was detected in 41 produce samples (lemons, oranges, peppers, turnips), with a detection limit of 0.25 ppm (Schattenburg and Hsu 1992). In a study of pesticide residue contamination of processed milk-based and soy-based infant formula, chlorpyrifos was not detected (Gelardi and Mountford 1993). However, in a study of pesticide residues in cornposited milk, chlorpyrifos was found in 23 of 806 composite samples (Trotter and Dickerson 1992).

The EPA Office of Water has recommended that chlorpyrifos residues be monitored by states in their fish and shellfish contaminant monitoring programs in watersheds where this pesticide has been or is currently used extensively in agriculture (EPA 1993c. While no fish or shellfish consumption advisories are currently in effect for chlorpyrifos, this contaminant has not been widely monitored in state fish contaminant monitoring programs or the U.S. Fish and Wildlife Service National Contaminant Biomonitoring Program (EPA 1993c). In a national study, EPA (1992a) did detect chlorpyrifos in fish in 26% of 362 sites, with mean and maximum concentrations of 4.09 ng/g and 344 ng/g, respectively.

5.5 GENERAL POPULATION AND OCCUPATIONAL EXPOSURE

The general population is exposed to chlorpyrifos primarily by inhaling indoor air and ingesting food containing chlorpyrifos, and through skin contact during or after pesticide application. Chlorpyrifos has been very infrequently detected in ambient air, and only at very low concentrations (see Section 5.4.1). It is not anticipated that the general population would experience substantial levels of exposure by inhaling ambient air. Chlorpyrifos has rarely been detected in drinking water (see Section 5.4.2), and consumption of chlorpyrifos-contaminated drinking water is not considered a significant exposure route for the general population.

Chlorpyrifos has been detected in some foods (see Section 5.4.4), so ingestion may be a route of exposure for the general population. The FDA has estimated daily food intakes of chlorpyrifos for different age/sex groups in the United States. The FDA estimated the dietary intake of chlorpyrifos for a 14-16-year-old male in the United States to be 3.4 ng/kg body weight/day, which is much lower than the Food and Agricultural Organization of the United Nations/World Health Organization's (FAO/WHO) acceptable daily intake (ADI) of 10 μg/kg body weight/day and ATSDR's intermediate oral MRL and EPA's RfD of 3 μg/kg body weight/day (FDA 1992; IRIS 1994).

Other than during home and garden insecticide application, exposure of the general public to chlorpyrifos through skin contact is not anticipated.

The Non-Occupational Exposure Survey (NOES) conducted by NIOSH from 1981 to 1983 on the number of workers and the number of facilities where workers could be potentially exposed to chlorpyrifos in the United States estimated that 911 janitors and cleaners in meat packing plants, and bread, cake, and related product industries; 10,452 pest control workers; and 41 groundskeepers and gardeners in the medical industry were potentially exposed (NOES 1994). The American Conference of Governmental Industrial Hygienists (ACGIH) (1993-94) recommends that workplace air levels of chlorpyrifos not exceed 0.2 mg/m^3 as a time-weighted average (TWA) for an 8-hour workday, 40-hour workweek and not exceed a 0.6 mg/m^3 short-term exposure limit (STEL). The STEL is a 15-minute TWA exposure which should not be exceeded during a workday, even if the 8-hour TWA is within the threshold limit value (TLV)-TWA; also exposure should not be >15 minutes and should occur not more than 4 times per day.

Workers involved in the manufacture, formulation, handling, or application of chlorpyrifos, or those involved in the disposal of chlorpyrifos-contaminated wastes are likely to be exposed to higher concentrations by dermal contact and inhalation than the general population. Persons working with plants that have been previously treated with these compounds also can be exposed by absorption through the respiratory system or skin (Aprea et al. 1994). A study of pet handlers responsible for flea control in California in 1987 indicated that chlorpyrifos was associated with increased frequency of blurred vision, flushing of skin, and a decrease in urination (Ames et al. 1989). In a study of airborne and surface concentrations of chlorpyrifos after application in offices, Currie et al. (1990) found airborne concentrations peaked 4 hours after application at 27 $\mu g/m^3$, and surface residue concentrations peaked at 5.9 ng/cm^2 48 hours after application. Airborne levels were found to be

lower in furnished offices than unfurnished offices. When granular chlorpyrifos at 0.75 active ingredient per acre was applied to a field by air, the estimated inhalation exposure to chlorpyrifos was 0.02 mg per 8-hour day for the pilot and 0.03 mg per 8-hour day for the ground staff (Myram and Forrest 1969). The estimated inhalation exposure to chlorpyrifos for workers using ground machines was 0.33 mg per 8-hour day (Myram and Forrest 1969).

Hodgson et al. (1986) reported symptoms of organophosphate intoxication among five office workers after chlorpyrifos treatment for termites. The duration of symptoms and erythrocyte cholinesterase levels over time suggested redistribution of the active ingredient after absorption to a second body compartment, with subsequent slow release into the bloodstream. Estimated potential dermal exposure (i.e., unprotected by clothing) of three greenhouse workers in Florida ranged from 17,500 to 24,000 μg/hour (Stamper et al. 1989), with highest exposure to applicators' legs. Tyvek® protective clothing afforded 89%, ±5% protection.

In a study of termiticide applicator exposure in eight North Carolina homes, exposures of 0.1-98 $\mu g/m^3$ were reported. Exposure levels were higher in houses constructed over a crawl-space (Wright et al. 1988). The NOES reported detectable levels of chlorpyrifos in indoor, outdoor, and personal air in Jacksonville, Florida, and in Springfield/Chicopee, Massachusetts (Whitmore et al.1994). Concentrations tended to be highest in summer, lower in spring, and lowest in winter. Indoor and personal air concentrations were generally higher than outdoor concentrations. Of 11 carpets sampled in the study, all had detectable levels of chlorpyrifos in carpet dust, (mean concentration of 5.8 μg/g), suggesting that infants and toddlers may be at higher risk of exposure. NAS/NRC (1982) recommends that air levels in houses not exceed 10 μg chlorpyrifos/m^3. Measurements of pesticides or their metabolites in human biological specimens, such as urine, are considered an appropriate way of approximating total pesticide exposure through all routes of entry into the body. As part of the National Health and Nutrition Examination Survey III (NHANES III), urine samples were collected from approximately 1,000 adults ranging in age from 20 to 59 years. These individuals represented a relatively board spectrum of the U. S. population, including individuals from both sexes-and different age groups, races/ethnicities, urban/rural residences, and regions of the country (Needham et al. 1995). Hill et al. (1995) examined the ranges of pesticide residues found in the urine of approximately 1,000 U.S. adults and found that 3,5,6-trichloro-2-pyridinol (TCP), considered a fairly specific metabolite and indicator of exposure to chlorpyrifos or chlorpyrifos-methyl, was present at detectable levels in 82% of the (993) individuals examined. Further, 31% of those subjects had urinary TCP concentrations of

5 μg/L or greater. This was consistent with the report of Bartele and Kastl (1992) that TCP was present in the pooled urine of unexposed control subjects at a concentration of 5 μg/L.

5.6 POPULATIONS WITH POTENTIALLY HIGH EXPOSURES

Workers in industries that manufacture and formulate chlorpyrifos and applicators of the insecticide are at higher risk than the general population for chlorpyrifos exposure. Farm workers who enter treated fields after insecticide application may also be exposed to chlorpyrifos at higher levels than the general population. Those who use the insecticide for homes and gardens are also at higher risk of exposure to chlorpyiifos. Although no investigative evidence from the hazardous waste sites was located, it is likely that people who live near hazardous waste sites containing chlorpyrifos wastes are at higher risk of exposure to chlorpyrifos.

5.7 ADEQUACY OF THE DATABASE

Section 104(i)(5) of CERCLA, as amended, directs the Administrator of ATSDR (in consultation with the Administrator of EPA and agencies and programs of the Public Health Service) to assess whether adequate information on the health effects of chlorpyrifos is available. Where adequate information is not available, ATSDR, in conjunction with the NTP, is required to assure the initiation of a program of research designed to determine the health effects (and techniques for developing methods to determine such health effects) of chlorpyrifos.

The following categories of possible data needs have been identified by a joint team of scientists from ATSDR, NTP, and EPA. They are defined as substance-specific informational needs that if met would reduce the uncertainties of human health assessment. This definition should not be interpreted to mean that all data needs discussed in this section must be filled. In the future, the identified data needs will be evaluated and prioritized, and a substance-specific research agenda will be proposed.

5.7.1 Identification of Data Needs

Physidal and Chemical Properties. As seen in Table 3-2, the relevant physical and chemical properties of chlorpyrifos are known (HSDB 1994; Sanbom et al. 1977), and it is possible to predict

the environmental fate and transport of chlorpyrifos based on K_{ow} K_{oc} and H. Therefore, further data acquisition and research are not recommended as a high-priority activity.

Production, Import/Export, Use, Release, and Disposal. Knowledge of production and use data for a chemical is important in predicting its potential for environmental contamination and human exposure. Since chlorpyrifos is produced by two manufacturers (SRI 1994), to maintain confidentiality, its recent production volume is not known. Similarly, data concerning the import and export volumes for chlorpyrifos in recent years have not been located. There is currently no federal requirement to report the use of chlorpyrifos. The most recent estimates of its yearly use in the United States were published in 1986 (Gianessi 1986). Therefore, more current estimates of use and projected trends are needed. No information in the available literature was located that indicates the use of chlorpyrifos in any consumer products other than edible crops and vegetables during and after their planting. Although some information regarding the disposal of wastes containing chlorpyrifos is available, more detailed and recent information would be helpful. The standards promulgated by the EPA for the disposal of wastes containing chlorpyrifos are available (Berlow and Cunningham 1989).

According to the Emergency Planning and Community Right-to-Know Act of 1986, 42 U.S.C. Section 11023, industries are required to submit chemical release and off-site transfer information to the EPA. The Toxics Release Inventory (TRI), which contains this information for 1992, became available in May of 1994. This database will be updated yearly and should provide a list of industrial facilities and emissions. However, no TRI data were located for chlorpyrifos because this chemical is not required to be reported. As with most pesticide agents, it is virtually impossible to make decent quantitative estimates of the amounts of chlorpyrifos produced, used, disposed, imported and exported. This presents some fundamental problems in making more than the most general sorts of risk assessments. Improved information for any of these categories is considered a major data need.

Environmental Fate. Information regarding the fate of chlorpyrifos in air was limited in the literature. Although the available data indicate that the concentration of chlorpyrifos in air will be low (Carey and Kutz 1985), more information would help predict the residence time and distance of its aerial transport. Knowledge about the fate of chlorpyrifos in water is also limited. Although it has been estimated that sorption onto particulates and settling into the sediment are important for chlorpyrifos in water, more information regarding the relative importance of sorption for removal of chlorpyrifos from water to sediment would be helpful. There is some evidence in the literature

regarding the mobility of chlorpyrifos in soil. Additional information on the degradation of chlorpyrifos in water and air and the fate of the degradation products in soil would be helpful.

Bioavailability from Environmental Media. Available information regarding the rate of chlorpyrifos absorption following inhalation, oral, or dermal contact has been discussed in Section 2.3, Toxicokinetics. Although no data on the bioavailability of chlorpyrifos from contaminated air are available, the bioavailability from inhalation exposure is expected to be high because chlorpyrifos is likely to be present in the vapor phase and not in the particulate phase in the adsorbed state. Similarly, no data on the bioavailability of chlorpyrifos from water, soil, or plant material are available; however, chlorpyrifos is adsorbed rather strongly to soil. Since the part that remains adsorbed to soil or sediments may be, at most, partially bioavailable, chlorpyrifos is expected to have reduced bioavailability from soil and water. Data on the bioavailability of chlorpyrifos from actual environmental media and the difference in bioavailability for different media need further development.

Food Chain Bioaccumulation. Measured BCF values for chlorpyrifos are available for a large number of aquatic invertebrate and fish species (Odenkirchen and Eisler 1988; Racke 1993). Research on accumulation of chlorpyrifos applied to soils in the roots, stems, and leaves of plants has also been undertaken (Rouchaud et al. 1991).

Exposure Levels in Environmental Media. A number of studies have been conducted dealing with chlorpyrifos concentrations in indoor air. Although some data on the levels of chlorpyrifos in ambient air are available (Carey and Kutz 1985), these data are neither current nor general enough to estimate inhalation exposure to chlorpyrifos for the general population in the United States. Limited data on the level of chlorpyrifos in drinking water were located in the literature. More recent data regarding the levels of chlorpyrifos in ambient air, drinking water, and soil are needed. Data on chlorpyrifos levels in food and recent estimates of the human intake of chlorpyrifos from foods are available (Duggan et al. 1983; FDA 1990, 1991, 1992, 1993; Gelardi and Mountford 1993; Gunderson 1988; Luke et al. 1988; Schattenburg and Hsu 1992; Yess et al. 1991a, 1991b).

Reliable monitoring data for the levels of chlorpyrifos in contaminated media at hazardous waste sites are needed so that the information obtained on levels of chlorpyrifos in the environment can be used

in combination with the known body burden of chlorpyrifos to assess the potential risk of adverse health effects in populations living in the vicinity of hazardous waste sites.

Exposure Levels in Humans. Aside from the NHANES III and Hill et al. (1995) data, no other quantitative information on chlorpyrifos levels in human tissues and body fluids for a control population, populations near hazardous waste sites, or occupationally exposed groups were located. Additionally, data on the levels of chlorpyrifos and its metabolites in body tissues and fluids in symptomatic, exposed individuals, as well as RBC and plasma ChE activity levels in these persons, are needed to correlate exposure levels with adverse symptoms and to identify levels of ChE inhibition associated with the onset of toxic manifestations. One potential source of this information is the American Association of National Poison Control Centers.

Exposure Registries. No exposure registries for chlorpyrifos were located. This substance is not currently one of the compounds for which a subregistry has been established in the National Exposure Registry. The substance will be considered in the future when chemical selection is made for subregistries establishment. The information that is amassed in the National Exposure Registry facilitates the epidemiological research needed to assess adverse health outcomes that may be related to exposure to a substance.

5.7.2 Ongoing Studies

As part of the National Pesticide Impact Assessment Program, research is in progress at North Carolina State University (Leidy) to study the movement of herbicides into poorly drained soils of the Tidewater region of North Carolina and to determine the dislodgeable residue of chlorpyrifos from carpet samples.

Research is in progress at the University of Florida, Belle Glade (Snyder) to quantify organophosphate losses in percolate, retention in soil and thatch, and removal in grass clippings.

Research is in progress at the University of Florida, Gainesville (Moye and Wheeler), Texas A&M (Plapp), and Clemson (Camper) to determine the metabolic fate of chlorpyrifos in different media.

Researchers at the University of Puerto Rico (Singmaster and Acin-Diaz) are determining the dissipation and persistence of chlorpyrifos in surface and vadose-zone soils and water.

The USDA Agricultural Research Service (ARS) (Wauchope) is determining chlorpyrifos residues for 22 minor food crops at Tifton, Georgia, 7 crops at Yakima, Washington (Toba), and chlorpyrifos residues in coffee in Puerto Rico (Acin-Diaz, Liu, Armstrong).

The USDA-ARS in Riverside, California (Spencer and Yates) is studying water and pesticide management systems for minimizing groundwater and air contamination, as well as the persistence (fate and transport) of chlorpyrifos (Gaston).

The USDA-ARS in Beltsville, Maryland (Wright and Hapeman) are quantifying chlorpyrifos volatilization, transport, partitioning, and deposition.

The University of Nevada at Reno (Seiber), with funding from the U.S. Department of Agriculture, is studying the aerial transport and deposition of organophosphate pesticides, including chlorpyrifos, in Sierra Nevada forests.

The National Taiwan University (Hsu and Epstein), with funding from the USDA, is investigating the effects of different processing/cooking variables on chlorpyrifos residues in meat and poultry products.

Research is in progress at the University of Nebraska (Shea) to determine the mobility and bioavailability of chlorpyrifos in soil and at Iowa State University to compare degradation kinetics at high as opposed to low concentrations, persistence of TCP, and effect of temperature and moisture on degradation of chlorpyrifos (coats).

The U.S. Department of Energy (DOE) is funding a cooperative research and development agreement (CRADA) between Argonne National Laboratory (Kakar), the University of Notre Dame, and COGNIS, Inc., to study the biodegradability of pesticides by direct enzyme treatment.

The University of California at Davis (Kilgore), with funding from the U.S. Department of Agriculture, is developing methods to measure exposure, ab,sorption, and toxicity of pesticides to

workers and is preparing guidelines for best management practices to reduce worker exposure to pesticides.

6. ANALYTICAL METHODS

The purpose of this chapter is to describe the analytical methods that are available for detecting, measuring, and/or monitoring chlorpyrifos, its metabolites, and other biomarkers of exposure and effect to chlorpyrifos. The intent is not to provide an exhaustive list of analytical methods. Rather, the intention is to identify well-established methods that are used as the standard methods of analysis. Many of the analytical methods used for environmental samples are the methods approved by federal agencies and organizations such as EPA and the National Institute for Occupational Safety and Health (NIOSH). Other methods presented in this chapter are those that are approved by groups such as the Association of Official Analytical Chemists (AOAC) and the American Public Health Association (APHA). Additionally, analytical methods are included that modify previously used methods to obtain lower detection limits, and/or to improve accuracy and precision.

6.1 BIOLOGICAL SAMPLES

Methods for the determination of chlorpyrifos and its metabolites are shown in Table 6- 1. Chlorpyrifos has been measured in human whole blood, plasma, and urine at concentrations as low as 10 ppb (Drevenkar et al. 1994; Jitsunari et al. 1989; Nolan et al. 1984). The chlorpyrifos oxygen analog (oxon) has been reported to be recoverable from serum and urine by hexane extraction, but no limit of detection (LOD) or recovery was reported (Drevenkar et al. 1993). The chlorpyrifos metabolite TCP has been measured at concentrations as low as 0.5 ng/mL weight per volume (0.5 ppb, w/v) in human blood and urine (Bartels and Kastl 1992; Jitsunari et al. 1.989; Nolan et al. 1984). The hydrolysis product diethyl phosphate (DEP) has been measured in urine and plasma (Drevenkar et al.1994; Takamiya 1994) and the hydrolysis product diethylthiophosphate (DETP) has been measured in plasma (Drevenkar et al. 1994) with LODs of approximately 50 ppb. Chlorpyrifos and its oxon can be extracted directly into organic solvent while TCP, DEP, and DETP can be isolated after acid hydrolysis of the conjugated forms. Chlorpyrifos and its oxon can be determined directly using gas chromatography (GC) and selective detection methods (see below). The metabolites TCP, DEP, and DETP are typically derivatized to improve the chromatography and, hence, detectability. No methods were found for chlorpyrifos and its metabolites in human tissue, but methods have been reported for animal tissue (see Table 6-2) (Brown et al. 1987; Clabom et al. 1968; Dishburger et al. 1977; Ivey and Clabom 1968; Lino and Noronha da Silveira 1994) and could most likely be applied to human tissues.

Table 6-1. Analytical Methods for Determining Chlorpyrifos and Metabolites in Biological Samples

Sample matrix	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Blood, urine (chlorpyrifos and TCP)	Blood: Chlorpyrifos extraction with acetone and solvent exchanged to hexane. Water was removed from the extract followed by clean-up using silica gel. TCP was recovered via SPE from separate aliquot of acidified blood. TCP elution from SPE with methanol then extraction into benzene and derivatization with N,O-bis(trimethylsilyl)acetamide. Urine: Chlorpyrifos extraction with hexane. Hydrolysis of conjugates of TCP with H_2SO_4 at 90 °C for 1 hour. TCP isolation via SPE, extraction into benzene, and derivatization as for blood.	Chlorpyrifos: GC/FPD; TCP: GC/ECD	Chlorpyrifos: No data; TCP: 10 ng/mL (10 ppb, w/v)	Chlorpyrifos: No data; TCP: 91.5% (4% RSD) at 0.1 µg/mL (0.1 ppm, w/v)	Jitsunari et al. 1989; Nolan et al. 1984
Urine (TCP)	TCP isolation from urine by acid hydrolysis of urine aliquots followed by extraction with diethyl ether. Residues dissolved in *o*-xylene followed by derivatization with N-(*tert*-butyldimethylsilyl)-N-methyl-trifluoroacetamide.	GC/NCIMS	0.5 ng/mL (0.5 ppb, w/v)	Relative recoveries 80.6 to 89.9% over concentration range of 4.1 to 411 ng/mL of urine	Bartels and Kastl 1992
Urine (DEP)	Inorganic phosphate removal by addition of $Ca(OH)_2$. DEP isolation using ion exchange and derivatization to pentafluorobenzyl derivative.	GC/FPD	No data	149% (9% RSD) at 0.50 ppm	Takamiya 1994

Table 6-1. Analytical Methods for Determining Chlorpyrifos and Metabolites in Biological Samples (continued)

Sample matrix	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Plasma (chlorpyrifos, DEP, DETP)	Chlorpyrifos extraction into hexane. DEP and DETP were recovered from hexane-extracted plasma as follows: plasma saturation with NaCl, acidification with 6N HCl, and extraction with diethyl ether. DEP and DETP methylation using diazomethane.	Chlorpyrifos: GC/ECD; DEP, DETP: GC/AFID	50 ng/mL (50 ppb, w/v)	DEP: 97% (3% RSD) at concentrations ≥ 2 µg/mL; DETP: 97% (11% RSD) at concentrations ranging from 0.1 to 2.8 µg/mL	Drevenkar et al. 1994
Serum and urine (chlorpyrifos, chlorpyrifos oxon, DEP, DETP)	Chlorpyrifos and its oxon recovered via extraction with hexane. Extracted sample was acidified and saturated with NaCl followed by extraction with diethyl ether. DEP and DETP derivatization with diazomethane.	GC/MS	No data	No data	Drevenkar et al. 1993

AFID = alkali flame ionization detector; DEP = diethyl phosphate; DETP = diethyl thiophosphate; GC = gas chromatography; ECD = electron capture detector; FPD = flame photometric detector; MS = mass spectrometry; NCIMS = negative ion chemical ionization mass spectrometry; TCP = 3,5,6-trichloro-2-pyridinol

Table 6-2. Analytical Methods for Determining Chlorpyrifos and Transformation Products in Environmental Samples

Sample matrix[a]	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Air	Known volumes of air drawn through XAD-2 adsorbent. Desorption with toluene.	GC/FPD (OSHA Method 62)	0.23 ppb (mole/mole); 0.003 mg/m^3	96.6 (5.3% standard error at 0.014 ppm)	OSHA 1986
Air	Known volumes of air drawn through polyurethane foam (PUF). Desorption via Soxhlet extraction using 5% diethyl ether in hexane. Extract volume reduction and further clean-up using Florisil if needed.	GC/ECD (EPA Method TO-10) May also use GC/FPD, GC/NPD, GC/MS	Approximately 0.01 µg/m^3 (0.7 ppt, mole/mole) This limit depends on the sampling volume	87 (20% RSD) for 10–1,000 ng/m^3 concentration and 24 h sampling	EPA 1988b
Air, surfaces	Air: Known volume of air pulled through ORBO-44 tubes (Supelpak 20) and elution with toluene. Surfaces: wiping with surgical gauze moistened with distilled water. Gauze extraction with toluene.	GC/ECD	Air: 83 ng/m^3 (5.8 ppt, mole/mole) Surface wipes: 0.6 ng/cm^2	Air: 85 (SD=6); Wipes: 84 (SD=10)	Fenske et al. 1990
Drinking Water (chlorpyrifos and TCP)	Chlorpyrifos: Water extraction with hexane. Water removal from extract followed by volume reduction. TCP: Water acidification, NaCl addition, and extraction with benzene. Water removal from extract followed by volume reduction.	TLC	100 ng/L or 100 ppb (w/v) for chlorpyrifos; 25 ng/L or 25 ppb (w/v) for TCP	Chlorpyrifos: 87 (8% RSD) at 5 ppb; TCP: 84 (5% RSD) at 5 ppb	Sherma and Slobodien 1984
Well water (drinking water)	Direct injection of 20 µL onto GC retention gap.	GC/ECD	<0.9 ppb (w/v)	95 (16% RSD) at 0.9 ppb	Gerhart and Cortes 1990

Table 6-2. Analytical Methods for Determining Chlorpyrifos and Transformation Products in Environmental Samples (continued)

Sample matrix[a]	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
River water, fish	Water: Water passage through C_{18} SPE cartridge and analyte elution with ethyl acetate. Solvent removal and redissolution in ethyl acetate. Fish: Sample lyophilization and Soxhlet extraction with ethyl acetate. Extract clean-up using SPE and GPC.	GC/NPD, GC/MS, GC/NCIMS	Water: 0.1 µg/L (0.1 ppb, w/v) NPD; 0.02 µg/L (0.02 ppb, w/v) NCIMS. Fish: 2 ng/g (2 ppt, w/w) NCIMS	Water: 94 (4% RSD) at 10–15 µg/L. Fish: 92–136 at 0.1 µg/g	Lacorte et al. 1993
Surface water	Water passage through XAD-2 and XAD-7 resins and analyte elution with methylene chloride. Internal standard addition, water removal and extract concentration.	GC/Ion Trap MS	0.005 ppb (w/v) or 5 ng/L	86.7 (17% RSD)	Mattern et al. 1991
Surface water	Water passage through C_8 SPE cartridge and elution of analytes with methanol.	HPLC/UV	5.0 ppb (w/v) or 5 µg/L	93 (14% RSD)	Bogus et al. 1990
Waste water	Extraction using methylene chloride. Water removal, solvent exchange to hexane and extract volume reduction.	GC/NPD or GC/FPD (P mode) (EPA Method 622)	0.3 µg/L (0.3 ppb, w/v)	98 (5.5% RSD over concentration range 1–50 µg/L)	EPA 1992b
Groundwater, soil, sludges, wastes	Aqueous samples: Extraction using methylene chloride; water removal and extract volume reduction. Soils, sludges, wastes: Extraction (sonication or Soxhlet) using methylene chloride after mixing sample with sodium sulfate. Additional clean-up using Florisil if needed.	GC/NPD or GC/FPD (EPA Method 8140); GC/MS (EPA Method 8270)	3 µg/L (3 ppb, w/v) for groundwater; 3 mg/kg (3 ppm, w/w) for high level soil and sludges	98 (5.5% RSD)	EPA 1986a (Method 8140); EPA 1986b (Method 8270).

Table 6-2. Analytical Methods for Determining Chlorpyrifos and Transformation Products in Environmental Samples (continued)

Sample matrix[a]	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Groundwater, soil, wastes	Extraction of aqueous samples at neutral pH using methylene chloride, water removal, and volume reduction. Extraction of solid samples with methylene chloride/acetone. Additional clean-up using Florisil if needed.	GC/NPD or GC/FPD (EPA Method 8141A)	0.7 µg/L (0.7 ppm, w/v) for groundwater; 5 mg/kg (5 ppm, w/w) for water-immiscible wastes	89±6% from water at 1.56 µg/L; 79±7% from soil at 52 µg/kg	EPA 1992a
Pesticide formulations (chlorpyrifos, TCP)	Liquids: Weighing sufficient sample to contain ca. 80 mg into vial and addition of 25 mL of acetonitrile containing 1,4-dibromonaphthalene (internal standard). Solids: As for liquids with added filtration step before analysis.	HPLC/UV	No data	No data	Helrich 1990a
Turkey and chicken (muscle, skin, heart, gizzard, brain, liver, fat)	Extraction of 250 mg of ground sample ground with petroleum ether. Water removal using sodium sulfate followed by centrifugation.	GC/ECD	0.05 ppm (w/w)	79–99 (at 0.05 and 0.10 ppm, w/w)	Hunt et al. 1969
Fatty and non-fatty foods (eggs, pasta)	Homogenization of sample with acetone (water addition needed for certain foods) and extraction with methylene chloride/acetone after NaCl addition. Water removal using sodium sulfate and extraction twice with methylene chloride. Water removal from extract and solvent evaporation. Further extract clean-up using carbon/Celite, Extrelut-3, or C_{18}-SPE. Solvent evaporation and redissolution in benzene.	GC/FPD	5.2 ppb (w/w)	80 at 0.03 ppm spike	Leoni et al. 1992

Table 6-2. Analytical Methods for Determining Chlorpyrifos and Transformation Products in Environmental Samples (continued)

Sample matrix[a]	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Beef fat	Tissue extraction sweep co-distillation to isolate analytes.	GC/ECD	No data	83.5% (5.3% RSD) at 0.16 mg/kg (0.16 ppm, w/w)	Luke and Richards 1984
Rumen content, liver	Homogenization of 5 g sample with methanol:methylene chloride (1:9, v/v). Water removal from extract followed by volume reduction prior to clean-up using GPC and silica SPE.	GC/FPD	0.01 to 0.05 µg/g (ppm, w/w)	Rumen content: 99 (3% RSD) at 0.1 µg/g. Liver: 105 (2% RSD) at 0.05 µg/g	Holstege et al. 1991
Fats and oils	Sample mixing with light petroleum and extraction five times with light petroleum-saturated acetonitrile. Chlorpyrifos isolation using C_{18} SPE followed by solvent exchange to acetone for analysis.	GC/FPD	<0.08 µg/g (0.08 ppm, w/w)	85–97 at 0.16–0.5 µg/g (ppm, w/w)	Gillespie and Walters 1991
Peppermint oil (chlorpyrifos, TCP)	Chlorpyrifos: Oil application to silica gel column and elution with 3% water-saturated diethyl ether in hexane followed by volume adjustment. TCP: Oil dissolution in benzene: pentane (2:3) and extraction with 0.5% sodium carbonate. Aqueous phase washing with chloroform, acidification and extraction with chloroform. Further extract purification via acidic alumina column chromatography. Trimethysilyl derivative formation.	GC/FPD (chlorpyrifos); GC/ECD (TCP)	0.1 ppm (µg/g, w/w) for chlorpyrifos; 0.5 ppm for TCP	73–104 for chlorpyrifos over concentration range 0.11–10 ppm; 70 to 101% at 0.5–1.0 ppm	Inman et al. 1981

Table 6-2. Analytical Methods for Determining Chlorpyrifos and Transformation Products in Environmental Samples (continued)

Sample matrix[a]	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Chicken muscle, skin	Homogenization of weighed tissue once with acetonitrile and twice with 70% acetonitrile/water followed by filtration. Filtrate extraction with zinc acetate/water, filtration and filtrate extraction with dichloromethane. Solvent exchange to hexane and Florisil clean-up.	GC/NPD	2.5 µg/kg (ppb w/w) for muscle; 2.2 µg/kg (ppb, w/w) for skin	Muscle: 91.9 at 6.6 µg/kg (6.6 ppb, w/w) Skin: 105 at 19 µg/kg (ppb, w/w)	Lino and Noronha da Silveira 1994
Bovine milk, tissues (muscle, liver, heart, kidney, brain, spleen, omental fat)	Fat: Sample dissolution in hexane, water removal and extraction with acetonitrile. Extract volume reduction, dilution with aqueous sodium sulfate and back-extraction with hexane. Water removal from extract, concentration and clean-up using silicic acid column chromatography. Tissue: Sample blending with Celite and acetone. Acetone removal and aqueous phase extraction with hexane; clean-up as for fat. Milk: Milk combined with activated Florisil. Application of mixture to Florisil column and elution with 10% (v/v) methylene chloride in hexane.	GC/ECD	0.002 ppm (w/w) for tissues and 0.005 ppm (w/v) for milk	Tissue: 75–100 at 0.012 ppm; Milk: 84 at 0.05 ppm	Claborn et al. 1968

Table 6-2. Analytical Methods for Determining Chlorpyrifos and Transformation Products in Environmental Samples (continued)

Sample matrix[a]	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Bovine milk, tissues (muscle, liver, heart, kidney, brain, spleen, omental fat); chlorpyrifos oxygen analog	Fat: Sample dissolution in hexane, water removal and extraction with acetonitrile. Extract volume reduction, dilution with aqueous sodium sulfate and back-extraction with hexane. Water removal from extract, concentration and clean-up using silicic acid column chromatography. Tissue: Sample blending with Celite and acetone. Acetone removal and aqueous phase extraction with hexane; clean-up as for fat. Milk: Milk combined with silicic acid followed by water removal and elution with hexane. Application of mixture to silicic acid column and elution with water-saturated methylene chloride.	GC/ECD	0.1 ppm (w/w) for fat and muscle; 0.025 ppm (w/v) for milk	70 and 92 for muscle and fat, respectively, at 0.1 ppm; 80 from milk at 0.025 ppm	Ivey and Claborn 1968
Bovine tissue (muscle, liver, kidney, fat); TCP	Tissue homogenization with methanol, filtration and mixing with acidified water containing NaCl. TCP extraction with benzene. TCP isolation using alumina column chromatography and derivatization to trimethylsilyl derivative. Total TCP (free plus conjugated) also examined after alkaline hydrolysis (any chlorpyrifos also converted to TCP).	GC/ECD	<0.05 ppm (w/w)	81–89 without hydrolysis; 86–101 with hydrolysis	Dishburger et al. 1977
Bovine fat	Tissue extraction and sweep co-distillation to isolate analytes. Extract clean-up using activated Florisil followed by extract volume reduction.	GC/NPD	No data	92 (5% RSD) at 0.4 mg/kg (ppm, w/w)	Brown et al. 1987

Table 6-2. Analytical Methods for Determining Chlorpyrifos and Transformation Products in Environmental Samples (continued)

Sample matrix[a]	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Butter fat, potatoes	Dispersion of homogenized sample with pelletized diatomaceous earth (Hydromatrix), packing into high pressure extraction cell, and extraction with supercritical carbon dioxide. Collection of extracts from fatty samples into a flask and clean-up using GPC and Florisil adsorption chromatography. Extracts from non-fatty samples trapped onto a Florisil column. Chlorpyrifos elution with acetone.	GC/NPD	<0.06 ppm (w/w)	Butter fat: 90 (0.06–0.6 ppm) potatoes: 97 at 0.120 ppm	Hopper and King 1991
Lettuce, strawberries, and tomatoes	Sample homogenization with acetone followed by filtration; pesticide extraction into organic phase by shaking with petroleum ether and methylene chloride. Water removal from extract and organic phase volume reduction in presence of petroleum ether and then acetone to remove methylene chloride.	GC/NPD (AOAC Method 985.22)	No data	No data	Helrich 1990b
Cucumbers, lettuce, radishes, strawberries, tomatoes, witloof chicory	Extraction of homogenized sample with acetone. Analytes recovered via back extraction with methylene chloride followed by water removal and clean-up using activated carbon-silica gel.	GC/NPD (German Pesticides Commission Method S8)	0.05 mg/kg (0.05 ppm, w/w) at 0.5 mg/kg	>70	Thier and Zeumer 1987a

Table 6-2. Analytical Methods for Determining Chlorpyrifos and Transformation Products in Environmental Samples (continued)

Sample matrix[a]	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Potatoes, lettuce, citrus fruit	Extraction of homogenized plant material with acetone and saturation of this extract with NaCl and dilution with methylene chloride. Clean-up of organic phase using GPC and silica gel column chromatography.	GC/FPD (German Pesticide Commission Method S19)	No data	>70	Thier and Zeumer 1987b
Non-fatty foods (chlorpyrifos and chlorpyrifos oxygen analog.)	Sample homogenization with acetone followed by filtration. Residues partitioned into methylene chloride and petroleum ether after addition of NaCl. Alternatively, acetone solution passage through Hydromatrix (diatomaceous earth) and residue elution with methylene chloride.	GC/FPD, GC/HECD, GC/NPD (US FDA PAM1 Method 302)	Approximately 20 ppb (w/w, µg/kg) depending on analytical system used	>80	FDA 1994a
Dates (chlorpyrifos and oxygen analog)	Extraction of homogenized sample with benzene. Application of extract to silica gel column and elution with benzene to collect chlorpyrifos and then with acetone to recover the oxygen analog.	GC/NPD	0.01 ppm (w/w, mg/kg) for chlorpyrifos; 0.05 ppm for oxygen analog	93 for chlorpyrifos and 84 for oxygen analog over concentration range 0.01–2.0 ppm	Mansour 1985

[a] Unless otherwise specified, method is for chlorpyrifos. If method was applied to transformation products, these are indicated in parentheses with the matrix studied.

AOAC = Association of Official Analytical Chemists; ECD = electron capture detector; EPA = Environmental Protection Agency; FPD = Flame photometric detector; GC = gas chromatography; GPC = gel permeation chromatography; HPLC = high performance liquid chromatography; MS = mass spectrometry; NCIMS = negative ion chemical ionization mass spectrometry; NPD = nitrogen phosphorus detector (thermionic); OSHA = Occupational Safety and Health Administration; RSD = relative standard deviation; SD = standard deviation; SPE = solid phase extraction; TCP = 3,5,6-trichloropyridinol; TLC = thin layer chromatography; UV = ultraviolet absorbance detection; v/v = volume/volume; w/v = weight/volume

6.2 ENVIRONMENTAL SAMPLES

Methods for the determination of chlorpyrifos and environmental transformation products are shown in Table 6-2.

The analytical methods for chlorpyrifos in air are based on GC with some form of selective detection. For air matrices, collection methods rely on the entrapment of chlorpyrifos onto a polymeric material, such as XAD or polyurethane foam, as the air is pulled through the sorbent (EPA 1988c; Fenske et al.1990; OSHA 1986). The analyte is subsequently recovered from the sorbent through solvent extraction. Losses of chlorpyrifos can occur during Soxhlet extraction or extract concentration using Kudema-Danish devices as a result of the boiling chips used (Hsu et al. 1988). Thus, it is very important that the performance of any method be verified prior to its application in a study. The proper use of field control samples is also very important. Reported LODs were as low as sub parts per trillion (EPA 1988c). Although chlorpyrifos can be converted to its oxygen analog (thiophosphate to phosphate) under normal environmental conditions (see Chapter 5), none of the methods surveyed indicated that this conversion was problematic for the determination of chlorpyrifos in air.

In the case of water, soils, and wastes, sample preparation is based on liquid/liquid extractions (EPA 1986c, 1986d, 1992b, 1992c; Sherma and Slobodien 1984), solid phase extraction (SPE) (Bogus et al.1991; Johnson et al. 1991; Lacorte et al. 1993; Mattem et al. 1991), or Soxhlet extractions (EPA 1986c, 1986d). Humic material in natural waters can reduce recoveries of chlorpyrifos in SPE-based sample preparation (Johnson et al. 1991). The decreased recovery is hypothesized to be the result of inefficient trapping of the chlorpyrifos/humic material complex. EPA Method 507 for the determination of nitrogen- and phosphorus-containing pesticides in drinking water (EPA 1991) should be applicable to chlorpyrifos but has not been validated for this compound. Soxhlet extractions are commonly employed in methods used to study chlorpyrifos residues in carpet dust and on surfaces sampled using wiping approaches (Fenske et al. 1990; Lewis et al. 1994). Supercritical fluid extraction (SFE) has shown promise for the recovery of chlorpyrifos from environmental solids (Lopez-Avila et al. 1991; Miles and Randall 1992). Chlorpyrifos in sample extracts is typically determined using GC, although thin-layer chromatography (TLC) and high-performance liquid chromatography (HPLC) have also been employed (Bogus et al. 1990; Sherma and Slobodien 1984). Sherma and Slobodien (1984) also used TLC to quantify the chlorpyrifos transformation product TCP in drinking water. Gerhart and Cortes (1990) have reported a method for chlorpyrifos that used direct

injection of well water into a GC retention gap. Reported lower LODs for chlorpyrifos ranged from 5 ppt (w/v) for surface water (Mattem et al. 1991) to 3 ppm (w/w) for soils and sludges (EPA 1986c).

The determination of chlorpyrifos and its transformation products, especially chlorpyrifos oxygen analog and TCP in foods has received considerable attention. Foods are generally divided into fatty (animal products, oils) and non-fatty types (produce). Chlorpyrifos is fairly non-polar and thus tends to partition into fat. This dictates that slightly different methods be used for the extraction of fatty and non-fatty samples. In general, chlorpyrifos, chlorpyrifos oxygen analog, and TCP are extracted from fatty foods using petroleum ether (Hunt et al. 1969), methylene chloride/acetone (Leoni et al. 1992), methanol/methylene chloride (Holstege et al. 1991) acetonitrile (Clabom et al. 1968), or methanol (Dishburger et al. 1977). The sample or initial extracts are usually acidified followed by additional extraction steps to recover TCP (Dishburger et al. 1977; Inman et al. 1981). Non-fatty samples are most often extracted with acetone (FDA 1994a; Helrich 1990b; Thier and Zeumer 1987a, 1987b), although the use of benzene has also been reported (Mansour 1985). Supercritical fluid extraction has been successfully used to recover chlorpyrifos from potatoes and butter fat (Hopper and King 1991) and grass (Cortes et al. 1991).

The determinative step for chlorpyrifos, chlorpyrifos oxygen analog, and TCP is usually GC in conjunction with selective detection such as flame photometric detection (FPD), nitrogen phosphorus thermionic detection (NPD), or electron capture detection (ECD). Depending on the original sample matrix, additional clean-up can be required to remove fats or other material that can interfere with the chromatography (Walters 1990) or with detection (FDA 1994a). In addition, natural sample constituents, such as large amounts of sulfur-containing compounds in cauliflower, onions and broccoli, can increase the FPD background detector signal and make the method less sensitive (Lee and Wylie 1991). Common approaches to further extract purification include SPE (Gillespie and Walters 1991; Leoni et al. 1992; Thier and Zeumer 1987a, 1987b), gel permeation chromatography (GPC) (FDA 1994a; Holstege et al. 1991; Thier and Zeumer 1987b), Florisil column chromatography (Brown et al. 1987; Clabom et al. 1968; FDA 1994a; Hopper and King 1991; Leoni et al. 1992), sweep co-distillation (Luke and Richards 1984) and HPLC (Gillespie and Walters 1986, 1989). The adequate recovery of the desired compound must be validated for the fractionation technique to be used. For example, SPE cartridges from different vendors or production lots have been shown to affect retention and recovery (Gillespie and Walters 1991). Chlorpyrifos oxygen analog has been found to be hydrolyzed by activated silica (Braun 1974). Florisil can also give rise to poor recoveries

of chlorpyrifos oxygen analog (FDA 1994a, 1994b; Leoni et al. 1992). The FDA method for fatty foods or cornposited food (Method 304) can be applied with limited success to chlorpyrifos (variable recovery) but not at all to the oxygen analog (FDA 1994b).

TLC has been used to separate chlorpyrifos and TCP (Judge et al. 1993) and to screen for 170 commonly used pesticides, including chlorpyrifos (Erdmann et al. 1990). Additional analytical techniques that have been applied to chlorpyrifos include GC with atomic emission detection (Lee and Wylie 1991), GC with pulsed positive ion/negative ion chemical ionization mass spectrometry (Stan and Kellner 1989), simultaneous analysis on two GC columns with both ECD and electrolytic conductivity detectors (Hopper 1991), and two-dimensional GC with simultaneous detection by ECD, NPD, and FPD (Stan and Heil 1991).

6.3 ADEQUACY OF THE DATABASE

Section 104(i)(5) of CERCLA, as amended, directs the Administrator of ATSDR (in consultation with the Administrator of EPA and agencies and programs of the Public Health Service) to assess whether adequate information on the health effects of chlorpyrifos is available. Where adequate information is not available, ATSDR, in conjunction with the NTP, is required to assure the initiation of a program of research designed to determine the health effects (and techniques for developing methods to determine such health effects) of chlorpyrifos.

The following categories of possible data needs have been identified by a joint team of scientists from ATSDR, NTP, and EPA. They are defined as substance-specific informational needs that if met would reduce the uncertainties of human health assessment. This definition should not be interpreted to mean that all data needs discussed in this section must be filled. In the future, the identified data needs will be evaluated and prioritized, and a substance-specific research agenda will be proposed.

6.3.1 Identification of Data Needs

Methods for Determining Biomarkers of Exposure and Effect. Chlorpyrifos and TCP can serve as biomarkers of exposure. TCP will be present at much greater concentrations relative to chlorpyrifos, so it is a better and more sensitive marker of exposure (He 1993; WHO 1975). The method for TCP in urine published by Bartels and Kastl (1992) should be adequately sensitive to study

background concentrations in the general population because they measured low concentrations in control urine from presumably unexposed individuals. A LOD of 0.5 ng/mL (0.5 ppb, w/v) for TCP in urine was stated. The methods of Nolan et al. (1989) and Jitsunari et al. (1989) for TCP in blood and urine claim an LOD of 10 ppb with a reproducibility of 4% at 100 ppb. Chlorpyrifos oxon was not detected in serum and urine of poisoned persons, presumably because of the rapid rate of hydrolysis of the oxon relative to its rate of formation from chlorpyrifos (Drevenkar et al. 1993). The metabolites DEP and DETP can serve as markers of exposure to chlorpyrifos but can also be present as a result of exposure to organophosphorus compounds that have the same phosphate moiety. Thus, they are not specific. Exposure to organophosphorus pesticides also results in decreases in whole blood and erythrocyte acetylcholinesterase activities (Drevenkar et al. 1993; He 1993) and are not specific to exposure to chlorpyrifos. The best marker of exposure to chlorpyrifos appears to be TCP, for which there are adequate methods; therefore, no new methods for TCP are needed.

Methods for Determining Parent Compounds and Degradation Products in Environmental Media. Methods are available for the determination of chlorpyrifos in air at sub-ppb concentrations (EPA 1988c; Fenske et al. 1990; OSHA 1986) and are adequate to estimate potential exposures of the general population. No methods were found for chlorpyrifos oxon in air. It has been reported that the oxon is more toxic than the parent compound (Drevenkar et al. 1993), but it does not persist (Walia et al. 1988). No additional methods are needed.

The predominant route of exposure to chlorpyrifos is through contact with contaminated environmental matrices such as food and water. Methods for the determination of chlorpyrifos in water, wastes, soils, and foods are available that have LODs in the ppb and sub-ppb range (e.g., EPA 1992c; FDA 1994a; Gerhart and Cortes 1990; Gillespie and Walters 1991; Mansour 1985; Mattem et al. 1991). Assuming an oral MRL of 0.003 mg/kg/day (Chapter 2), 2 L/day water consumption and a 70-kg person, this converts to a needed method LOD of 0.105 ppm (w/v) in drinking water. Reported LODs in water are 2 ppb (Sherma and Slobodien 1984), 0.9 ppb (Gerhart and Cortes 1990), 0.1 ppb (Lacorte et al. 1993), 0.005 ppb (Mattem et al. 1991), and 5 ppb (Bogus et al. 1990). These methods are sufficiently sensitive to detect concentrations at or below the MRL. Method reproducibilities range from 4 to 16% and will be adequate for most measurements. If 2 kg/day food consumption is assumed, method LODs of 0.105 ppm or 105 ppb (w/w) are needed. The methods of Hunt et al. (1969), Leoni et al. (1992), Lino and Noronha da Silveira (1994), Clabom et al. (1968), Ivey and Clabom (1968), Dishburger et al. (1977), Hopper and King (1991), Thier and Zeumer (1987a), FDA (1994a), and

Mansour (1985) claim method LODs that range from 2 to 100 ppb and are sufficiently sensitive to detect concentrations at or below the MRL. No reproducibility information was available. No additional methods for chlorpyrifos in foods are needed.

Methods are also available for the determination of the oxon in some foods (tissue and produce) (FDA 1994a; Ivey and Claborn 1968; Mansour 1985) at the sub-ppm level. Chlorpyrifos and its oxon are quickly hydrolyzed to TCP; some methods exist for the determination of TCP in drinking water (Sherma and Slobodien 1984), peppermint oil (Gillespie and Walters 1991), and bovine tissue (Dishburger et al. 1977).

6.3.2 Ongoing Studies

Researchers at North Dakota State University (Fargo) and at the University of Maine, Department of Food Science, have been working on immunochemical-based methods for the determination of chlorpyrifos.

Researchers at the U.S. Department of Agriculture in Beltsville, Maryland; at the University of Florida (Gainesville) Department of Food Science and Nutrition; and at the University of Puerto Rico (Mayaguez), Crop Protection, are working on fate and transport of chlorpyrifos in the environment and will be developing methods as needed to define the processes and to develop models to predict fate and transport.

Researchers at National Taiwan University (Taipei) are studying the degradation of chlorpyrifos residues in meat and poultry as a function of cooking methods for modeling purposes and might need to develop some methods.

7. REGULATIONS AND ADVISORIES

The international, national, and state regulations and guidelines regarding chlorpyrifos in air, water, and other media are summarized in Table 7-l.

ATSDR has derived a Minimal Risk Level (MRL) of 0.003 mg/kg/day for both acute (14 days or less) and intermediate (15-364 days) duration oral exposure to chlorpyrifos, based on a NOAEL of 0.03 mg/kg/day observed in human adult males exposed orally to chlorpyrifos (Coulston et al. 1972). An uncertainty factor of 10 was used in the calculation of the MRL to account for variability in susceptibility within the human population.

ATSDR has derived a chronic-duration oral MRL of 0.001 mg/kg/day, based on a NOAEL for acetylcholinesterase inhibition in rats exposed to 0.1 mg/kg/day chlorpyrifos in feed for 2 years (McCollister et al. 1974). An uncertainty factor of 100 was used in the calculation of the MRL: 10 for extrapolation from animals to humans and 10 for variability within the human population.

The U.S. EPA oral reference dose for chlorpyrifos is $3x10^{-3}$ mg/kg/day (IRIS 1994). No inhalation reference concentration exists for this compound.

Chlorpyrifos is one of the chemicals regulated under “The Emergency Planning and Community Rightto-Know Act of 1986” (EPCRA) (EPA 1988a). Section 313 of Title III of EPCRA requires owners and operators of certain facilities that manufacture, import, process, or otherwise use the chemicals on this list to report annually their release of those chemicals to any environmental media.

An Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) for chlorpyrifos has not been set.

Chlorpyrifos is designated a hazardous substance and subject to regulations implementing Section 311 of the Federal Water Pollution Act (EPA 1978b) and Section 311 of the Clean Water Act (EPA 1986b). A maximum contaminant level in (MCL) drinking water does not exist.

Tolerances for chlorpyrifos in raw agricultural commodities, foods, and animal feeds have been established by EPA (EPA 1987, 1982, 1979) ranging from 0.05 to 25 ppm.

Table 7-1. Regulations and Guidelines Applicable to Chlorpyrifos

Agency	Description	Information	References
INTERNATIONAL			
Guidelines:			
WHO	Drinking-water guideline values for health-related organics	None	WHO 1984
NATIONAL			
Regulations:			
a. Water			
EPA OW	Designation of Hazardous Substances	Yes	40 CFR 116.4 EPA 1978a
	Reportable Quantities of Hazardous Substances Pursuant to the Clean Water Act	1 lbs.	40 CFR 117.3 EPA 1986a
	National Pollutant Discharge Elimination System (NPDES) -- List of Toxic Pollutants and Hazardous Substances	Yes	40 CFR 122, App. D EPA 1993a
	Instructions -- Form 2c, NPDES Criteria and Standards	Yes	40 CFR 125 EPA 1984
	Proposed Rule: Water Quality Guidance for the Great Lakes System	Yes	58 FR 20802 EPA 1993b
b. Food:			
EPA OPTS	Tolerances for Related Pesticide Chemicals	Yes	40 CFR 180.3 EPA 1976b
	Tolerance Range for Agriculture Products	0.05–15.0 ppm	40 CFR 180.342 EPA 1987
	Listing of Pesticide Chemicals	Yes	40 CFR 180 EPA 1976a
	Tolerance in Food: Citrus Oil Corn Oil Mint Oil Peanut Oil	Yes 25 ppm 3.0 ppm 10.0 ppm 1.5 ppm	40 CFR 185.1000 EPA 1982a
	Tolerance Range in Animal Feeds	0.5–15.0 ppm	40 CFR 186.1000] EPA 1979
c. Other			
EPA OERR	Reportable Quantity	1 lb.	40 CFR 302.4 EPA 1989
Guidelines:			
a. Air:			
ACGIH	Threshold Limit Value for Occupational Exposure (TLV-TWA)	0.90 mg/m^3 (skin)	ACGIH 1994
NIOSH	Recommended Exposure Limit for Occupational Exposure (TWA)	0.2 mg/m^3	NIOSH 1992
	Recommended Exposure Limit for Occupational Exposure (STEL)	0.6 mg/m^3	NIOSH 1992
NRC	Recommended maximum air concentration in residential houses	10 µg/m^3	NAS/NRC 1982

Table 7-1. Regulations and Guidelines Applicable to Chlorpyrifos (continued)

Agency	Description	Information	References
NATIONAL (cont.)			
b. Water:			
EPA OW	1-d Health Advisory	0.03 mg/L (child)	EPA 1994
	10-d Health Advisory	0.03 mg/L (child)	EPA 1994
	Lifetime Health Advisory	0.02 mg/L	EPA 1994
	Longer-term Health	0.03 mg/L (child 0.1 mg/L (adult)	EPA 1994
	Drinking water cancer classification	D (not assigned)	EPA 1995
c. Other			
EPA	RfD	$3x10^{-3}$ mg/kg/day	IRIS 1997
STATE			
Regulations and Guidelines:			
a. Air:	Average Acceptable Ambient Air Concentrations		NATICH 1992
CT	8-hour	4.00 $\mu g/m^3$	
FL-Pinella	8-hour 24-hour	2.00 $\mu g/m^3$ 0.48 $\mu g/m^3$	
ND	8-hour 1-hour	0.002 mg/m^3 0.006 mg/m^3	
NV	8-hour	0.005 mg/m^3	
TX	30-minutes Annual	2.00 $\mu g/m^3$ 0.20 $\mu g/m^3$	
VA	Annual	3.30 $\mu g/m^3$	
WA-SWEST	24-hour	0.70 $\mu g/m^3$	
b. Water:	Water Quality: Human Health		FSTRAC 1990
VT	Drinking Water Standard	21 µg/L	
AR	Water Quality Criteria: Human Health		CELDs 1994
	Toxic Substances - Chronic Toxicity 4-day avg	0.041 µg/L	
	Toxic Substances - Acute Toxicity - 1-hr avg	0.083 µg/L	
HI	Toxic Substances Applicable to All Waters		
	Fresh water acute	0.083 µg/L	
	Fresh water chronic	0.041 µg/L	
	Saltwater acute	0.011 µg/L	
	Saltwater chronic	0.0056 µg/L	
	Fish consumption	NS	
	Water Quality Criteria: Aquatic Life		CELDs 1994
CO	Aquatic Life Segments Organic Compounds to Second Power		
	Standard acute	0.083 µg/L	
	Standard chronic	0.041 µg/L	

Table 7-1. Regulations and Guidelines Applicable to Chlorpyrifos (continued)

Agency	Description	Information	References
STATE			
PR	Maximum Allowable Conc. for Organothiophosphorus and Other Non-Persistent Pesticides		
	Coastal estuaries	0.0056 µg/L	
	Surface waters	0.41 µg/L	
	Groundwaters	0.041 µg/L	
OK	Numeric Criteria for Toxic Substances to Protect Fish and Wildlife		
	Acute	.083 µg/L	
	Chronic	.041 µg/L	
VT	WQ Criteria for Protection of Aquatic - Biota		
	Acute	.083 µg/L	
	Chronic	.041 µg/L	
	Restricted Pesticides		
NJ		All conc. above 15%	CELDs 1994

ACGIH = American Conference of Governmental Industrial Hygienists; CELDs = Computer-assisted Environmental Legislative Database; EPA = Environmental Protection Agency; FSTRAC = Federal State Toxicology and Regulatory Alliance Committee; IRIS = Integrated Risk Information System; NATICH = National Air Toxics Information Clearinghouse; NIOSH = National Institute of Occupational Safety and Health; NPDES = National Pollutant Discharge Elimination System; RfD = Reference Dose; STEL = Short-term Exposure Limit; TLV = Threshold Limit Value; TWA = Time Weighted Average

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9. GLOSSARY

Acute Exposure-Exposure to a chemical for a duration of 14 days or less, as specified in the Toxicological Profiles.

Adsorption Coefficient (K_{oc})-The ratio of the amount of a chemical adsorbed per unit weight of organic carbon in the soil or sediment to the concentration of the chemical in solution at equilibrium.

Adsorption Ratio (Kd)-The amount of a chemical adsorbed by a sediment or soil (i.e., the solid phase) divided by the amount of chemical in the solution phase, which is in equilibrium with the solid phase, at a fixed solid/solution ratio. It is generally expressed in micrograms of chemical sorbed per gram of soil or sediment.

Bioconcentration Factor (BCF)-The quotient of the concentration of a chemical in aquatic organisms at a specific time or during a discrete time period of exposure divided by the concentration in the surrounding water at the same time or during the same period.

Cancer Effect Level (CEL)-The lowest dose of chemical in a study, or group of studies, that produces significant increases in the incidence of cancer (or tumors) between the exposed population and its appropriate control.

Carcinogen-A chemical capable of inducing cancer.

Ceiling Value-A concentration of a substance that should not be exceeded, even instantaneously.

Chronic Exposure-Exposure to a chemical for 365 days or more, as specified in the Toxicological Profiles.

Developmental Toxicity-The occurrence of adverse effects on the developing organism that may result from exposure to a chemical prior to conception (either parent), during prenatal development, or postnatally to the time of sexual maturation. Adverse developmental effects may be detected at any point in the life span of the organism.

Embryotoxicity and Fetotoxicity-Any toxic effect on the conceptus as a result of prenatal exposure to a chemical; the distinguishing feature between the two terms is the stage of development during which the insult occurred. The terms, as used here, include malformations and variations, altered growth, and in utero death.

EPA Health Advisory-An estimate of acceptable drinking water levels for a chemical substance based on health effects information. A health advisory is not a legally enforceable federal standard, but serves as technical guidance to assist federal, state, and local officials.

Immediately Dangerous to Life or Health (IDLH)-The maximum environmental concentration of a contaminant from which one could escape within 30 min without any escape-impairing symptoms or irreversible health effects.

Intermediate Exposure-Exposure to a chemical for a duration of 15-364 days, as specified in the Toxicological Profiles.

Immunologic Toxicity-The occurrence of adverse effects on the immune system that may result from exposure to environmental agents such as chemicals.

***In Vitro*-**Isolated from the living organism and artificially maintained, as in a test tube.

***In Vivo*-**Occurring within the living organism.

Lethal Concentration($_{LO}$) (LC_{LO})-The lowest concentration of a chemical in air which has been reported to have caused death in humans or animals.

Lethal Concentration $_{(50)}$ (LC_{50})-A calculated concentration of a chemical in air to which exposure for a specific length of time is expected to cause death in 50% of a defined experimental animal population.

Lethal Dose ($_{50}$) (LD_{50}) -The lowest dose of a chemical introduced by a route other than inhalation that is expected to have caused death in humans or animals.

Lethal Dose $_{(50)}$ (LD_{50})-The dose of a chemical which has been calculated to cause death in 50% of a defined experimental animal population.

Lethal Time $_{(50)}$ (LT_{50})-A calculated period of time within which a specific concentration of a chemical is expected to cause death in 50% of a defined experimental animal population.

Lowest-Observed-Adverse-Effect Level (LOAEL)-The lowest dose of chemical in a study, or group of studies, that produces statistically or biologically significant increases in frequency or severity of adverse effects between the exposed population and its appropriate control.

Malformations-Permanent structural changes that may adversely affect survival, development, or function.

Minimal Risk Level-An estimate of daily human exposure to a dose of a chemical that is likely to be without an appreciable risk of adverse noncancerous effects over a specified duration of exposure.

Mutagen-A substance that causes mutations. A mutation is a change in the genetic material in a body cell. Mutations can lead to birth defects, miscarriages, or cancer.

Neurotoxicity-The occurrence of adverse effects on the nervous system following exposure to chemical.

No-Observed-Adverse-Effect Level (NOAEL) -The dose of chemical at which there were no statistically or biologically significant increases in frequency or severity of adverse effects seen between the exposed population and its appropriate control. Effects may be produced af this dose, but they are not considered to be adverse.

Octanol-Water Partition Coefficient (K_{ow})-The equilibrium ratio of the concentrations of a chemical in n-octanol and water, in dilute solution.

Permissible Exposure Limit (PEL) -An allowable exposure level in workplace air averaged over an 8-hour shift.

q_1*- The upper-bound estimate of the low-dose slope of the dose-response curve as determined by the multistage procedure. The q_1* can be used to calculate an estimate of carcinogenic potency, the incremental excess cancer risk per unit of exposure (usually μg/L for water, mg/kg/day for food, and $\mu g/m^3$ for air).

Reference Dose (RfD)-An estimate (with uncertainty spanning perhaps an order of magnitude) of the daily exposure of the human population to a potential hazard that is likely to be without risk of deleterious effects during a lifetime. The RfD is operationally derived from the NOAEL (from animal and human studies) by a consistent application of uncertainty factors that reflect various types of data used to estimate RfDs and an additional modifying factor, which is based on a professional judgment of the entire database on the chemical. The RfDs are not applicable to nonthreshold effects such as cancer.

Reportable Quantity (RQ)-The quantity of a hazardous substance that is considered reportable under CERCLA. Reportable quantities are (1) 1 pound or greater or (2) for selected substances, an amount established by regulation either under CERCLA or under Sect. 311 of the Clean Water Act. Quantities are measured over a 24-hour period.

Reproductive Toxicity-The occurrence of adverse effects on the reproductive system that may result from exposure to a chemical. The toxicity may be directed to the reproductive organs and/or the related endocrine system. The manifestation of such toxicity may be noted as alterations in sexual behavior, fertility, pregnancy outcomes, or modifications in other functions that are dependent on the integrity of this system.

Short-Term Exposure Limit (STEL)-The maximum concentration to which workers can be exposed for up to 1.5 min continually. No more than four excursions are allowed per day, and there must be at least 60 min between exposure periods. The daily TLV-TWA may not be exceeded.

Target Organ Toxicity-This term covers a broad range of adverse effects on target organs or physiological systems (e.g., renal, cardiovascular) extending from those arising through a single limited exposure to those assumed over a lifetime of exposure to a chemical.

Teratogen-A chemical that causes structural defects that affect the development of an organism.

Threshold Limit Value (TLV)-A concentration of a substance to which most workers can be exposed without adverse effect. The TLV may be expressed as a TWA, as a STEL, or as a CL.

Time-Weighted Average (TWA)-An allowable exposure concentration averaged over a normal 8-hour workday or 40-hour workweek.

Toxic Dose (TD_{50})-A calculated dose of a chemical, introduced by a route other than inhalation, which is expected to cause a specific toxic effect in 50% of a defined experimental animal population.

Uncertainty Factor (UF)-A factor used in operationally deriving the RfD from experimental data. UFs are intended to account for (1) the variation in sensitivity among the members of the human population, (2) the uncertainty in extrapolating animal data to the case of human, (3) the uncertainty in extrapolating from data obtained in a study that is of less than lifetime exposure, and (4) the uncertainty in using LOAEL data rather than NOAEL data. Usually each of these factors is set equal to 10.

APPENDIX A

ATSDR MINIMAL RISK LEVEL

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) [42 U.S.C. 9601 et seq.], as amended by the Superfund Amendments and Reauthorization Act (SARA) [Pub. L. 994991, requires that the Agency for Toxic Substances and Disease Registry (ATSDR) develop jointly with the U.S. Environmental Protection Agency (EPA), in order of priority, a list of hazardous substances most commonly found at facilities on the CERCLA National Priorities List (NPL); prepare toxicological profiles for each substance included on the priority list of hazardous substances; and assure the initiation of a research program to fill identified data needs associated with the substances.

The toxicological profiles include an examination, summary, and interpretation of available toxicological information and epidemiologic evaluations of a hazardous substance. During the development of toxicological profiles, Minimal Risk Levels (MRLs) are derived when reliable and sufficient data exist to identify the target organ(s) of effect or the most sensitive health effect(s) for a specific duration for a given route of exposure. An MRL is an estimate of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse noncancer health effects over a specified duration of exposure. MRLs are based on noncancer health effects only and are not based on a consideration of cancer effects. These substance-specific estimates, which are intended to serve as screening levels, are used by ATSDR health assessors to identify contaminants and potential health effects that may be of concern at hazardous waste sites. It is important to note that MRLs are not intended to define clean-up or action levels.

MRLs are derived for hazardous substances using the no-observed-adverse-effect level/uncertainty factor approach. They are below levels that might cause adverse health effects in the people most sensitive to such chemical-induced effects. MRLs are derived for acute (1-14 days), intermediate (15-364 days), and chronic (365 days and longer) durations and for the oral and inhalation routes of exposure. Currently, MRLs for the dermal route of exposure are not derived because ATSDR has not yet identified a method suitable for this route of exposure. MRLs are generally based on the most sensitive chemical-induced end point considered to be of relevance to humans. Serious health effects (such as irreparable damage to the liver or kidneys, or birth defects) are not used as a basis for

establishing MRLs. Exposure to a level above the MRL does not mean that adverse health effects will occur.

MRLs are intended only to serve as a screening tool to help public health professionals decide where to look more closely. They may also be viewed as a mechanism to identify those hazardous waste sites that are not expected to cause adverse health effects. Most MRLs contain a degree of uncertainty because of the lack of precise toxicological information on the people who might be most sensitive (e.g., infants, elderly, nutritionally or immunologically compromised) to the effects of hazardous substances. ATSDR uses a conservative (i.e., protective) approach to address this uncertainty consistent with the public health principle of prevention. Although human data are preferred, MRLs often must be based on animal studies because relevant human studies are lacking. In the absence of evidence to the contrary, ATSDR assumes that humans are more sensitive to the effects of hazardous substance than animals and that certain persons may be particularly sensitive. Thus, the resulting MRL may be as much as a hundredfold below levels that have been shown to be nontoxic in laboratory animals.

Proposed MRLs undergo a rigorous review process: Health Effects/MRL Workgroup reviews within the Division of Toxicology, expert panel peer reviews, and agencywide MRL Workgroup reviews, with participation from other federal agencies and comments from the public. They are subject to change as new information becomes available concomitant with updating the toxicological profiles. Thus, MRLs in the most recent toxicological profiles supersede previously published levels. For additional information regarding MRLs, please contact the Division of Toxicology, Agency for Toxic Substances and Disease Registry, 1600 Clifton Road, Mailstop E-29, Atlanta, Georgia 30333.

APPENDIX A

MINIMAL RISK LEVEL WORKSHEET

Chemical name:	Chlorpyrifos
CAS number:	508 15-00-4
Date:	August 1997
Profile status:	Final Post-public Draft
Route:	[ ] Inhalation [X] Oral
Duration:	[X] Acute [ ] Intermediate [ ] Chronic
Key to figure:	5
Species:	Human

MRL: 0.003 [X] mg/kg/day [ ] ppm [ ] mg/m^3

Reference: Coulston et al. (1972)

Exnerimental design: 16 adult human male volunteers (4 per dose group) were treated with 0,0.014,0.03, or 0.10 mg/kg/day chlorpyrifos by capsule. Those subjects receiving 0.014 and 0.03 mg/kg/day were exposed for 20 days; those receiving 0.10 mg/kg/day were exposed for only 9 days.

Effects noted in study and corresnonding doses: Those subjects receiving 0.10 mg/kg/day were exposed for only 9 days because of blurred vision and a runny nose in one of the subjects. Plasma cholinesterase was decreased approximately 65% compared to controls in that group. No effect on plasma cholinesterase was seen at the lower doses and erythrocyte cholinesterase was unaffected by any of the chlorpyrifos doses. Thus, the NOAEL for chlorpyrifos plasma cholinesterase inhibition was 0.03 mg/kg/day. Based on this NOAEL, an MRL of 0.003 mg/kg was calculated: 0.03 mg/kg divided by an uncertainty factor of 10 for human variability. Please note that the combination of length of exposure period and the critical effect in this study enable it to be used for the derivation of both acute- and intermediate-duration oral exposure MRLs.

MRL = Human dose t Uncertainty factor

= 0.03 mg/kg ÷ 10

= 0.003 mg/kg

Dose endpoint used for MRL derivation: Plasma cholinesterase inhibition

[X] NOAEL [ ] LOAEL

Uncertainty factors used in MRL derivation:

[] 1 [ ] 3 [ ] 10(for use of a LOAEL)

[ ] 1 [ ] 3 [ ] 10 (for extrapolation from animals to humans)

[ ] 1 [ ] 3 [X] 10 (for human variability)

Was a conversion factor used from num in food or water to a mg/bodv weight dose? No.

If so, explain:

If an inhalation studv in animals. list conversion factors used in determining human eauivalent dose:

APPENDIX A

If an inhalation study in animals, list conversion factors used in determining human equivalent dose:

Was a conversion used from intermittent to continuous exposure? No.

If so, explain:

Other additional studies or pertinent information that lend support to this MRL:

Deacon et al. (1980) *Embryotoxicity and Fetotoxicity of Orally Administered Chlorpyrifos in Mice.*Toxicology and Applied Pharmacology. 54, 31-40.

The MRL study is further supported by a study by Deacon et al. (1980). Female CF-1 mice were exposed by gavage to 1, 10, or 2 mg/kg/day Dursban F® (96.8% chlorpyrifos) as a solution in cottonseed oil on gestation day (Gd) 6, Gds 610, or Gds 6-15. Controls received cottonseed oil alone. Five hours after the final dosing (Gds 6, 10, or 15) blood was obtained via cardiac puncture and plasma and erythrocyte cholinesterase activities determined. Plasma and erythrocyte cholinesterase levels were significantly decreased from control values among mice given 10 or 25 mg/kg chlorpyrifos on day 6 (plasma, 95 and 97%, respectively; erythrocyte, 40 and 20%, respectively) and, days 6-10 (plasma, 97 and 99%, respectively; erythrocyte, 43 and 71%, respectively), or Gds 6-15 (plasma, 96 and 98%, respectively; erythrocyte, 43 and 57%, respectively). Plasma cholinesterase levels were significantly reduced among mice given 1 mg/kg chlorpyrifos during the same time intervals (69, 78, and 85%, respectively). Erythrocyte cholinesterase levels were also reduced (43%) after 1 mg/kg chlorpyrifos, but only after exposure on Gds 6-10. In a concurrent study, no effects on plasma or erythrocyte cholinesterase activity were observed at 0.1 mg/kg chlorpyrifos.

Agency Contact (Chemical Manager): John F. Risher, Ph.D.

APPENDIX A

MINIMAL RISK LEVEL WORKSHEET

Chemical name: Chlorpyrifos
CAS number: 50815-00-4
Date: July 1997
Profile status: Final Post-public Draft
Route: [ ] Inhalation [X] Oral
Duration: [ ] Acute [X] Intermediate [ ] Chronic
Key to figure: 15
Species: Human

MRL: 0.003 [X] mg/kg/day [ ] ppm [ ] mg/m^3

Reference: Coulston et al. 1972.

Experimental design: 16 adult human male volunteers (4 per dose group) were treated with 0, 0.014, 0.03, or 0.10 mg/kg/day chlorpyrifos by capsule. Those subjects receiving 0.014 and 0.03 mg/kg/day were exposed for 20 days; those receiving 0.10 mg/kg/day were exposed for only 9 days.

Effects noted in study and corresnonding doses: Those subjects receiving 0.10 mg/kg/day were exposed for only 9 days because of blurred vision and a runny nose in one of the subjects. Plasma cholinesterase was decreased approximately 65% compared to controls in that group. No effect on plasma cholinesterase was seen at the lower doses and erythrocyte cholinesterase was unaffected by any of the chlorpyrifos doses. Thus, the NOAEL for chlorpyrifos plasma cholinesterase inhibition was 0.03 mg/kg/day. Based on this NOAEL, an MRL of 0.003 mg/kg was calculated: 0.03 mg/kg divided by an uncertainty factor of 10 for human variability. Please note that the combination of length of exposure period and the critical effect in this study enable it to be used for the derivation of both acute- and intermediate-duration oral exposure MRLs.

MRL = Human dose ÷ Uncertainty factor

$$= 0.03 \text{ mg/kg} \times \frac{1}{10}$$
$$= 0.003 \text{ mg/kg/day}$$

Dose endpoint used for MRL derivation: Plasma cholinesterase inhibition

[X] NOAEL [ ] LOAEL
Uncertainty factors used in MRL derivation:
[ ] 1 [ ] 3 [ ] 10 (for use of a LOAEL)
[ ] 1 [ ] 3 [ ] 10 (for extrapolation from animals to humans)
[ ] 1 [ ] 3 [X] 10 (for human variability)

Was a conversion factor used from ppm in food or water to a ma/body weight dose? No.
If so, explain:

If an inhalation study in animals, list conversion factors used in determining. human equivalent dose:

Was a conversion used from intermittent to continuous exposure? No.
If so, explain:

Other additional studies or pertinent information that lend support to this MRL:

Deacon et al. (1980) *Embryotoxicity and Fetotoxicity of Orally Administered Chlorpyrifos in Mice.* Toxicology and Applied Pharmacology. 54, 31-40.

The MRL study is further supported by a study by Deacon et al. (1980). Female CF-1 mice were exposed by gavage to 1, 10, or 2 mg/kg/day Dursban F® (96.8% chlorpyrifos) as a solution in cottonseed oil on Gds 6, 6-10, or 6-15. Controls received cottonseed oil alone. Five hours after the final dosing (Gds 6, 10, or 15), blood was obtained via cardiac puncture and plasma and erythrocyte cholinesterase activities determined. Plasma and erythrocyte cholinesterase levels were significantly decreased from control values among mice given 10 or 25 mg/kg chlorpyrifos on day 6 (plasma, 95 and 97%, respectively; erythrocyte, 40 and 20%, respectively) and, days 6-10 (plasma, 97 and 99%, respectively; erythrocyte, 43 and 71%, respectively), or Gds 6-15 (plasma, 96 and 98%, respectively; erythrocyte, 43 and 57%, respectively). Plasma cholinesterase levels were significantly reduced among mice given 1 mg/kg chlorpyrifos during the same time intervals (69, 78, and 85%, respectively). Erythrocyte cholinesterase levels were also reduced (43%) after 1 mg/kg chlorpyrifos, but only after exposure on Gds 6-10. In a concurrent study, no effects on plasma or erythrocyte cholinesterase activity were observed at 0.1 mg/kg chlorpyrifos.

Agency Contact (Chemical Manager): John F. Risher, Ph.D.

APPENDIX A

MINIMAL RISK LEVEL WORKSHEET

Chemical name: Chlorpyrifos
CAS number: 50815-00-4
Date: July 1997
Profile status: Final Post-public Draft
Route: [ ] Inhalation [X] Oral
Duration: [ ] Acute [] Intermediate [X] Chronic
Key to figure: 42
Species: Rat

MRL: 0.001 [X] mg/kg/day [ ] ppm [ ] mg/m^3

Reference: McCollister et al. 1974

Experimental design: Sherman rats (25 males and 25 females) were dose fed chlorpyrifos at 0, 0.01, 0.03, 0.1, 1, or 3 mg/kg/day for 2 years beginning at 7-weeks of age. Additional groups of 5-7 rats of each sex at each dose level were set up to provide interim pathological examination and cholinesterase (ChE) determinations. Clinical observations, body weights, food consumption and mortality were monitored. At 6-month intervals, blood and urine samples were collected from selected rats receiving 0, 1, or 3 mg/kg/day. The packed cell volume, hemoglobin, erythrocyte count and total and differential leucocyte counts were determined in the blood. Urine was analyzed for total solids, pH, albumin, sugar, occult blood and ketones. The ChE activity of the plasma and red blood cells (RBC) was determined for all rats in the groups that were killed after receiving the test diets for 1 week, and 1, 3, 6, 9, 12, and 18 months, as well as for selected rats from those given each dose for 2 years. Brain ChE was measured in rats killed at 6, 12, 18, and 24 months. To characterize the recovery of the ChE activity in plasma, red cells and brain, some rats were maintained on the various diets containing chlorpyrifos for 12 months, and subsequently on the control diet for 7-8 weeks prior to sacrifice. Blood urea nitrogen (BUN), serum alkaline phosphatase (AP) and serum glutamic-pyruvic transaminase (SGPT) were determined on blood samples collected from rats killed at 12, 18, and 24 months. Necropsies were conducted on all rats killed at 12, 18, and 24 months and on those that received control feed for 7-8 weeks after having received chlorpyrifos diets for 12 months. These rats were fasted for 16 hours, decapitated, and weighed. The brain, heart, liver, kidney, spleen, and testes were removed and weighed. Portions of these tissues were preserved in 10% formalin, and histopathological examinations were performed on these tissues, as well as eye, pituitary, thyroid, and parathyroid glands, trachea, esophagus, lungs, aorta, stomach, pancreas, small intestine, colon, mesenteric lymph nodes, urinary bladder, accessory sex glands, ovaries, uterus, skeletal muscle, sciatic nerve, spinal cord, sternum, sternal bone marrow, adrenal gland, and any nodules or masses suggestive of tumor development or other pathological processes. Histopathological examinations were also conducted on the tissues of all rats exhibiting grossly visible nodules or masses, and on those killed in a moribund state or that died spontaneously, unless this was precluded by autolysis.

Effects noted in study and corresponding doses: Clinical observations did not detect evidence of a cholinergic overstimulation or any other compound-related effect. Brain cholinesterase (ChE) activity in both male and female rats displayed an overall reduction of 56% in rats fed 3 mg/kg/day chlorpyrifos during the 2-year study. No overall effect on brain ChE was observed at the lower doses. Plasma and RBC ChE activity were depressed for both male and female rats dosed with diets containing 1 or 3 mg/kg/day chlorpyrifos. At 1 mg/kg/day chlorpyrifos, plasma ChE was depressed

20-53%; RBC ChE activity was decreased 65-70% at that dose. Doses of 0.1 mg/kg/day and below had no effect on either plasma or RBC activity. Cholinesterase activities in plasma, RBC, and brain of rats fed chlorpyrifos-containing diets for 1 year returned to normal levels after switching to a control diet for 7-8 weeks. There was no effect of treatment on organ weights, histopathology, or number and types of tumors. It was concluded that 0.1 mg chlorpyrifos/kg/day fed in the diet for 2 years produced no significant toxicological effect in rats.

MRL = Human dose + Uncertainty factor (UF = 10 for extrapolation from animal data; UF = 10 for human variability)

$$= 0.1 \text{ mg/kg/day} \times \frac{1}{10} \times \frac{1}{10}$$

$$= 0.00\,1 \text{ mg/kg/day}$$

Dose endpoint used for MRL derivation: Acetylcholinesterase inhibition

[X] NOAEL [ ] LOAEL

Uncertainty factors used in MRL derivation:

[ ] 1 [ ] 3 [ ] 10 (for use of a LOAEL)
[ ] 1 [ ] 3 [X] 10 (for extrapolation from animals to humans)
[ ] 1 [ ] 3 [X] 10 (for human variability)

Was a conversion factor used from ppm in food or water to a mg/bodv weight dose? No.
If so, explain:

If an inhalation study in animals, list conversion factors used in determining human equivalent dose:

Was a conversion used from intermittent to continuous exposure? No.
If so, explain:

Other additional studies or pertinent information that lend support to this MRL: No.

Agency Contact (Chemical Manager): John F. Risher, Ph.D.

APPENDIX B

USER'S GUIDE

Chapter 1

Public Health Statement

This chapter of the profile is a health effects summary written in non-technical language. Its intended audience is the general public especially people living in the vicinity of a hazardous waste site or chemical release. If the Public Health Statement were removed from the rest of the document, it would still communicate to the lay public essential information about the chemical.

The major headings in the Public Health Statement are useful to find specific topics of concern. The topics are written in a question and answer format. The answer to each question includes a sentence that will direct the reader to chapters in the profile that will provide more information on the given topic.

Chapter 2

Tables and Figures for Levels of Significant Exposure (LSE)

Tables (2-1, 2-2, and 2-3) and figures (2-l and 2-2) are used to summarize health effects and illustrate graphically levels of exposure associated with those effects. These levels cover health effects observed at increasing dose concentrations and durations, differences in response by species, minimal risk levels (MRLs) to humans for noncancer endpoints, and EPA's estimated range associated with an upperbound individual lifetime cancer risk of 1 in 10,000 to 1 in 10,000,000. Use the LSE tables and figures for a quick review of the health effects and to locate data for a specific exposure scenario. The LSE tables and figures should always be used in conjunction with the text. All entries in these tables and figures represent studies that provide reliable, quantitative estimates of No-Observed-Adverse- Effect Levels (NOAELs), Lowest-Observed- Adverse-Effect Levels (LOAELs), or Cancer Effect Levels (CELs).

The legends presented below demonstrate the application of these tables and figures. Representative examples of LSE Table 2-l and Figure 2-l are shown. The numbers in the left column of the legends correspond to the numbers in the example table and figure.

LEGEND

See LSE Table 2-1

(1) Route of Exposure One of the first considerations when reviewing the toxicity of a substance using these tables and figures should be the relevant and appropriate route of exposure. When sufficient data exists, three LSE tables and two LSE figures are presented in the document. The three LSE tables present data on the three principal routes of exposure, i.e., inhalation, oral, and dermal (LSE Table 2-1, 2-2, and 2-3, respectively). LSE figures are limited to the inhalation (LSE Figure 2-l) and oral (LSE Figure 2-2) routes. Not all substances will have data on each route of exposure and will not therefore have all five of the tables and figures.

(2) Exposure Period Three exposure periods - acute (less than 15 days), intermediate (15-364 days), and chronic (365 days or more) are presented within each relevant route of exposure. In this example, an inhalation study of intermediate exposure duration is reported. For quick reference to health effects occurring from a known length of exposure, locate the applicable exposure period within the LSE table and figure.

(3) Health Effect The major categories of health effects included in LSE tables and figures aredeath, systemic, immunological, neurological, developmental, reproductive, and cancer. NOAELs and LOAELs can be reported in the tables and figures for all effects but cancer. Systemic effects are further defined in the "System" column of the LSE table (see key number 18).

(4) Key to Figure Each key number in the LSE table links study information to one or more datapoints using the same key number in the corresponding LSE figure. In this example, the study represented by key number 18 has been used to derive a NOAEL and a Less Serious LOAEL (also see the 2 "18r" data points in Figure 2-l).

(5) Species The test species, whether animal or human, are identified in this column. Section 2.4, "Relevance to Public Health," covers the relevance of animal data to human toxicity and Section 2.3, "Toxicokinetics," contains any available information on comparative toxicokinetics. Although NOAELs and LOAELs are species specific, the levels are extrapolated to equivalent human doses to derive an MRL.

(6) Exposure Freouencv/Duration The duration of the study and the weekly and daily exposure regimen are provided in this column. This permits comparison of NOAELs and LOAELs from different studies. In this case (key number 18), rats were exposed to toxaphene via inhalation for 6 hours per day, 5 days per week, for 3 weeks. For a more complete review of the dosing regimen refer to the appropriate sections of the text or the original reference paper, i.e., Nitschke et al. 1981.

(7) System This column further defines the systemic effects. These systems include: respiratory, cardiovascular, gastrointestinal, hematological, musculoskeletal, hepatic, renal, and dermal/ocular. "Other" refers to any systemic effect (e.g., a decrease in body weight) not covered in these systems. In the example of key number 18, 1 systemic effect (respiratory) was investigated.

(8) NOAEL A No-Observed-Adverse-Effect Level (NOAEL) is the highest exposure level at which no harmful effects were seen in the organ system studied. Key number 18 reports a NOAEL of 3 ppm for the respiratory system which was used to derive an intermediate exposure, inhalation MRL of 0.005 ppm (see footnote "b").

(9) LOAEL A Lowest-Observed-Adverse-Effect Level (LOAEL) is the lowest dose used in the study that caused a harmful health effect. LOAELs have been classified into "Less Serious" and "Serious" effects. These distinctions help readers identify the levels of exposure at which adverse health effects first appear and the gradation of effects with increasing dose. A brief description of the specific endpoint used to quantify the adverse effect accompanies the LOAEL. The respiratory effect reported in key number 18 (hyperplasia) is a Less serious LOAEL of 10 ppm. MRLs are not derived from Serious LOAELs.

(10) Reference The complete reference citation is given in chapter 8 of the profile.

(11) CEL A Cancer Effect Level (CEL) is the lowest exposure level associated with the onset ofcarcinogenesis in experimental or epidemiologic studies. CELs are always considered serious effects. The LSE tables and figures do not contain NOAELs for cancer, but the text may report doses not causing measurable cancer increases.

(12) Footnotes Explanations of abbreviations or reference notes for data in the LSE tables are found in the footnotes. Footnote "b" indicates the NOAEL of 3 ppm in key number 18 was used to derive an MRL of 0.005 ppm.

LEGEND

See Figure 2-1

LSE figures graphically illustrate the data presented in the corresponding LSE tables. Figures help the reader quickly compare health effects according to exposure concentrations for particular exposure periods.

(13) Exposure Period The same exposure periods appear as in the LSE table. In this example, health effects observed within the intermediate and chronic exposure periods are illustrated.

(14) Health Effect These are the categories of health effects for which reliable quantitative data exists. The same health effects appear in the LSE table.

(15) Levels of Exposure concentrations or doses for each health effect in the LSE tables are graphically displayed in the LSE figures. Exposure concentration or dose is measured on the log scale "y" axis. Inhalation exposure is reported in mg/m^3 or ppm and oral exposure is reported in mg /kg/day.

(16) NOAEL In this example, 18r NOAEL is the critical endpoint for which an intermediate inhalation exposure MRL is based. As you can see from the LSE figure key, the open-circle symbol indicates to a NOAEL for the test species-rat. The key number 18 corresponds to the entry in the LSE table. The dashed descending arrow indicates the extrapolation from the exposure level of 3 ppm (see entry 18 in the Table) to the MRL of 0.005 ppm (see footnote "b" in the LSE table).

(17) CEL Key number 38r is 1 of 3 studies for which Cancer Effect Levels were derived. The diamond symbol refers to a Cancer Effect Level for the test species-mouse. The number 38 corresponds to the entry in the LSE table.

(18) Estimated Upper-Bound Human Cancer Risk Levels This is the range associated with the upper-bound for lifetime cancer risk of 1 in 10,000 to 1 in 10,000,000. These risk levels are derived from the EPA's Human Health Assessment Group's upper-bound estimates-of the slope of the cancer dose response curve at low dose levels (q_1*).

(19) Key to LSE Figure The Key explains the abbreviations and symbols used in the figure.

.

SAMPLE

1 → **TABLE 2-1. Levels of Significant Exposure to [Chemical x] – Inhalation**

Key to figure[a]	Species	Exposure frequency/ duration	System	NOAEL (ppm)	LOAEL (effect) Less serious (ppm)	LOAEL (effect) Serious (ppm)	Reference
2 → INTERMEDIATE EXPOSURE							
	5	6	7	8	9		10
3 → Systemic	↓	↓	↓	↓	↓		↓
4 → 18	Rat	13 wk 5d/wk 6hr/d	Resp	3[b]	10 (hyperplasia)		Nitschke et al. 1981
CHRONIC EXPOSURE							
					11		
Cancer					↓		
38	Rat	18 mo 5d/wk 7hr/d			20	(CEL, multiple organs)	Wong et al. 1982
39	Rat	89–104 wk 5d/wk 6hr/d			10	(CEL, lung tumors, nasal tumors)	NTP 1982
40	Mouse	79–103 wk 5d/wk 6hr/d			10	(CEL, lung tumors, hemangiosarcomas)	NTP 1982

[a] The number corresponds to entries in Figure 2-1.

12 → [b] Used to derive an intermediate inhalation Minimal Risk Level (MRL) of 5 x 10^{-3} ppm; dose adjusted for intermittent exposure and divided by an uncertainty factor of 100 (10 for extrapolation from animal to humans, 10 for human variability).

SAMPLE

1 → **TABLE 2-1. Levels of Significant Exposure to [Chemical x] – Inhalation**

Key to figure[a]	Species	Exposure frequency/ duration	System	NOAEL (ppm)	LOAEL (effect) Less serious (ppm)	Reference
2 → INTERMEDIATE EXPOSURE						
	5	6	7	8	9	10
3 → Systemic	↓	↓	↓	↓	↓	↓
4 → 18	Rat	13 wk 5d/wk 6hr/d	Resp	3 [b]	10 (hyperplasia)	Nitschke et al. 1981
CHRONIC EXPOSURE					11	
Cancer					↓	
38	Rat	18 mo 5d/wk 7hr/d			20 (CEL, multiple organs)	Wong et al. 1982
39	Rat	89–104 wk 5d/wk 6hr/d			10 (CEL, lung tumors, nasal tumors)	NTP 1982
40	Mouse	79–103 wk 5d/wk 6hr/d			10 (CEL, lung tumors, hemangiosarcomas)	NTP 1982

[a] The number corresponds to entries in Figure 2-1.

12 → [b] uncertainty factor of 100 (10 for extrapolation from animal to humans, 10 for human variability).

CEL = cancer effect level; d = days(s); hr = hour(s); LOAEL = lowest-observed-adverse-effect level; mo = month(s); NOAEL = no-observed-adverse-effect level; Resp = respiratory; wk = week(s)

APPENDIX B

Chapter 2 (Section 2.5)

Relevance to Public Health

The Relevance to Public Health section provides a health effects summary based on evaluations of existing toxicologic, epidemiologic, and toxicokinetic information. This summary is designed to present interpretive, weight-of-evidence discussions for human health endpoints by addressing the following questions.

1. What effects are known to occur in humans?
2. What effects observed in animals are likely to be of concern to humans?
3. What exposure conditions are likely to be of concern to humans, especially around hazardous waste sites?

The section covers endpoints in the same order they appear within the Discussion of Health Effects by Route of Exposure section, by route (inhalation, oral, dermal) and within route by effect. Human data are presented first, then animal data. Both are organized by duration (acute, intermediate, chronic). *In vitro* data and data from parenteral routes (intramuscular, intravenous, subcutaneous, etc.) are also considered in this section. If data are located in the scientific literature, a table of genotoxicity information is included.

The carcinogenic potential of the profiled substance is qualitatively evaluated, when appropriate, using existing toxicokinetic, genotoxic, and carcinogenic data. ATSDR does not currently assess cancer potency or perform cancer risk assessments. Minimal risk levels (MRLs) for noncancer endpoints (if derived) and the endpoints from which they were derived are indicated and discussed.

Limitations to existing scientific literature that prevent a satisfactory evaluation of the relevance to public health are identified in the Data Needs section.

Interpretation of Minimal Risk Levels

Where sufficient toxicologic information is available, we have derived minimal risk levels (MRLs) for inhalation and oral routes of entry at each duration of exposure (acute, intermediate, and chronic). These MRLs are not meant to support regulatory action; but to acquaint health professionals with exposure levels at which adverse health effects are not expected to occur in humans. They should help physicians and public health officials determine the safety of a community living near a chemical emission, given the concentration of a contaminant in air or the estimated daily dose in water. MRLs are based largely on toxicological studies in animals and on reports of human occupational exposure.

MRL users should be familiar with the toxicologic information on which the number is based. Chapter 2.4, “Relevance to Public Health,” contains basic information known about the substance. Other sections such as 2.6, “Interactions with Other Substances,” and 2.7, “Populations that are Unusually Susceptible” provide important supplemental information.

MRL users should also understand the MRL derivation methodology. MRLs are derived using a modified version of the risk assessment methodology the Environmental Protection Agency (EPA) provides (Barnes and Dourson 1988) to determine reference doses for lifetime exposure (RfDs).

APPENDIX B

To derive an MRL, ATSDR generally selects the most sensitive endpoint which, in its best judgement, represents the most sensitive human health effect for a given exposure route and duration. ATSDR cannot make this judgement or derive an MRL unless information (quantitative or qualitative) is available for all potential systemic, neurological, and developmental effects. If this information and reliable quantitative data on the chosen endpoint are available, ATSDR derives an MRL using the most sensitive species (when information from multiple species is available) with the highest NOAEL that does not exceed any adverse effect levels. When a NOAEL is not available, a lowest-observed-adverse-effect level (LOAEL) can be used to derive an MRL, and an uncertainty factor (UF) of 10 must be employed. Additional uncertainty factors of 10 must be used both for human variability to protect sensitive subpopulations (people who are most susceptible to the health effects caused by the substance) and for interspecies variability (extrapolation from animals to humans). In deriving an MRL, these individual uncertainty factors are multiplied together. The product is then divided into the inhalation concentration or oral dosage selected from the study. Uncertainty factors used in developing a substance-specific MRL are provided in the footnotes of the LSE Tables.

APPENDIX C

ACRONYMS, ABBREVIATIONS, AND SYMBOLS

ACGIH	American Conference of Governmental Industrial Hygienists
ADME	Absorption, Distribution, Metabolism, and Excretion
atm	atmosphere
ATSDR	Agency for Toxic Substances and Disease Registry
BCF	bioconcentration factor
BSC	Board of Scientific Counselors
C	Centigrade
CDC	Centers for Disease Control
CEL	Cancer Effect Level
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CLP	Contract Laboratory Program
cm	centimeter
CNS	central nervous system
d	day
DHEW	Department of Health, Education, and Welfare
DHHS	Department of Health and Human Services
DOL	Department of Labor
ECG	electrocardiogram
EEG	electroencephalogram
EPA	Environmental Protection Agency
EKG	see ECG
F	Fahrenheit
F_1	first filial generation
FAO	Food and Agricultural Organization of the United Nations
FEMA	Federal Emergency Management Agency
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
fpm	feet per minute
ft	foot
FR	*Federal Register*
g	gram
GC	gas chromatography
gen	generation
HPLC	high-performance liquid chromatography
hr	hour
IDLH	Immediately Dangerous to Life and Health
IARC	International Agency for Research on Cancer
ILO	International Labor Organization
in	inch
Kd	adsorption ratio
kg	kilogram
kkg	metric ton
K_{oc}	organic carbon partition coefficient
K_{ow}	octanol-water partition coefficient

L	liter
LC	liquid chromatography
LC_{Lo}	lethal concentration, low
LC_{50}	lethal concentration, 50% kill
LD_{Lo}	lethal dose, low
LD_{50}	lethal dose, 50% kill
LOAEL	lowest-observed-adverse-effect level
LSE	Levels of Significant Exposure
m	meter
mg	milligram
min	minute
mL	milliliter
mm	millimeter
mm Hg	millimeters of mercury
mmol	millimole
mo	month
mppcf	millions of particles per cubic foot
MRL	Minimal Risk Level
MS	mass spectrometry
NIEHS	National Institute of Environmental Health Sciences
NIOSH	National Institute for Occupational Safety and Health
NIOSHTIC	NIOSH's Computerized Information Retrieval System
ng	nanogram
nm	nanometer
NHANES	National Health and Nutrition Examination Survey
nmol	nanomole
NOAEL	no-observed-adverse-effect level
NOES	National Occupational Exposure Survey
NOHS	National Occupational Hazard Survey
NPL	National Priorities List
NRC	National Research Council
NTIS	National Technical Information Service
NTP	National Toxicology Program
OSHA	Occupational Safety and Health Administration
PEL	permissible exposure limit
pg	picogram
pmol	picomole
PHS	Public Health Service
PMR	proportionate mortality ratio
ppb	parts per billion
ppm	parts per million
ppt	parts per trillion
REL	recommended exposure limit
RfD	Reference Dose
RTECS	Registry of Toxic Effects of Chemical Substances
sec	second
SCE	sister chromatid exchange
SIC	Standard Industrial Classification
SMR	standard mortality ratio

STEL	short term exposure limit
STORET	STORAGE and RETRIEVAL
TLV	threshold limit value
TSCA	Toxic Substances Control Act
TRI	Toxics Release Inventory
TWA	time-weighted average
U.S.	United States
UF	uncertainty factor
yr	year
WHO	World Health Organization
wk	week

>	greater than
≥	greater than or equal to
=	equal to
<	less than
≤	less than or equal to
%	percent
α	alpha
β	beta
δ	delta
γ	gamma
μm	micrometer
μg	microgram

Chlorpyrifos

Technical Fact Sheet

As of 2011, NPIC stopped creating technical pesticide fact sheets. The old collection of technical fact sheets will remain available in this archive, but they may contain out-of-date material. NPIC no longer has the capacity to consistently update them. To visit our general fact sheets, click here. For up-to-date technical fact sheets, please visit the Environmental Protection Agency's webpage.

Chemical Class and Type:

- Chlorpyrifos is a broad-spectrum, chlorinated organophosphate (OP) insecticide, acaricide and nematicide. Chlorpyrifos is the common name for the chemical 0,0-diethyl 0-(3,5,6-

trichloro-2-pyridinyl)-phosphorothioate. The Chemical Abstracts Service (CAS) registry number is 2921-88-2.[1]

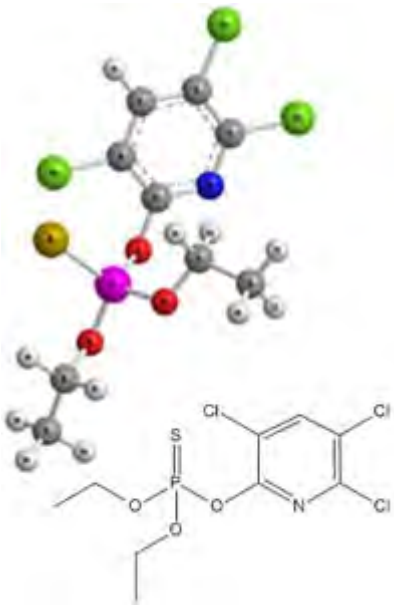
- Chlorpyrifos was first registered for use in the United States in 1965.[1] The United States Environmental Protection Agency (U.S. EPA) completed the OP cumulative risk assessment in July 2006. At that time, the reregistration eligibility decision for chlorpyrifos was considered complete.[1] See the text box on **Laboratory Testing**.

Laboratory Testing: Before pesticides are registered by the U.S. EPA, they must undergo laboratory testing for short-term (acute) and long-term (chronic) health effects. Laboratory animals are purposely given high enough doses to cause toxic effects. These tests help scientists judge how these chemicals might affect humans, domestic animals, and wildlife in cases of overexposure.

Physical / Chemical Properties:

- Chlorpyrifos is a colorless to white crystalline solid.[1,2] Chlorpyrifos has a mild mercaptan (thiol) odor, similar to the smell of sulfur compounds found in rotten eggs, onions, garlic and skunks.[2,3]
- Vapor pressure[4]: 1.87 x 10^{-5} mmHg at 25 °C
- Octanol-Water Partition Coefficient (K_{ow})[2]: 4.70
- Henry's constant may be determined by estimation or experimentally derived. Reported values include: 4.2 x 10^{-6} atm·m^3/mol at 25 °C and 6.7 x 10^{-6} atm·m^3/mol, depending on the technique used.[2,4]
- Molecular weight[1]: 350.6 g/mol
- Solubility (water)[2]: 0.0014 g/L (1.4 mg/L) at 25 °C
- Soil Sorption Coefficient (K_{oc})[5]: 360 to 31,000 depending on soil type and environmental conditions.

Molecular Structure - Chlorpyrifos



Uses:

- Chlorpyrifos is used on agricultural food and feed crops, cattle ear tags, golf course turf, industrial plants and vehicles, non-structural wood treatments including processed wood products, fence posts and utility poles, and to control public health pests such as mosquitoes and fire ants. Chlorpyrifos is registered for indoor residential use only in the form of containerized baits.[1] Uses for individual products containing chlorpyrifos vary widely. Always read and follow the label when applying pesticide products.
- Chlorpyrifos is a non-systemic insecticide designed to be effective by direct contact, ingestion, and inhalation.[2]
- Signal words for products containing chlorpyrifos may range from Caution to Danger. The signal word reflects the combined toxicity of the active ingredient and other ingredients in the product. See the pesticide label on the product and refer to the NPIC fact sheets on **Signal Words** and **Inert or "Other" Ingredients**.
- To find a list of products containing chlorpyrifos which are registered in your state, visit the website **http://npic.orst.edu/reg/state_agencies.html** select your state then click on the link for "State Products."

Mode of Action:

Target Organisms

- Chlorpyrifos is a broad-spectrum insecticide which kills insects upon contact by affecting the normal function of the nervous system.[4] Chlorpyrifos affects the nervous system by inhibiting the breakdown of acetylcholine (ACh), a neurotransmitter.[5] When insects are exposed, chlorpyrifos binds to the active site of the cholinesterase (ChE) enzyme, which prevents breakdown of ACh in the synaptic cleft.[6] The resulting accumulation of ACh in the synaptic cleft causes overstimulation of the neuronal cells, which leads to neurotoxicity and eventually death.[6,7]
- Chlorpyrifos shares a common mechanism of toxicity with other organophosphate insecticides such as malathion and parathion, thus, chlorpyrifos would not be effective against organophosphate-resistant insect populations.

Non-target Organisms

- The mode of action of chlorpyrifos is similar for target and non-target organisms.[8]
- Acetylcholine is found throughout the mammalian nervous system, including at cholinergic synapses in the central nervous system, the junction of post-ganglionic parasympathetic neurons in exocrine glands and smooth and cardiac muscles, at pre- and post-ganglionic neurons in the autonomic nervous system, at neuromuscular junctions of the somatic nervous system, and on the surface of red blood cells.[8,9]
- Chlorpyrifos affects ChE levels differently in various systems throughout the body. Scientists have observed plasma and red blood cell ChE inhibition in experimental animals at doses lower than those required to cause ChE inhibition in the brain.[5]
- The physiological functions of the neuropathy target esterase (NTE) enzyme were studied in genetically altered mice, which lacked the NTE enzyme. The results demonstrated that NTE plays an essential role in placental development, blood vessel development and protein synthesis in the central nervous system.[10] Chlorpyrifos can inhibit NTE by binding to the active site of the enzyme. Inhibition of the NTE enzyme results in loss of myelin and degeneration of axon fibers of the peripheral and central nerves.[8,9]
- Chlorpyrifos can cause permanent inhibition of the ChE or NTE enzymes, a process known as aging. Cleavage of an alkyl group from the chlorpyrifos residue produces a negative charge at the active site of the enzyme. This causes an unbreakable bond to form between the phosphorous atom on chlorpyrifos and the active site of the ChE or NTE enzyme.[9,10]
- Chlorpyrifos also interacts with other enzymes, such as carboxylesterases and A-esterases. The functional role of these enzymes is not well understood, although they occur in many mammalian systems.[6]

Acute Toxicity:

Oral

- Chlorpyrifos is moderately toxic to mice and rats.[1] The oral LD_{50} for mice is 60 mg/kg; for rats it ranges from 95 to 270 mg/ kg.[1,2,11] See the text boxes on **Toxicity Classification** and **LD_{50}/LC_{50}**.
- Chlorpyrifos is slightly toxic to rabbits. The acute oral LD_{50} in rabbits ranges from 1000 to 2000 mg/kg.[2]
- Chlorpyrifos is moderately toxic to guinea pigs and sheep. The acute oral LD_{50} in guinea pigs ranges from 500 to 504 mg/ kg and 800 mg/kg in sheep.[2,11]
- Chlorpyrifos is highly toxic to chickens. The acute oral LD_{50} in chickens ranges from 32 mg/kg to 102 mg/kg.[2,11]

- Data from two human studies indicate that humans may be more sensitive to chlorpyrifos compared to rats or dogs, following acute oral and dermal exposure, based on plasma ChE inhibition and blurred vision. Rats have relatively more acetylcholinesterase while humans and dogs have a higher concentration of butyrylcholinesterase (BuChE). Butyrylcholinesterase appears to be more sensitive to ChE inhibitors than AChE. This sensitivity may contribute to the different effects observed in rats, compared to humans and dogs.[5]

LD_{50}/LC_{50}: A common measure of acute toxicity is the lethal dose (LD_{50}) or lethal concentration (LC_{50}) that causes death (resulting from a single or limited exposure) in 50 percent of the treated animals. LD_{50} is generally expressed as the dose in milligrams (mg) of chemical per kilogram (kg) of body weight. LC_{50} is often expressed as mg of chemical per volume (e.g., liter (L)) of medium (i.e., air or water) the organism is exposed to. Chemicals are considered highly toxic when the LD_{50}/LC_{50} is small and practically non-toxic when the value is large. However, the LD_{50}/LC_{50} does not reflect any effects from long-term exposure (i.e., cancer, birth defects or reproductive toxicity) that may occur at levels below those that cause death.

- Research has shown that neonates and the young are more susceptible than adults to adverse effects from exposure to chlorpyrifos at levels below those causing ChE inhibition.[5] Researchers reported adverse neurobehavioral effects in rats,[12,13] effects on rat neuronal cell development,[14] DNA synthesis in rats,[15] gene transcription and cell differentiation in in vitro models,[16] synaptogenesis in rats,[17] and behavioral and social effects in rat neonates and adolescent mice.[6,18] Rat neonates showed up to a 9-fold greater sensitivity to chlorpyrifos compared with adult rats at the highest doses tested.[19]
- Based on lethality and measurements of ChE inhibition in several studies, female rats appear to have a slightly elevated sensitivity to oral chlorpyrifos exposure compared to males.[5,20]
- In cattle, bulls are more sensitive to chlorpyrifos exposure compared to cows.[21]

Dermal

- Chlorpyrifos absorbs more easily through rat skin than human skin. Chlorpyrifos is not readily absorbed through human skin.[22,23]
- Skin-applied chlorpyrifos has low toxicity based on animal studies. The acute dermal LD_{50} for rabbits is >5,000 mg/kg and >2,000 mg/kg for rats,[2] although an acute dermal LD_{50} of 202 mg/kg has also been reported for rats.[1]

TOXICITY CLASSIFICATION - CHLORPYRIFOS

	High Toxicity	Moderate Toxicity	Low Toxicity	Very Low Toxicity
Acute Oral LD_{50}	Up to and including 50 mg/kg (≤ 50 mg/kg)	**Greater than 50 through 500 mg/kg (>50-500 mg/kg)**	**Greater than 500 through 5000 mg/kg (>500-5000 mg/kg)**	Greater than 5000 mg/kg (>5000 mg/kg)
Inhalation LC_{50}	Up to and including 0.05 mg/L (≤0.05 mg/L)	**Greater than 0.05 through 0.5 mg/L (>0.05-0.5 mg/L)**	Greater than 0.5 through 2.0 mg/L (>0.5-2.0 mg/L)	Greater than 2.0 mg/L (>2.0 mg/L)
Dermal LD_{50}	Up to and including 200 mg/kg (≤200 mg/kg)	**Greater than 200 through 2000 mg/kg (>200-2000 mg/kg)**	**Greater than 2000 through 5000 mg/kg (>2000-5000 mg/kg)**	**Greater than 5000 mg/kg (>5000 mg/kg)**
Primary Eye Irritation	Corrosive (irreversible destruction of ocular tissue) or corneal involvement or irritation persisting for more than 21 days	Corneal involvement or other eye irritation clearing in 8 - 21 days	**Corneal involvement or other eye irritation clearing in 7 days or less**	Minimal effects clearing in less than 24 hours

Primary Skin Irritation	Corrosive (tissue destruction into the dermis and/or scarring)	Severe irritation at 72 hours (severe erythema or edema)	Moderate irritation at 72 hours (moderate erythema)	**Mild or slight irritation at 72 hours (no irritation or erythema)**

The highlighted boxes reflect the values in the "Acute Toxicity" section of this fact sheet. Modeled after the U.S. Environmental Protection Agency, Office of Pesticide Programs, Label Review Manual, Chapter 7: Precautionary Labeling. https://www.epa.gov/sites/default/files/2018-04/documents/chap-07-mar-2018.pdf

- Chlorpyrifos is a mild skin and moderate eye irritant based on rabbit studies. Chlorpyrifos is not a skin sensitizer according to results of tests on guinea pigs.[2]
- The acute dermal NOAEL for chlorpyrifos is 5 mg/kg/day. The NOAEL is based on a 21-day dermal study where rats were exposed to 10 mg/kg/day. In this study, researchers observed 45% plasma ChE inhibition and 16% red blood cell ChE inhibition after four days of exposure to the LOAEL (10 mg/kg/day).[5] See the text box on **NOAEL, NOEL, LOAEL, and LOEL**.

NOAEL: No Observable Adverse Effect Level

NOEL: No Observed Effect Level

LOAEL: Lowest Observable Adverse Effect Level

LOEL: Lowest Observed Effect Level

Inhalation

- Chlorpyrifos is considered moderately toxic by inhalation. The 4- to 6-hour LC_{50} is >0.2 mg/L in rats.[2,11]
- The NOAEL for short- and intermediate-term inhalation is 0.1 mg/kg/day. The NOAEL is based on two separate 90-day studies of rats where researchers observed no effect at the highest vapor concentration tested.[5]

Signs of Toxicity - Animals

- Acute signs of toxicity can appear within minutes of exposure to chlorpyrifos. The signs typically appear at muscarinic receptor sites first, followed by nicotinic receptor sites and finally at central nervous system receptor sites.[9]
- Muscarinic signs from acute exposure to chlorpyrifos include abdominal pain, bronchospasm, constricted pupils, coughing, decreased heart rate, defecation, difficulty breathing, diminished appetite, distress, vomiting and increased tear production, salivation, and urination. Nicotinic signs include muscle tremors that are noted first in the head and then the body, generalized sustained muscle contractions, stiffness, weakness with paresis, and paralysis. Reported signs from extremely high oral doses include an increase in heart rate and constriction of the pupils. Central nervous system signs include diminished appetite, anxiety, restlessness, hyperactivity, depression, clonic-tonic seizures, depressed respiration, and coma.[9]
- Cats have experienced lethal effects from chlorpyrifos at doses of 10 to 40 mg/kg.[9]
- An exposure to chlorpyrifos may result in an intermediate syndrome, in which signs appear more than 24 hours after exposure, and can last several days or even weeks. Signs have been reported to develop within 24 to 72 hours in dogs and cats. It appears that intermediate syndrome involves tolerance to the overstimulation of ACh in muscarinic receptors. This tolerance does not develop at nicotinic receptors, and therefore the syndrome is characterized primarily by nicotinic effects. Signs from intermediate syndrome include: weakness of the neck, front limbs and respiratory muscles, diminished appetite, depression, diarrhea, muscle tremors, unusual posturing and behavior (including cervical

ventroflexion), and death. Additional signs may include cranial nerve defects and clonic-tonic convulsions.[9,24]

- When chlorpyrifos was registered for residential use, dermal exposure of cats to chlorpyrifos residues in the home environment was the most commonly reported cause of intermediate syndrome in domestic animals. In such cases, symptoms appeared 3-10 days after exposure to chlorpyrifos.[9] See the NPIC fact sheet on **Pets and Pesticide Use**.
- Another phenomenon, Organophosphate Induced Delayed Neuropathy (OPIDN) differs from intermediate syndrome in that the onset of signs may occur weeks after an acute, high-dose exposure to OPs.[25] Cats and chickens exposed to supralethal doses of chlorpyrifos showed signs consistent with delayed neuropathy. In both cases, the animals were treated with atropine to resolve acute cholinergic symptoms. Ataxia, altered movements, and impairment of spatial perception were reported signs of delayed neuropathy.[26,27] OPIDN signs are primarily evident in the hind or pelvic limbs of exposed animals.[24]

Signs of Toxicity - Humans

- Signs and symptoms typically develop within minutes to hours after an acute exposure to chlorpyrifos. Initial signs and symptoms include tearing of the eyes, runny nose, increased saliva and sweat production, nausea, dizziness and headache. Signs of progression include muscle twitching, weakness or tremors, lack of coordination, vomiting, abdominal cramps, diarrhea, and pupil constriction with blurred or darkened vision.[8,28,29] Signs of severe toxicity include increased heart rate, unconsciousness, loss of control of the urine or bowels, convulsions, respiratory depression, and paralysis.[8,28]
- Psychiatric symptoms associated with acute exposure include anxiety, depression, memory loss, confusion, stupor, bizarre behavior, and restlessness.[8,28,29]
- Children may experience different signs and symptoms from exposure to chlorpyrifos than adults, and diagnosis of poisoning in general may be more difficult.[8,29] Commonly reported signs and symptoms in poisonings with children include seizures, flaccid muscle weakness, pupil constriction, excess salivation ,and mental status changes including lethargy and coma. Some of the typical symptoms seen in adults, such as decreased heart rate, muscle twitching, increased tear production, and sweating, are less common in children.[8]
- Single, high-dose exposures to organophosphates in humans can also result in intermediate syndrome. Signs and symptoms typically occur 24-96 hours after exposure. As in animals, the syndrome is characterized by the absence of muscarinic signs. Signs of toxicity result from the inhibition of nicotinic receptors. Signs observed in humans include reduced tendon reflexes, cranial nerve palsies, weakness in the facial, neck, proximal limb muscles, and partial respiratory paralysis.[8]
- Delayed neurological symptoms, beginning 1-4 weeks after exposure, may also result from an acute, high-dose exposure to OPs.[11] As in animals, this prolonged delay in neurological symptoms is referred to as OPIDN and onset depends on the dose and route of exposure. Reports of OPIDN from exposure to chlorpyrifos are limited to acute, high-dose exposures where treatment with therapeutic agents was used to resolve acute cholinergic toxicity.[30] In one case, a 42-year old man intentionally ingested chlorpyrifos in a suicide attempt, and in a second case, a 3-year-old boy accidentally ingested chlorpyrifos.[31,32] It has been suggested that supralethal doses followed with antidotal therapy, rather than low-level, chronic exposures, would be necessary for chlorpyrifos to cause OPIDN in humans.[30]
- OPIDN typically affects the lower extremities and can cause cramping, muscle pain, weakness and paresthesia, which is described as numbness and tingling sensations. In more severe cases, musculoskeletal effects including depression of tendon reflexes in the arms, symmetrical wasting, flaccid weakness, and paralysis of distal muscles (most

commonly the legs) have been reported. Signs and symptoms from OPIDN may persist from weeks to years.[8,10,25]

- Always **follow label instructions** and take steps to **minimize exposure**. If any exposure occurs, be sure to follow the First Aid instructions on the product label carefully. For additional treatment advice, contact the Poison Control Center at 1-800- 222-1222. If you wish to **discuss an incident** with the National Pesticide Information Center, please call 1-800-858-7378.

Chronic Toxicity:

Animals

- The most sensitive endpoint in rats, mice and dogs chronically exposed to chlorpyrifos is inhibition of ChE in the plasma, red blood cells and brain. Dogs showed increased liver weights at doses of 3 mg/kg/day. Rats exposed to 7-10 mg/kg/day displayed fluctuations in body weight as well as adverse effects on the eyes, adrenal glands and liver chemistry. Mice appear to be less sensitive to chronic oral exposures of chlorpyrifos, with decreases in body weights and increases in tissue abnormalities occurring at doses of 45-48 mg/kg/day.[5]
- In rats, age-related differences in sensitivity to chronic chlorpyrifos exposure do not appear to be as significant as the agerelated sensitivity differences observed in rats exposed to acute doses of chlorpyrifos.[19]
- The chronic dermal NOAEL and the long-term inhalation NOAEL are 0.03 mg/kg/day based on five chronic toxicity studies reported in dogs and rats. These studies demonstrated adverse effects including plasma and red blood cell ChE inhibition at 0.22 to 0.30 mg/kg/day.[5]
- Both sexes of Fischer 344 rats exposed orally to 1 mg/kg/day of technical grade chlorpyrifos for 2 years had significantly reduced plasma and red blood cell cholinesterase levels.[33]
- Chronic, low level exposures to organophosphates may lead to the development of a tolerance to the effects of ChE inhibition in exposed animals. Though the exact mechanism of tolerance development has not been identified, it is possible that changes in postsynaptic receptors may mitigate some of the anticholinesterase effects.[34] When a tolerance to anticholinesterase compounds has developed, animals may appear more resistant to the effects of ChE inhibition, and signs of toxicity may be decreased or disappear entirely. Some experimental animals have also shown the ability to handle higher doses of organophosphates than unexposed animals.[34,35]

Humans

- A panel of scientists reviewed the available research on chlorpyrifos and its potential to affect human health. The researchers concluded that the current literature does not show that chronic chlorpyrifos exposure causes adverse effects on human health beyond cholinesterase inhibition. The group suggested that further research be conducted on workers in chlorpyrifos manufacturing, as they are likely to be exposed with more frequency and possibly at higher levels than the general population. The group suggested that further research should focus on the potential for chlorpyrifos to cause peripheral neuropathy and cognitive and affective disorders.[36]
- An occupational study was conducted to evaluate the potential for chronic, low-level exposure to chlorpyrifos to affect the central nervous system. Investigators used a prospective cohort study design involving one group of chlorpyrifos-manufacturing workers and a control group. The chlorpyrifos-exposed workers had significantly higher levels of a chlorpyrifos urinary metabolite, 3,5,6-trichloro-2-pyridinol (TCP), and had lower average

BuChE levels. There was no significant difference in neurological symptoms or signs between the two groups, nor was there clinical evidence of adverse effects on the central nervous system at baseline or at the 1-year follow-up evaluation.[37] See the text box on **Exposure**.

> **Exposure: Effects of chlorpyrifos on human health and the environment depend on how much chlorpyrifos is present and the length and frequency of exposure. Effects also depend on the health of a person and/or certain environmental factors.**

- Male volunteers consumed doses up to 0.1 mg/kg/day for up to seven weeks. Significant plasma cholinesterase inhibition was observed, which ranged from 36-82% at the highest dose after nine days of treatment. On the final day of the study, one of the four men in the highest dose group had a runny nose, blurred vision, and felt faint. Exposure in the highest dose group was discontinued due to plasma cholinesterase inhibition greater than 20-30%, the study guideline. Plasma cholinesterase levels resolved to baseline levels after 25 days of recovery.[38]
- Acute, high-dose exposures to chlorpyrifos described in case reports have shown evidence of delayed neuropathy.[30,31,32] Supralethal exposures occurred in two of the cases, and interventions were required to reverse acute toxic effects. Delayed effects were noted, but due to the nature of clinical reports, limited information regarding signs, symptoms and/or laboratory results are available for these cases.[30]

Endocrine Disruption:

- Chlorpyrifos is included in the 2007 draft list of initial chemicals for screening under the U.S. EPA Endocrine Disruptor Screening Program (EDSP). The list of chemicals was generated based on exposure potential, not based on whether the pesticide is a known or likely potential cause of endocrine effects.[39]
- No data were found regarding possible effects of chlorpyrifos on endocrine systems.

Carcinogenicity:

Animals

- Chlorpyrifos did not induce treatment-related tumors or carcinogenicity in two chronic rat and two chronic mouse studies.[5]
- Rats exposed to chlorpyrifos for two years at 0.05, 0.10, 1.0 and 10.0 mg/kg/day did not show any carcinogenic effects.[33]
- Scientists observed no genotoxic effects from chlorpyrifos in a range of in vitro and in vivo studies.[2]
- According to the Agency for Toxic Substances and Disease Registry (ATSDR), animal studies do not indicate that chlorpyrifos causes cancer.[7]

Humans

- In 1993, chlorpyrifos was classified in Group E, evidence of non-carcinogenicity for humans, by the U.S. EPA.[40] See the text box on **Cancer**.
- No human data were found regarding carcinogenic effects of chlorpyrifos.

> **Cancer: Government agencies in the United States and abroad have developed programs to evaluate the potential for a chemical to cause cancer. Testing**

guidelines and classification systems vary. To learn more about the meaning of various cancer classification descriptors listed in this fact sheet, please visit the appropriate reference, or call NPIC.

Reproductive or Teratogenic Effects:

Animals

- Researchers have reported behavioral effects from chlorpyrifos in studies with rats, including developmental delays in coordination, reflexes, and locomotor activity.[41,42] Researchers have also noted altered expressions of social behavior[18] and impaired spatial learning in exposed animals.[43] Gender differences in behavioral effects appear to be dependent on the age of the rat at the time of chlorpyrifos exposure.[18]
- Several studies have shown an increased sensitivity and susceptibility to adverse biochemical and behavioral effects in developing rats exposed either pre- or post-natally to chlorpyrifos when compared to adults.[19,20]
- Researchers observed structural changes in brain development of female offspring of rats exposed to chlorpyrifos at 1 mg/ kg/day, the lowest dose administered. In the dams, researchers observed inhibition of ChE in plasma and red blood cells at the same dose. The male and female pups of the exposed dams were exposed to 5 mg/kg/day and exhibited decreased body weight, decreased body weight gain, decreased food consumption, reductions in the number of viable offspring, developmental delays, decreased brain weight and morphological changes in the brain.[5]
- Reproductive and developmental effects from chlorpyrifos exposure have been observed at varying developmental stages in rats, mice and rabbits.[5]
- Age-related differences in neurotoxic effects independent of ChE inhibition have been observed in numerous developmental studies with rats, rabbits and mice exposed to chlorpyrifos. Neurotoxic effects observed include: programmed cell death, altered neuronal development, altered gene transcription and cell differentiation, impaired synthesis of DNA, RNA, and proteins, adverse effects on cell reproduction, and changes in brain development.[18,41,44]
- Some studies have observed neurodevelopmental effects at exposure levels below those causing AChE inhibition, but the mechanism for these effects is uncertain. Researchers have proposed that chlorpyrifos, rather than the oxon or other metabolites, may play a role in developmental neurotoxicity. Due to the relationship between low-level exposures to chlorpyrifos and some observed neurodevelopmental effects, as well as the environmental relevance of low-level exposures, researchers have concluded that further studies are needed to characterize the mechanisms of this potential effect.[45]
- In subacute reproductive studies with mallard ducks (***Anas platyrhynchos***), scientists observed reduced egg production, thinning of eggshells, reduced number of young, and death when hens were fed chlorpyrifos in their diets at concentrations of 60, 100, and 125 ppm. At the highest dose tested, researchers observed an 84% reduction in the number of eggs and 89% reduction in the number of young.[4]

Humans

- A prospective cohort study evaluated the relationship between chlorpyrifos levels in both umbilical cord plasma and mother's plasma at the time of birth, and impacts on neurological and behavioral development of children exposed prenatally. The study included 254 children and assessed cognitive and motor development at 12, 24, and 36 months. Researchers found that children and mothers with detected chlorpyrifos levels at or above 6.17 pg/g

plasma were significantly more likely to experience adverse effects, including developmental delays and disorders, attention problems, and attention-deficit/ hyperactivity disorder at three years of age compared to children and/or mothers with levels lower than 6.17 pg/g.[46]

Fate in the Body:

Absorption

- Chlorpyrifos is absorbed by all routes of exposure. Urinalysis of exposed human volunteers indicates that approximately 70% is absorbed by the oral route, while less than 3% is absorbed through the skin.[23] Exposure to chlorpyrifos by inhalation results in the fastest appearance of symptoms, followed by oral and then dermal routes of exposure.[8]
- Researchers evaluated the absorption of chlorpyrifos by oral and dermal exposure in five human volunteers. Absorption of chlorpyrifos was based on levels of the dialkylphosphate metabolites of chlorpyrifos, diethylphosphate and diethylthiophosphate. Peak urinary metabolite levels were observed at seven hours following oral exposure. For dermal exposure, peak metabolite concentrations were observed at 17 to 24 hours post-exposure.[47]
- In a similar study, maximum absorption levels for oral and dermal chlorpyrifos exposure were determined with six human volunteers. In this study, oral and dermal absorption rates were based on urinary concentrations of TCP, a primary chlorpyrifos metabolite. For oral exposure, peak levels were measured 6 hours after exposure. Maximum urinary TCP levels occurred 24 hours after dermal exposure.[23]
- The chlorine group on chlorpyrifos increases the compound's lipid solubility and half-life in the body, resulting in a more gradual, but persistent, lowering of ChE levels compared to other organophosphorus pesticides.[9]

Distribution

- Chlorpyrifos is distributed throughout the body following exposure.[9]
- Although some chlorpyrifos may be stored in fat tissue, bioaccumulation is not expected to be significant due to an elimination half-life in humans of less than three days.[11]

Metabolism

- Metabolic bioactivation is necessary for chlorpyrifos to exert cholinesterase inhibition.[6,48] Bioactivation occurs primarily in the liver by cytochrome P450 enzymes (CYP). The CYP2B6 enzyme metabolizes chlorpyrifos to chlorpyrifos-oxon by replacing the sulfur group with oxygen.[48]
- Oxidase enzymes in the liver detoxify chlorpyrifos-oxon through inactivation. B-esterases such as carboxylesterase and BuChE become structurally inhibited after the process of inactivation, whereas the A-esterases such as paraoxonase 1 (PON1) can hydrolyze chlorpyrifos-oxon to TCP and remain functional.[48]
- The activity of PON1 in humans is genetically determined and varies among individuals. A higher level of PON1 appears to be protective against cholinergic effects, as evidenced by research in some animals exposed to organophosphates. Thus, certain individuals may have an increased sensitivity to chlorpyrifos toxicity based on a reduced capacity to detoxify chlorpyrifos-oxon.[5] Rabbits have greater PON1 activity and resistance to toxicity than rats, and birds are more sensitive than mammals in general. Birds have nearly undetectable levels of PON1.[5]

- Chlorpyrifos-oxon is metabolized primarily to TCP in addition to diethylphosphate and diethylthiophosphate.[22]
- Glucuronide and sulfate conjugates of TCP have also been observed in the urine of humans and rodents.[5,49] Chlorpyrifos-oxon is the only metabolite of chlorpyrifos that induces ChE inhibition; therefore all other metabolites are considered less toxic.[1,22]
- Subchronic or chronic exposure to TCP at 30 mg/kg/day resulted in altered liver enzyme profiles. At exposures of 100 mg/ kg/day, researchers noted increases in liver and kidney weights.[1]

Excretion

- Elimination of chlorpyrifos occurs mainly through the kidneys. Chlorpyrifos is excreted in the urine as TCP, diethylphosphate and diethylthiophosphate.[11,22]
- In a study with five human volunteers, Griffin and colleagues reported elimination half-lives for oral and dermal exposure of 15.5 hours and 30.0 hours, respectively. Rates were based on levels of diethylphosphate and diethylthiophosphate in the urine. A total of 93% of the oral dose was recovered as urinary metabolites, while 1% of the dermal dose was recovered.[47]
- In a similar study, Nolan ***et al*** observed an elimination half-life of 27 hours following both dermal and oral exposure, based on urinary TCP levels. Nolan and colleagues recovered 70.0% of the oral dose and 1.3% of the dermal dose in the urine as TCP.[23]
- Following oral exposure, rats excreted 90% of ingested chlorpyrifos through the urine and 10% in the feces.[11]

Medical Tests and Monitoring:

- The most common laboratory tests for organophosphate pesticide exposures are ChE inhibition tests which are used to analyze the blood for lowered levels of plasma or red blood cell AChE. These tests may be conducted by hospital laboratories, local clinical laboratories, or other referred laboratories. Other tests for chlorpyrifos exposure are less common and include detection of the parent compound or metabolites in blood or urine.[50]
- The potential for exposure to chlorpyrifos is present in several occupational fields, including agriculture, manufacturing, animal health technicians, pesticide applicators, and others. A baseline analysis of ChE levels in the blood may be mandatory for people who work closely with organophosphates. Following the establishment of a baseline, ChE testing of workers may be conducted to detect cumulative effects from daily exposure before clinical signs are apparent. Monitoring may also be useful to characterize exposures to the workforce as a whole to identify problem areas in the workplace.[51,52]
- Humans and animals may be exposed to metabolites of chlorpyrifos through dietary sources and from background levels found in the environment. The metabolites excreted by humans and animals are in the same family of chemicals as degradates that form when chlorpyrifos is broken down in the environment. Therefore, the presence of metabolites in human urine may indicate direct exposure to metabolites themselves, and doesn't necessarily confirm exposure to chlorpyrifos.[22,53]
- The presence of chlorpyrifos metabolites in the blood or urine does not necessarily indicate that adverse health effects will occur.[22]
- The National Health and Nutrition Examination Survey (NHANES) III study found that 82% of the 993 adults measured had detectable levels of TCP in their urine. The Minnesota Children's Exposure Study found that 92% of the 89 children evaluated had detectable concentrations of TCP in their urine. Similarly, a biomonitoring study in North and South Carolina detected urinary metabolites in 100% of the 416 children evaluated.[5] Amounts of

TCP detected in food samples were greater than amounts of the parent chemical, chlorpyrifos, indicating a high background level of TCP in food. High background levels of TCP may contribute to higher detected urinary TCP levels.[45] See the **NPIC medical case profile** on **Biomarkers of Exposure: Organophosphates**.

Environmental Fate:

The "half-life" is the time required for half of the compound to break down in the environment.

1 half-life = 50% remaining
2 half-lives = 25% remaining
3 half-lives = 12% remaining
4 half-lives = 6% remaining
5 half-lives = 3% remaining

Half-lives can vary widely based on environmental factors. The amount of chemical remaining after a half-life will always depend on the amount of the chemical originally applied. It should be noted that some chemicals may degrade into compounds of toxicological significance.

Soil

- Chlorpyrifos is stable in soils with reported half-lives ranging between 7 and 120 days. Studies have found chlorpyrifos in soils for over one year following application. Soil persistence may depend on the formulation, rate of application, soil type, climate and other conditions. [4,11,54] See the text box on **Half-life**.
- Chlorpyrifos bound to soil may be broken down by UV light, chemical hydrolysis, dechlorination, and soil microbes.[11,54]
- Chlorpyrifos binds strongly to soils, is relatively immobile, and has low water solubility. In contrast, its degradate TCP adsorbs weakly to soil particles and is moderately mobile and persistent in soils.[4,11]
- The major degradates of chlorpyrifos found in soils are similar to the metabolites created by plants and animals. The degradates are formed by oxidative dealkylation or hydrolysis to diethyl phosphates and TCP.[54]
- In a study of seven aerobic soils ranging in texture from loamy sand to clay, with soil pH values from 5.4 to 7.4, the soil halflife for radiolabeled chlorpyrifos ranged from 11 to 141 days. After 360 days, researchers detected carbon dioxide (27-88%), TCP (up to 22%), and small amounts of 3,5,6-trichloro-2-methoxypyridine (≤8%) in the soil.[4,11]
- In medium-textured soils in field conditions in California, Illinois and Michigan, the half-lives reported for chlorpyrifos ranged from 33 to 56 days.[4]
- Chlorpyrifos is less persistent in soils with a higher pH.[4,11]
- Volatilization of chlorpyrifos from soil is not likely. According to a laboratory volatility study, carbon dioxide appears to be the major volatile degradate of chlorpyrifos. In this study, less than 10% of chlorpyrifos applied to soil volatilized within 30 days after application.[4]

Water

- Chlorpyrifos does not partition easily from soil to water. Therefore, chlorpyrifos found in runoff water is likely a result of soil-bound chlorpyrifos from eroding soil, rather than from dissolved chlorpyrifos.[4]
- Volatilization of chlorpyrifos from water is the most likely route of loss for chlorpyrifos, with volatilization half-lives of 3.5 and 20 days estimated for pond water.[11]
- During midsummer, the photolysis half-life of chlorpyrifos in water is between three and four weeks.[11]
- The rate of hydrolysis for chlorpyrifos increases with temperature and alkalinity. Half-lives ranging from 35 to 78 days have been reported in water with a pH of 7 and a temperature of 25 °C.[11]
- The U.S. EPA conducted an analysis of well-monitoring data from the United States Geological Survey's (USGS) National Water Quality Assessment (NAWQA) Program

database and the EPA's Pesticide Ground Water Database. Chlorpyrifos was detected in less than 1% of the more than 3000 wells sampled. The majority of the water concentrations reported were less than 0.01 ppb, with a maximum concentration of 0.65 ppb. Groundwater contamination could be significantly higher in areas treated with a termiticide containing chlorpyrifos, especially if contamination of a well occurs.[5]

- The U.S. EPA also analyzed NAWQA data for surface water contamination. A total of 1530 agricultural streams and 604 urban streams were tested. Of the streams tested, 15% of the agricultural streams and 26% of the urban streams contained chlorpyrifos at concentrations ranging from 0.026 ppb to 0.400 ppb. However, monitoring data were not collected for the watersheds where chlorpyrifos use is pervasive.[5] See the **NPIC fact sheet** on **Pesticides in Drinking Water**.

Air

- Researchers monitored concentrations of chlorpyrifos in outdoor air following ground application of chlorpyrifos in an agricultural setting. Air was sampled for chlorpyrifos and chlorpyrifos-oxon over a four week period during late spring, 24 hours a day, five days per week. Monitoring stations were located within three miles of average daily chlorpyrifos applications of 7.7 pounds per square mile per day. Median air concentrations of chlorpyrifos and chlorpyrifos-oxon were measured at 33 ng/m^3 and 22 ng/m^3, respectively.[55]
- Chlorpyrifos reacts with photochemically-produced hydroxyl radicals in the atmosphere and degrades to chlorpyrifosoxon. An atmospheric vapor half-life of 4.2 hours has been estimated for this reaction.[56] In one study, researchers estimated an outdoor air residence time of 4 and 11 hours for chlorpyrifos and chlorpyrifos oxon, respectively. However, these calculations are based on approximate hydroxyl radical concentrations in a specific geographical area.[57]

Plants

- Chlorpyrifos is not expected to be taken up from soil through the roots of plants.[2]
- Chlorpyrifos was applied to the leaves and fruit of orange and grapefruit trees, and residues and dissipation on the rinds were measured using gas chromatography. Chlorpyrifos residues on fruit rinds were found to dissipate quickly, with initial mean half-lives of 2.8 days in oranges and 3.7 to 6.7 days in grapefruit, at which point residues were at or below 2 ppm. Chlorpyrifos residues were not found above levels of detection (0.03 ppm) in the edible portion (pulp) of citrus fruit tested.[58]
- Though some chlorpyrifos may be taken up by plants through leaf surfaces, much of the applied chlorpyrifos is usually lost from volatilization, and very little is translocated throughout the plant.[54] Chlorpyrifos taken up by plant tissues is primarily metabolized to TCP, which is then stored as glycoside conjugates.[2,54]
- Foliar applied chlorpyrifos on leaf surfaces is lost primarily by volatilization.[54]
- Studies report chlorpyrifos residues remain on plant surfaces for 10 to 14 days after application.[11]
- Although most of the chlorpyrifos applied to plants is lost through volatilization or converted to TCP and sequestered, desulfuration to the chlorpyrifos oxon on plant surfaces has been reported.[54]

Indoor

- Several studies have reported detections of chlorpyrifos in dust, air, carpets, and on surfaces within indoor environments.[59,60,61]
- Research was conducted as part of the Children's Total Exposure to Persistent Pesticides and Other Persistent Organic Pollutants (CTEPP) study to evaluate the potential exposures of preschool children to chlorpyrifos and TCP in their homes and at day care centers in North Carolina. Monitoring of residues was performed at 129 homes and 13 day care centers, and included indoor and outdoor air, indoor floor dust, duplicate meals, transferable residues and surface wipe samples from floors, food preparation surfaces and children's hands. Urine was also collected from children by caretakers. Chlorpyrifos was detected in the indoor floor dust and indoor air at all locations. Median amounts of TCP were 12 and 29 times higher than those of chlorpyrifos in solid food at homes and daycare centers, respectively. Mean chlorpyrifos levels in homes were 19 ng/m^3 in indoor air, 413 ng/g in indoor floor dust and 0.6 ng/g in solid food. Mean chlorpyrifos levels in day care centers were 8.2 ng/m^3 in indoor air, 237.0 ng/g in indoor floor dust, and 0.2 ng/g in solid food.[61]
- Researchers detected chlorpyrifos in all seven homes tested in a New Jersey study. Concentrations in dust ranged from 0.053 ppm to 15.00 ppm. The highest indoor air concentrations detected were between 151.2 ng/m^3 and 154.2 ng/m^3.[59] The air samples with detectable levels of chlorpyrifos were correlated with dust samples that contained the highest levels of chlorpyrifos.[59]
- In another study, researchers tested the indoor air and surfaces of ten urban residences in New Jersey. Chlorpyrifos residues were measured in samples of air and from non-target surfaces including plush toys, smooth surfaces, furniture, windowsills and flooring after the homes were treated with a water emulsion crack and crevice formulation containing 0.25 to 0.50% chlorpyrifos. Chlorpyrifos was detected in all homes within the treated areas throughout the two week post-application period. The highest concentrations of chlorpyrifos detected were 816 ng/m^3 in air, 24.6 ng/m^3 on non-target surfaces, and 1949 ng per toy on plush toys.[60] See the **NPIC fact sheet** on **Pesticides in Indoor Air of Homes - Technical**.

Food Residue

- The United States Department of Agriculture (USDA) Pesticide Data Program collects data on pesticide residues in foods and compiles an annual report of the findings. The 2007 annual summary reported 9734 samples of fruit and vegetable commodities tested for chlorpyrifos residues. Chlorpyrifos was detected in 339 (3.48%) of these samples.[62]
- Chlorpyrifos residues were found in 18.0% of peaches tested (100 detections), in 15.8% of nectarines tested (89 detections), in 6.8% of broccoli tested (50 detections) and in 5.2% of kale greens (20 detections). Chlorpyrifos residues were also monitored in almonds (46% of samples tested, 166 detections) and corn grain (30% of samples tested, 195 detections).[62]
- Chlorpyrifos was detected at levels exceeding the U.S. EPA tolerance in one sample each of collard greens (353 samples, 10 with detectable residues) and summer squash (742 samples, 5 with detectable residues). In collard greens, residues were detected in one sample at 6.3 ppm (tolerance of 2.0 ppm). In summer squash, residues were detected in one sample at 0.33 ppm (tolerance 0.10 ppm).[62]

Ecotoxicity Studies:

Birds

- Chlorpyrifos is very highly toxic to common grackles (***Quiscalus quiscula***) and ring-necked pheasants (***Phasianus colchicus***) with an LD_{50} of 5.62 mg/kg and 8.41 mg/kg, respectively.

Chlorpyrifos is highly toxic to common pigeons (***Columba livia***) and house sparrows (***Passer domesticus***) with an LD_{50} of 10 mg/kg.[4]

- Chlorpyrifos is highly toxic to chickens with an oral LD_{50} ranging from 32-102 mg/kg.[2]
- Chlorpyrifos is moderately toxic to mallard ducks (***Anas platyrhynchos***) with an acute oral LD_{50} of 490 mg/kg.[2]
- The American robin (***Turdus migratorius***) is the most frequently reported avian species killed in field incidents with chlorpyrifos.[4] Currently the acute LD_{50} for the American robin is unknown.

Fish and Aquatic Life

- Chlorpyrifos is very highly toxic to aquatic invertebrates, freshwater fish, and other estuarine and marine organisms.[11]
- The 96-hour LC_{50} is 0.007-0.051 mg/L for rainbow trout (***Oncorhynchus mykiss***), 0.002-0.010 mg/L for bluegill sunfish (***Lepomis macrochirus***), and 0.12-0.54 mg/L for fathead minnows (***Pimephales promelas***).[2]
- The 48-hour LC_{50} for ***Daphnia*** is 1.7 µg/L. The LC_{50} for Korean shrimp (***Palaemon macrodactylus***) is 0.05 µg/L.[2]
- There is potential for chlorpyrifos to bioaccumulate in the tissues of aquatic species.[1] Residues of chlorpyrifos found in fish tissue included the metabolites TCP and two glucuronide conjugates of TCP.[4] Researchers exposed various fish species to chlorpyrifos continuosly during early development, and calculated bioconcentration values ranging from 58 to 5100.[63]

Terrestrial Invertebrates

- There are data gaps in terrestrial risk assessment due to a lack of quantitative methods available to assess risks posed by dermal and inhalation exposures for wildlife.[4]
- Chlorpyrifos is highly toxic to bees. The honey bee (***Apis sp.***) oral LD_{50} is 360 ng/bee.[2] Contact LD_{50}s for honey bees of 59 and 70 ng/bee have been reported.[2,4]
- The 14-day LC_{50} for worms (***Eisenia foetida***) is 210 mg/kg chlorpyrifos in soil.[2]
- Foliar residues from spray applications of 0.5 and 1.0 lbs active ingredient/acre demonstrated toxicity to non-target insects for up to 24 hours post-treatment.[4] See the **NPIC fact sheet** on **Wildlife and Pesticides**.

Regulatory Guidelines:

- The acute Reference Dose (RfD) for chlorpyrifos is 5×10^{-3} mg/kg/day.[1] See the text box on **Reference Dose (RfD)**.
- The chronic RfD for chlorpyrifos is 3×10^{-4} mg/kg/day.[1] The chronic population adjusted dose (cPAD) is 3×10^{-5} mg/kg/day for sensitive subpopulations.[1]
- A Food Quality Protection Act (FQPA) factor of 10 is applied to the acute RfD to derive an acute population adjusted dose (aPAD) which accounts for

Reference Dose (RfD): The RfD is an estimate of the quantity of chemical that a person could be exposed to every day for the rest of their life with no appreciable risk of adverse health effects. The reference dose is typically measured in milligrams (mg) of chemical per kilogram (kg) of body weight per day.

U.S. Environmental Protection Agency, Integrated Risk Information System, IRIS Glossary, 2009. https://www.epa.gov/iris/iris-glossary#r

increased sensitivities in infants, children and females ages 13-50. The aPAD for children and females ages 13-50 is 5 x 10^{-4} mg/kg/day.[1]

- Chlorpyrifos was classified as Group E, evidence of non-carcinogenicity for humans, by the U.S. EPA, in 1993.[40] See the text box on **Cancer**.
- The acute drinking water level of concern (DWLOC) for the general U.S. population is 166 ppb, the chronic DWLOC is 10 ppb. The acute DWLOC for all infants less than one year of age is 2.4 ppb; the chronic is 0.2 ppb. The acute DWLOC for children ages 1-6 years is 0.9 ppb; the chronic is 0.15 ppb. The acute DWLOC for females ages 13-50 years is 9 ppb; the chronic is 0.72 ppb.[1]
- No drinking water standard exists for chlorpyrifos. However, the U.S. EPA has set a one-day and 10-day health advisory for children at 0.03 mg/L. The drinking water RfD is 3 x 10^{-4} mg/kg/day. The drinking water equivalent level is 0.01 mg/L and a lifetime health advisory is set at 2 x 10^{-3} mg/L.[64]
- Pesticide exposure reporting laws vary by state. For example, some states may require mandatory medical monitoring with laboratory reporting for workers with blood cholinesterase levels below the normal range.[65] Reporting rules also vary by state regarding the individual responsible for reporting the results (e.g. the physician ordering the test, the laboratory responsible for sample collection, or the laboratory conducting the test).65 See the NPIC medical case profile on Pesticide Incident Reporting.
- The National Institute for Occupational Safety and Health (NIOSH) occupational exposure Threshold Limit Value (TLV) for inhalable vapor or aerosol is 0.1 mg/m^3.[51]
- The NIOSH Recommended Exposure Limit (REL) is 0.2 mg/m^3, with a short-term skin exposure limit (15 minutes) of 0.6 mg/m^3.[51]

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OFFICE OF
CHEMICAL SAFETY AND
POLLUTION PREVENTION

MEMORANDUM

Date: September 21, 2020

SUBJECT: Chlorpyrifos: Third Revised Human Health Risk Assessment for Registration Review.

PC Code: 059101
Decision No.: 559846
Petition No.: NA
Risk Assessment Type: Single Chemical Aggregate
TXR No.: NA
MRID No.: NA

DP Barcode: D456427
Registration No.: NA
Regulatory Action: Registration Review
Case No.: NA
CAS No.: 2921-88-2
40 CFR: §180.342

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Pesticide Re-evaluation Division (PRD) (7508P)

As part of Registration Review, the Pesticide Re-evaluation Division (PRD) of the Office of Pesticide Programs (OPP) has requested that Health Effects Division (HED) evaluate the hazard and exposure data and conduct dietary (food and drinking water), residential, aggregate, and occupational exposure assessments to estimate the risk to human health that will result from the currently registered uses of pesticides. This memorandum serves as HED's draft human health risk assessment (DRA) for chlorpyrifos to support Registration Review.

The most recent human health risk assessment for chlorpyrifos was completed in 2016 (W. Britton *et al*, D436317, 11/03/2016). The following revisions have been included in the current risk assessment:

- The toxicological points of departure (PODs) are derived from 10% red blood cell (RBC) acetyl cholinesterase (AChE) inhibition using a physiologically-based pharmacokinetic-pharmacodynamic (PBPK-PD) model, as reported in the 2014 revised chlorpyrifos Human Health Risk Assessment (HHRA) (2014 (D. Drew *et al.*, D424485, 12/29/2014);
- Because the science addressing neurodevelopmental effects remains unresolved, the dietary, residential, aggregate, and non-occupational risk assessments have been conducted both with retention of the 10X Food Quality Protection Act (FQPA) safety factor (SF) and without retention of the 10X FQPA SF (*i.e.*, FQPA SF reduced to 1X). Similarly, the occupational risk assessments have been conducted both with and without retention of a 10X Database Uncertainty Factor (UF_{DB}).

As part of an international effort, the EPA's Office of Research and Development (ORD) has been developing a battery of new approach methodologies (NAMs)[1] for evaluating developmental neurotoxicity (DNT). The suite of *in vitro* assays developed by ORD evaluates the majority, but not all, of the critical processes of neurodevelopment. The ORD assays will be presented, using the organophosphates (OPs) as a case study, to the Federal Insecticide, Fungicide, and Rodenticide (FIFRA) Scientific Advisory Panel (SAP) in September 2020.[2] Additional assays that evaluate processes not covered by the ORD assays are currently under development by researchers funded by the Europen Food Safey Authority (EFSA). Once data are available from these additional assays, any OP data may be considered in combination with the results of the ORD assays in the future as part of an overall weight of evidence evaluation of the DNT potential for individual OPs, including chlorpyrifos.

[1] The term NAM has been adopted as a broadly descriptive reference to any non-animal technology, methodology, approach, or combination thereof that can be used to provide information on chemical hazard and risk assessment.
[2] https://www.epa.gov/sap/use-new-approach-methodologies-nams-derive-extrapolation-factors-and-evaluate-developmental

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1.0 Executive Summary

This document presents the third revision to the human health risk assessment for the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) Registration Review of the organophosphate (OP) insecticide chlorpyrifos.

Background
A preliminary human health risk assessment (HHRA) for chlorpyrifos was completed on June 30, 2011 (D. Drew *et al.*, D388070, 06/30/2011) as part of the FIFRA Section 3(g) Registration Review program. A revised HHRA was completed in 2014 (D. Drew *et al.*, D424485, 12/29/2014) to address comments received on the preliminary HHRA and to incorporate new information and new approaches that became available since the June 2011 risk assessment. Most notably, the 2014 revised HHRA incorporated the following: (1) a physiologically-based pharmacokinetic-pharmacodynamic (PBPK-PD) model for deriving toxicological points of departure (PODs) based on 10% red blood cell (RBC) acetyl cholinesterase (AChE) inhibition; and (2) evidence on neurodevelopmental effects in fetuses and children resulting from chlorpyrifos exposure as reported in epidemiological studies, particularly the results from the Columbia Center for Children's Environmental Health (CCCEH) study on pregnant women which reported an association between fetal cord blood levels of chlorpyrifos and neurodevelopmental outcomes. The 2014 HHRA retained the 10X Food Quality Protection Act (FQPA) Safety Factor (SF) because of the uncertainties around doses that may cause neurodevelopmental effects.

Based on the aggregate risks identified in 2014 (D. Drew *et al.*, D424485, 12/29/2014), a proposed rule (PR) for revoking all tolerances of chlorpyrifos was published in the Federal Register on November 6, 2015 (80 FR 69079). At that time, the EPA had not completed a refined drinking water assessment or an additional analysis of the hazard of chlorpyrifos that was suggested by several commenters to the EPA's 2014 revised HHRA. Those commenters raised the concern that the use of 10% RBC AChE inhibition for deriving PODs for chlorpyrifos may not provide a sufficiently health protective human health risk assessment given the potential for neurodevelopmental outcomes. Accordingly, following the issuance of the proposed rule, the EPA conducted additional hazard analyses using data on chlorpyrifos levels in fetal cord blood (reported by the CCCEH study investigators) as the source for PODs for the 2016 risk assessment (W. Britton *et al.*, D436317, 11/03/2016). In the 2016 assessment, the 10X FQPA SF was retained.

In the current risk assessment, EPA is utilizing the same endpoint and points of departure as those used in the 2014 HHRA (i.e., the PBPK-PD model has been used to estimate exposure levels resulting in 10% RBC AChE inhibition following acute (single day, 24 hours) and steady state (21-day) exposures for a variety of exposure scenarios for chlorpyrifos and/or chlorpyrifos oxon). Despite several years of study, the science addressing neurodevelopmental effects remains unresolved. Therefore, the dietary, residential, aggregate, and non-occupational risk assessments have been conducted both with retention of the 10X FQPA SF and without retention of the 10X FQPA SF (*i.e.*, FQPA SF reduced to 1X). Similarly, the occupational risk assessments have been conducted both with and without retention of a 10X Database Uncertainty Factor (UF_{DB}).

This 2020 human health risk assessment substantially relies on the previous documents developed for chlorpyrifos, along with an updated animal toxicity literature review, and an updated drinking water assessment. Those primary documents include the following:

- D. Drew *et al.,* Chlorpyrifos: Revised Human Health Risk Assessment for Registration Review, December 29, 2014, D424485;
- U.S. Environmental Protection Agency, Literature Review on Neurodevelopment Effects & FQPA Safety Factor Determination for the Organophosphate Pesticides, September 15, 2015, D331251;
- R. Bohaty, Updated Chlorpyrifos Refined Drinking Water Assessment for Registration Review, September 15, 2020, D459269.
- R. Bohaty, Evaluating the Impact of Removal of the 10x FQPA Safety Factor on Chlorpyrifos, September 15, 2020, D459270.
- U.S. Environmental Protection Agency, Chlorpyrifos Issue Paper: Evaluation of Biomonitoring Data from Epidemiology Studies, March 11, 2016 and supporting analyses presented to the FIFRA Scientific Advisory Panel's (SAP) meeting on April 19-21, 2016, (EPA-HQ-OPP-2016-0062).
- W. Britton *et al*., Chlorpyrifos: Revised Human Health Risk Assessment for Registration Review, November 3, 2016, D436317.
- E. Méndez, Chlorpyrifos: Review of 5 Open Literature Studies Investigating Potential Developmental Neurotoxicity Following Early Lifestage Exposure, June 1, 2020, D457378.

Hazard Characterization

The hazard characterization for chlorpyrifos and its oxon is based on adverse health effects in animals and humans related to two different endpoints - AChE inhibition and potential for neurodevelopmental effects. A weight-of-the-evidence (WOE) analysis on the potential for neurodevelopmental effects following chlorpyrifos exposure has been completed using OPP's *Framework for Incorporating Human Epidemiologic & Incident Data in Health Risk Assessment* (USEPA, 2010; FIFRA SAP 2010). The Agency is using a robust PBPK-PD model to estimate human PODs for chlorpyrifos and/or its oxon for multiple exposure pathways (e.g., food, water, occupational, non-occupational, and residential) and using the PBPK-PD model to replace default inter- and intra-species factors for risk assessment.

The key issues considered in the WOE are 1) whether chlorpyrifos causes long-term effects from prenatal and/or early lifestage exposure and 2) whether adverse effects can be attributed to doses lower than those which elicit 10% inhibition of RBC AChE. Evidence from 1) the experimental toxicology studies evaluating adverse outcomes such as behavior and cognitive function; 2) mechanistic data on possible modes of action/ adverse outcome pathways (MOAs/AOPs); and 3) epidemiologic and biomonitoring studies, must be considered in making these determinations.

Despite several years of study, the science addressing neurodevelopmental effects remains unresolved. Therefore, the dietary, residential, aggregate, and non-occupational risk assessments have been conducted both with and without retention of the 10X FQPA safety factor; the occupational risk assessments have been conducted both with and without retention of a 10X UF_{DB}.

EPA has applied the Data-Derived Extrapolation Factor (DDEF) guidance (USEPA, 2014), in its use of the PBPK-PD model; the human model replaces the use of default intra-species uncertainty factor for some populations. The PBPK-PD model simulates human RBC AChE inhibition from exposures via oral, dermal, and inhalation routes and thus obviates the need for a default inter-species uncertainty factor to convert an animal POD to a human POD. In addition, the PBPK-PD model incorporates inter-individual variation in response to chlorpyrifos to estimate a distribution of administered doses that could have resulted in 10% RBC AChE inhibition in humans. The DDEF for intra-species extrapolation can then be estimated as the ratio between the mean dose and a dose at the tail of the distribution representing sensitive individuals. For this risk assessment, the 99th percentile of the distribution is being used to account for variation of sensitivity; the intra-species DDEF is 4X for chlorpyrifos and 5X for the oxon for all groups except women who are pregnant or may become pregnant for whom the 10X intra-species factor was retained (Dow, 2014b). While the current PBPK-PD model accounts for age-related growth from infancy to adulthood by using polynomial equations to describe tissue volumes and blood flows as a function of age, this model does not include any descriptions on physiological, anatomical and biochemical changes associated with pregnancy. Due to the uncertainty in extrapolating the current model predictions among women of childbearing age, the Agency is applying the standard 10X intra-species extrapolation factor for women of childbearing age.

In addition to DDEF, the PBPK-PD model has been used to estimate exposure levels resulting in 10% RBC AChE inhibition following acute (single day, 24 hours) and steady state (21-day) exposures for a variety of exposure scenarios for chlorpyrifos and/or chlorpyrifos oxon. For OPs, repeated exposures generally result in more AChE inhibition at a given administered dose compared to acute studies. Moreover, AChE inhibition in repeated dosing guideline toxicology studies with OPs show a consistent pattern of inhibition reaching steady state at or around 2-3 weeks of exposure in adult laboratory animals (U.S. EPA, 2002). This pattern observed with repeated dosing is a result of the amount of inhibition coming to equilibrium (or steady state) with the production of new enzyme. As such, AChE studies of 2-3 weeks generally show the same degree of inhibition with those of longer duration (*i.e.*, up to 2 years of exposure), so the model simulates a 21-day exposure as a steady-state condition.

Separate PODs have been calculated for dietary (food, drinking water), residential, non-occupational, and occupational exposures by varying inputs on exposure routes (dermal, oral, inhalation), exposure duration and frequency (such as 2 hours per day), and populations exposed based on body weights at different life stages (such as infants or adults).

Use Profile

Chlorpyrifos is a broad-spectrum, chlorinated OP insecticide. Registered use sites include a large variety of food crops and non-food use settings. Public health uses include aerial and ground-based fogger adulticide treatments to control mosquitoes. There is a wide range of registered formulations, application rates, and application methods. Registered labels generally require that handlers use normal work clothing (i.e., long sleeved shirt and pants, shoes and socks) and coveralls, chemical resistant gloves, and dust/mist respirators. Also, some products are marketed in engineering controls such as water-soluble packets. The restricted entry

intervals (REIs) on the registered chlorpyrifos labels range from 24 hours to 5 days. The pre-harvest intervals (PHIs) range from 0 days (Christmas trees) to 365 days (ginseng).

Dietary Risk Assessment
The acute and steady state dietary (food only) exposure analyses are highly refined. The majority of food residues used were based upon U.S. Department of Agriculture's (USDA's) Pesticide Data Program (PDP) monitoring data. Percent crop treated information and food processing factors were included, where available. All commodities with U.S. tolerances for residues of chlorpyrifos are included in the assessment.

Acute dietary (food only) risk estimates are all <100 % of the acute population adjusted dose for food ($aPAD_{food}$) at the 99.9th percentile of exposure and are not of concern. With the 10X FQPA SF retained, the population with the highest risk estimate is females (13-49 years old) at 3.2 % $aPAD_{food}$. With the FQPA SF reduced to 1X, the acute dietary risk estimates are <1% of the $aPAD_{food}$ for all populations.

Steady state dietary (food only) risk estimates are all <100 % of the steady state PAD for food ($ssPAD_{food}$) at the 99.9th percentile of exposure and are not of concern. With the 10X FQPA SF retained, the population with the highest risk estimate is children (1-2 years old) at 9.7 % $ssPAD_{food}$. With the FQPA SF reduced to 1X, the steady state dietary risk estimates are <1% of the $ssPAD_{food}$ for all populations.

The total dietary exposure to chlorpyrifos is through both food and drinking water. The acute and steady state dietary exposure analyses discussed above only include food and do not include drinking water; the drinking water exposure and risk assessment is discussed in the aggregate exposure/risk characterization portion of this document (Section 7).

Residential (Non-occupational) Risk Assessment
Based upon review of all chlorpyrifos registered uses, only the registered roach bait products may be applied by a homeowner in a residential setting. Residential handler exposure from applying roach bait products has not been quantitatively assessed because these exposures are considered negligible. Residential post-application exposures can occur for adults and children golfing on chlorpyrifos-treated golf course turf and from contacting treated turf following a mosquitocide application. The residential post-application assessment considered and incorporated all relevant populations and chemical-specific turf transferable residue (TTR) data. The residential post-application risk assessment results incorporate PODs derived from 10% RBC AChE inhibition using the PBPK-PD model and assuming both that the FQPA SF is retained at 10X and reduced to 1X.

There are no residential post-application risk estimates of concern for adults or children from chlorpyrifos use on golf course turf or as a mosquitocide on the day of application assuming either the FQPA SF is retained at 10X or reduced to 1X.

Non-Occupational Spray Drift Exposure and Risk Assessment
An updated quantitative non-occupational spray drift (from treatment of agricultural fields) assessment was conducted to assess the potential for residential bystander (who live on, work in,

or frequent areas adjacent to chlorpyrifos-treated agricultural fields) exposures. The potential risks from spray drift and the impact of potential risk reduction measures were assessed in a July 2012[3] memorandum. To increase protection for children and other bystanders, chlorpyrifos technical registrants voluntarily agreed to lower application rates and adopt other spray drift mitigation measures such as buffer zones.[4] The spray drift risk assessment results incorporate PODs derived from 10% RBC AChE inhibition using the PBPK-PD model and assuming both that the FQPA SF is retained at 10X and reduced to 1X. There are no risk estimates of concern incorporating the agreed-upon buffer distances[5] and droplet sizes/nozzle types by the EPA and the technical registrants in 2012 if the FQPA SF FQPA SF is retained at 10X or reduced to 1X.

Non-Occupational Bystander Post-Application Inhalation Exposure and Risk Assessment
In January 2013, a preliminary assessment of the potential risks from chlorpyrifos volatilization was conducted.[6] However, this assessment was revised in June 2014[7] following submission of two high-quality vapor phase nose-only inhalation toxicity studies for chlorpyrifos and chlorpyrifos oxon[8]. The studies were conducted to address the uncertainty surrounding exposure to aerosol versus vapor phase chlorpyrifos. At the saturation concentration there was no statistically significant inhibition of AChE activity in RBC, plasma, lung, or brain at any time after the six-hour exposure period in either study. Under actual field conditions, exposures are likely to be much lower to vapor phase chlorpyrifos and its oxon as discussed in the January 2013 preliminary volatilization assessment. Because these studies demonstrated that no toxicity occurred even at the saturation concentration, which is the highest physically achievable concentration, there are no anticipated risks of concern from exposure through volatilization of either chlorpyrifos or chlorpyrifos oxon.

Aggregate Risk Assessment
The Agency has considered aggregate exposures and risks from combined food, drinking water, and residential exposures to chlorpyrifos and chlorpyrifos oxon. The acute aggregate assessment includes only food and drinking water. The steady state aggregate assessment includes exposures from food, drinking water, and residential uses. Exposure to the parent compound chlorpyrifos is

[3] J. Dawson, W. Britton, R. Bohaty, N. Mallampalli, and A. Grube. Chlorpyrifos: Evaluation of the Potential Risks from Spray Drift and the Impact of Potential Risk Reduction Measures. 7/13/12. U.S. EPA Office of Chemical Safety and Pollution Prevention. D399483, D399485.
[4] R. Keigwin. Spray Drift Mitigation Decision for Chlorpyrifos (059101). 7/2012. U.S. EPA Office of Chemical Safety and Pollution Prevention. EPA-HQ-OPP-2008-0850-0103.
[5] The 2012 agreement between EPA and the technical registrants (R. Keigwin, 2012) indicates that buffer distances of 80 feet are required for coarse or very coarse droplets and buffer distances of 100 feet are required for medium droplets for aerial applications for application rates $\geq$ 2.3 lb ai/A. In addition, the 2012 agreement requires buffer distances of $\geq$ 25 feet and medium to coarse drops for airblast applications at rates >3.76 lb ai/A.
[6] R. Bohaty, C. Peck, A. Lowit, W. Britton, N. Mallampalli, A. Grube. Chlorpyrifos: Preliminary Evaluation of the Potential Risks from Volatilization. 1/31/13. U.S. EPA Office of Chemical Safety and Pollution Prevention. D399484, D400781.
[7] W. Britton. W. Irwin. J. Dawson. A. Lowit. E. Mendez. Chlorpyrifos: Reevaluation of the Potential Risks from Volatilization in Consideration of Chlorpyrifos Parent and Oxon Vapor Inhalation Toxicity Studies. 6/25/2014. U.S. EPA Office of Chemical Safety and Pollution Prevention. D417105.
[8] W. Irwin. Review of Nose-Only Inhalation of Chlorpyrifos Vapor: Limited Toxicokinetics and Determination of Time-Dependent Effects on Plasma, Red Blood Cell, Brain and Lung Cholinesterase Activity in Femal CD(SD): Crl Rats. U.S. EPA Office of Chemical Safety and Pollution Prevention. 6/25/14. D411959. TXR# 0056694. EPA MRID# 49119501.

expected for food and residential uses. Exposure to either chlorpyrifos or chlorpyrifos oxon may be expected from drinking water sources. The drinking water assessment assumed 100% conversion of chlorpyrifos to the more toxic chlorpyrifos oxon (the predominant chlorpyrifos transformation product formed during drinking water treatment (*e.g.*, chlorination)).

For acute and steady state aggregate assessments, EPA has used a drinking water level of comparison (DWLOC) approach to calculate the amount of exposure available in the total "risk cup" for chlorpyrifos in drinking water after accounting for any chlorpyrifos exposures from food and residential uses. This DWLOC can be compared to the estimated drinking water concentrations (EDWCs) of chlorpyrifos oxon to determine if there is an aggregate risk of concern. The EDWCs are presented in the Environmental Fate and Effects Division's (EFED) updated drinking water assessment (DWA) (see R. Bohaty, 09/15/2020, D459269 and 09/15/2020, D459270).

The acute aggregate assessment includes only food and drinking water. Acute DWLOCs were calculated for infants, children, youths, and adult females. With the 10X FQPA SF retained, the lowest acute DWLOC calculated was for infants (<1 year old) at 23 ppb. With the FQPA SF reduced to 1X, the lowest acute DWLOC calculated was for infants (<1 year old) at 230 ppb.

The steady state aggregate assessment includes dietary exposures from food and drinking water and dermal exposures from residential uses (dermal exposures represent the highest residential exposures). Steady state DWLOCs were calculated for infants, children, youths, and adult females. With the 10X FQPA SF retained, the lowest steady state DWLOC calculated was for infants (<1 year old) at 4.0 ppb. With the FQPA SF reduced to 1X, the lowest steady state DWLOC calculated was for infants (<1 year old) at 43 ppb.

Occupational Handler Risk Assessment

In this assessment for the non-seed treatment scenarios, a total of 288 steady state occupational handler exposure scenarios were assessed. Using the PBPK-derived steady state PODs based on 10% RBC AChE inhibition and assuming a 10X database uncertainty factor has been retained (LOC = 100), 119 scenarios are of concern with label-specified personal protective equipment (PPE; baseline attire, chemical resistant gloves, coveralls, and a PF10 respirator) (MOEs < 100). Risks of concern for 45 additional exposure scenarios could potentially be mitigated if engineering controls are used. If the 10X database uncertainty factor is reduced to 1X (LOC = 10), 19 scenarios are of concern with label-specified PPE (baseline attire, chemical resistant gloves, coveralls, and a PF10 respirator) (MOEs < 10). Risks of concern for 15 additional scenarios could potentially be mitigated if engineering controls are used.

For the seed treatment scenarios, a total of 93 steady state scenarios were assessed. These scenarios are assessed using default amount handled assumptions for short-term and intermediate exposure durations. These assumptions are appropriate for the steady state exposures. Assuming the 10X database uncertainty factor has been retained (LOC = 100), 12 short-term exposure and 10 intermediate-term scenarios are of concern with label-specified PPE (baseline attire, chemical resistant gloves, coveralls, and a PF10 respirator) (MOEs < 100). Assuming the 10X database uncertainty factor has been reduced to 1X (LOC = 10), there are no short- or intermediate-term

risk estimates of concern with label-specified PPE (baseline attire, chemical resistant gloves, coveralls, and a PF10 respirator) (MOEs > 10).

Occupational Post-Application Risk Assessment
Steady state occupational post-application exposures and risks were assessed for any crops where hand labor is anticipated following applications of chlorpyrifos. The assessment was completed using seven chlorpyrifos dislodgeable foliar residue (DFR) studies. Chlorpyrifos parent compound is the residue of concern for occupational post-application exposures that occur outdoors; however, it may be possible that the formation of chlorpyrifos oxon is greater and its degradation slower in greenhouses when compared to the outdoor environment. Occupational post-application assessments were performed for: 1) exposures to the parent compound chlorpyrifos in outdoor environments (uses other than greenhouse), 2) exposures to the parent chlorpyrifos (only) in greenhouses and 3) exposures to both the parent and chlorpyrifos oxon in greenhouses.

Current labels require a Restricted Entry Interval (REI) of 24 hours for most crops and activities, but in some cases such as tree fruit, REIs are up to 5 days after application. All post-application worker risks have been updated in the current assessment to incorporate PBPK-derived steady state PODs based on 10% RBC AChE inhibition and assuming the database uncertainty factor has been either retained at 10X and reduced to 1X. Using the PBPK-derived steady state PODs based on 10% RBC AChE inhibition and assuming the UF_{DB} of 10X has been retained, the majority of the post-applications scenarios are not of concern 1 day after application (REI = 24 hours). However, for some activities such as irrigation, hand harvesting, scouting, and thinning result in risks of concern up to as many as 10 days following application for the non-microencapsulated formulations and > 35 days for the microencapsulated formulation. Using the PBPK-derived steady state PODs based on 10% RBC AChE inhibition and assuming the UF_{DB} has been reduced to 1X, the majority of the post-application risk estimates are not of concern 1 day after application (REI = 24 hours).

Due to uncertainty regarding the formation of chlorpyrifos oxon in greenhouses, HED also estimated risks for reentry into treated greenhouses (all 4 formulations) for the parent chlorpyrifos plus chlorpyrifos oxon using a total toxic residue approach. The total toxic residue approach[9] estimates the chlorpyrifos oxon equivalent residues by 1) assuming a specific fraction of the measured chlorpyrifos dislodgeable foliar residues are available as the oxon and 2) factoring in the relative potency of chlorpyrifos oxon with use of a TAF of 18. It was conservatively assumed that 5% (0.05) of the total chlorpyrifos present as DFR in greenhouses is available for worker contact during post-application activities. When the total toxic residue approach is used and with the PBPK-derived steady state PODs based on 10% RBC AChE inhibition and assuming a 10X UF_{DB} has been retained, MOEs are not of concern 0 to 6 days after treatment for non-microencapsulated formulations. For the microencapsulated formulation, MOEs are not of concern 3 to > 35 days after treatment (the completion of the monitoring period), depending on the exposure activity considered.

When the total toxic residue approach is used and with the PBPK-derived steady state PODs based on 10% RBC AChE inhibition and assuming the 10X UF_{DB} has been reduced to 1X, there

[9] Total DFR ($\mu g/cm^2$) = [Chlorpyrifos DFR ($\mu g/cm^2$) * TAF] + [Chlorpyrifos DFR ($\mu g/cm^2$)]

are no risk estimates of concern with the current labeled REI (24 hours), except for the microencapsulated formulation. For the microencapsulated formulation, MOEs are of concern 0 to > 35 days after treatment (the completion of the monitoring period), depending on the exposure activity considered.

2.0 Risk Assessment Conclusions

Despite several years of study, the science addressing neurodevelopmental effects remains unresolved. Therefore, the dietary, residential, aggregate, and non-occupational risk assessments have been conducted both with retention of the 10X FQPA SF and without retention of the 10X FQPA SF (*i.e*., FQPA SF reduced to 1X). Similarly, the occupational risk assessments have been conducted both with and without retention of a 10X Database Uncertainty Factor (UF_{DB}). There are no acute or steady state dietary (food only) risks of concern with or without the retention of the 10X FQPA SF. There are no residential post-application risk estimates of concern for adults or children with or without the 10X FQPA SF. The aggregate risks are variable and can be determined by comparison of the calculated DWLOCs presented herein with the EDWCs presented in EFED's DWA. Many occupational handler scenarios are of concern with the retention of a 10X $UF_{DB.}$ With the 10X UF_{DB} removed, there are still some handler scenarios of concern. For occupational post-application exposures, even with the 10X UF_{DB} removed, some scenarios are of concern one day after application.

2.1 Data Deficiencies

Toxicology
None.

Residue Chemistry

860.1500:
Separate magnitude of the residue studies for lemons are needed after application of Lorsban 4E and 75% WDG formulations in order to reevaluate the existing tolerance for chlorpyrifos for the citrus fruit crop group.

Magnitude of the residue studies are needed to establish a tolerance for residues of chlorpyrifos on wheat hay.

860.1520:
Processing studies are needed for soybean meal, hulls and refined oil.

Occupational/Residential

No new data requirements have been identified for chlorpyrifos; however, in the 2011 preliminary HHRA, additional studies to address the uncertainties regarding the formation and degradation of chlorpyrifos oxon in greenhouses were recommended. To date, those data have not been submitted. In the absence of the recommended data, and to account for the potential for

oxon to form in greenhouses, EPA has used a conservative total toxic residue approach for parent chlorpyrifos plus the chlorpyrifos oxon.

2.2 Tolerance Considerations

2.2.1 Enforcement Analytical Method

The methods in the Pesticide Analytical Manual (PAM) Volume II are adequate to analyze the residue of concern for tolerance enforcement purposes, chlorpyrifos only. The limit of detection of these methods is adequate to cover the lowest tolerance level included in the 40 CFR 180.342 for detection of chlorpyrifos only, 0.01 ppm. In addition, chlorpyrifos is completely recovered using FDA multiresidue protocols D and E (nonfatty matrices) and partially recovered using multiresidue method protocol E (fatty matrices).

2.2.2 Recommended & Established Tolerances

According to HED's *Guidance on Tolerance Expressions* (S. Knizner, 05/27/2009), the tolerance expression for chlorpyrifos in the 40 CFR§180.342 should read as follows:

> "(a) General. (1) Tolerances are established for residues of chlorpyrifos, including its metabolites and degradates, in or on the commodities in the table below. Compliance with the tolerance levels specified below is to be determined by measuring only chlorpyrifos (*O,O* -diethyl *O* -(3,5,6-trichloro-2-pyridyl) phosphorothioate."

The current tolerance expression reads "Tolerances are established for residues of the pesticide chlorpyrifos *per se* (*O,O*-diethyl-*O*-(3,5,6-trichloro-2-pyridyl) phosphorothioate) in or on the following food commodities."

Based on residue data, HED is recommending tolerances for chlorpyrifos on the following: cotton, gin byproducts (15 ppm); grain, aspirated fractions (30 ppm); corn, field, milled byproducts (0.1 ppm); and wheat, milled byproducts (1.5 ppm). These recommendations, along with recommendations for revisions to current tolerances based on the Organization for Economic Cooperation and Development (OECD) rounding class practice, commodity definition revisions, crop group conversions/revisions, and harmonizition with Codex, are presented in Tables 2.2.2.1 and 2.2.2.2.

Table 2.2.2.1. Summary of Tolerance Revisions for Chlorpyrifos (40 CFR §180.342(a)).[1]

Commodity/ **Correct Commodity Definition**	Established Tolerance (ppm)	Recommended Tolerance (ppm)	Comments
Alfalfa, forage	3.0	3	Corrected values to be consistent with OECD Rounding Class Practice.
Grain, aspirated fractions	--	22	Recommended tolerance based on submitted residue data.
Beet, sugar, dried pulp	5.0	5	Corrected values to be consistent with OECD Rounding Class Practice.
Beet, sugar, roots	1.0	1	Corrected values to be consistent with

Table 2.2.2.1. Summary of Tolerance Revisions for Chlorpyrifos (40 CFR §180.342(a)).[1]			
Commodity/ **Correct Commodity Definition**	Established Tolerance (ppm)	Recommended Tolerance (ppm)	Comments
			OECD Rounding Class Practice.
Beet, sugar, leaves [2]	--	8	Commodity definition revision. Corrected values to be consistent with OECD Rounding Class Practice.
Beet, sugar, tops	8.0	remove	
Brassica, leafy greens, subgroup 4-16B	--	1	Crop group conversion/revision.[3,4]
Cherry, sweet	1.0	1	Corrected values to be consistent with OECD Rounding Class Practice.
Cherry, tart	1.0	1	Corrected values to be consistent with OECD Rounding Class Practice.
Fruit, citrus, group 10-10, dried pulp	--	5	Crop group conversion/revision. Corrected values to be consistent with OECD Rounding Class Practice.
Citrus, dried pulp	5.0	remove	
Fruit, citrus, group 10-10, oil	--	20	Crop group conversion/revision.
Citrus, oil	20	remove	
Corn, field, forage	8.0	8	Corrected values to be consistent with OECD Rounding Class Practice.
Corn, field, stover	8.0	8	Corrected values to be consistent with OECD Rounding Class Practice.
Corn, milled byproducts	--	0.1	Recommended tolerance based on submitted residue data.
Corn, sweet, forage	8.0	8	Corrected values to be consistent with OECD Rounding Class Practice.
Corn, sweet, stover	8.0	8	Corrected values to be consistent with OECD Rounding Class Practice.
Cotton, gin byproducts	--	15	Recommended tolerance based on submitted residue data.
Cotton, undelinted seed	0.2	0.3	Harmonization with Codex.
Cranberry	1.0	1	Corrected values to be consistent with OECD Rounding Class Practice.
Fruit, citrus, group 10-10	--	1	Crop group conversion/revision. Corrected values to be consistent with OECD Rounding Class Practice.
Fruit, citrus, group 10	1.0	remove	
Kohlrabi	--	1	Crop group conversion/revision.[3,4]
Kiwifruit, fuzzy	--	2	Commodity definition revision. Corrected values to be consistent with OECD Rounding Class Practice.
Kiwifruit	2.0	remove	
Milk	--	0.01	Commodity definition revision.
Milk, fat	--	0.25	
Milk, fat (Reflecting 0.01 ppm in whole milk)	0.25	remove	
Pepper, bell	--	1	Commodity definition revision. Corrected values to be consistent with OECD Rounding Class Practice.
Pepper, nonbell	--	1	
Pepper	1.0	remove	
Peppermint, fresh leaves	--	0.8	Commodity definition revision.
Peppermint, tops	0.8	remove	
Peppermint, oil	8.0	8	Corrected values to be consistent with OECD Rounding Class Practice.
Radish, roots	--	2	Commodity definition revision. Corrected values to be consistent with OECD Rounding Class Practice
Radish	2.0	remove	

Table 2.2.2.1. Summary of Tolerance Revisions for Chlorpyrifos (40 CFR §180.342(a)).[1]			
Commodity/ **Correct Commodity Definition**	Established Tolerance (ppm)	Recommended Tolerance (ppm)	Comments
Rutabaga, roots	--	0.5	Commodity definition revision.
Rutabaga	0.5	remove	
Spearmint, fresh leaves	--	0.8	Commodity definition revision.
Spearmint, tops	0.8	remove	
Spearmint, oil	8.0	8	Corrected values to be consistent with OECD Rounding Class Practice.
Sorghum, grain, stover	2.0	2	Corrected values to be consistent with OECD Rounding Class Practice.
Strawberry	0.2	0.3	Harmonization with Codex.
Sweet potato, tuber	--	0.05	Commodity definition revision.
Sweet potato, roots	0.05	remove	
Turnip, roots	1.0	1	Corrected values to be consistent with OECD Rounding Class Practice.
Turnip, leaves	--	0.3	Commodity definition revision.
Turnip, tops	0.3	remove	
Vegetable, brassica, head and stem, group 5-16	--	1	Crop group conversion/revision.[3] Corrected values to be consistent with OECD Rounding Class Practice.
Vegetable, brassica, leafy, group 5	1.0	remove	
Wheat, forage	3.0	3	Corrected values to be consistent with OECD Rounding Class Practice.
Wheat, milled byproducts	--	1.5	Recommended tolerance based on submitted residue data.
Wheat, straw	6.0	6	Corrected values to be consistent with OECD Rounding Class Practice.

[1] This table only includes recommended revisions to established tolerances and recommended establishment of new tolerances. For a complete list of all established tolerances see the International Residue Level Summary (IRLS) in Appendix 4.
[2] Sugar beet leaves/tops are no longer considered a significant livestock feed item. Commodity/tolerance may be removed.
[3] The recommended conversion of existing tolerance in/on **Vegetable, brassica, leafy, group 5** is to the following: **Vegetable, brassica, head and stem, group 5-16; Brassica, leafy greens, subgroup 4-16B;** and **Kohlrabi (“**Crop Group Conversion Plan for Existing Tolerances as a Result of Creation of New Crop Groups under Phase IV (4-16, 5-16, and 22)” dated 11/3/2015).
[4] HED is recommending for individual tolerances of 1 ppm for Kohlrabi based on the currently established tolerance for this commodity as part of crop group 5 (Vegetable, brassica, leafy). Kohlrabi is displaced by the crop group conversion noted in the footnote 3 above.

Table 2.2.2.2. Summary of Tolerance Revisions for Chlorpyrifos (40 CFR §180.342(c))[1, 2]			
Commodity/ **Correct Commodity Definition**	Established Tolerance (ppm)	Recommended Tolerance (ppm)	Comments
Asparagus	5.0	5	Corrected values to be consistent with OECD Rounding Class Practice.

[1] This table only includes recommended revisions to established tolerances. For a complete list of all established tolerances see the IRLS in Appendix 4.
[2] Regional registrations.

2.2.3 International Harmonization

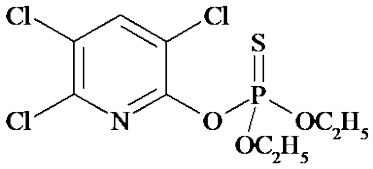
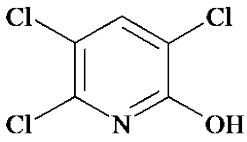
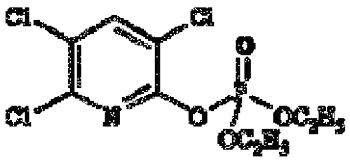
The Codex Alimentarius Commission and Canada Pesticide Management Rgulatory Agency (PMRA) have established Maximum Residue Limits (MRLs) for chlorpyrifos. Mexico generally adopts U.S. tolerances and/or Codex MRLs for its export purposes. The residue definition for enforcemnt is harmonized for U.S. tolerances and Codex MRLs and includes parent compound

chlorpyrifos only. However, Canada MRLs are for chlorpyrifos for a few commodities and for both parent chlorpyrifos and its metabolite TCP (3,5,6-trichloro-2-pyridinol) which is not a U.S. residue of concern, for other commodities.

Except for apple commodities, Canada MRLs are currently not harmonized with the U.S. tolerances because of the difference in residue definition. Codex MRLs are currently harmonized with U.S. tolerances for the following commodities: field corn grain; citrus; cranberry; egg; sorghum grain (and stover); wheat grain; and head and Chinese cabbage. HED is recommending that the current tolerances for strawberry and cotton, undelinted seed be increased to harmonize with the Codex MRLs. There are several U.S. tolerances that are not harmonized with Codex MRLs; harmonization is not currently being recommended for these commodities because the large difference in residue levels indicates that domestic and foreign use patterns are much different. A summary of the U.S. tolerances and international MRLs is included in Appendix 4.

3.0 Introduction

3.1 Chemical Identity

Table 3.1 Chlorpyrifos Degradate/ Residues of Concern Nomenclature.	
Chlorpyrifos	
IUPAC name	*O,O*-diethyl *O*-3,5,6-trichloro-2-pyridyl phosphorothioate
CAS name	*O,O*-diethyl *O*-(3,5,6-trichloro-2-pyridinyl) phosphorothioate
CAS registry number	2921-88-2
TCP Metabolite/Degradate (Residue of Concern for Canada) IUPAC Name 3,5,6 Trichloro-2-pyridinol	
Oxon Metabolite/Degradate Common Name Chlorpyrifos Oxon IUPAC Name O,O-diethyl. O-3,5,6-trichloro-2-pyridyl phosphate	

3.2 Physical/Chemical Characteristics

Technical chlorpyrifos is a white crystalline solid. Chlorpyrifos is stable in neutral and acidic aqueous solutions; however, stability decreases with increasing pH. Chlorpyrifos is practically insoluble in water, but is soluble in most organic solvents (i.e., acetone, xylene and methylene

chloride). Chlorpyrifos is moderately volatile based on its vapor pressure of $1.87x10^{-5}$ mmHg at 25°C. See Appendix 3.

Laboratory studies show chlorpyrifos is susceptible to hydrolysis under alkaline conditions and that volatilization and photo-degradation are not likely to play a significant role in the dissipation of chlorpyrifos in the environment. Nonetheless, chlorpyrifos has been detected in air samples, and so volatilization may play more of a role in dissipation than laboratory studies indicate. The major route of dissipation appears to be aerobic and anaerobic metabolism, as well as partitioning to the soil (partition coefficient of 6040). The aerobic aquatic metabolism half-life is 30.4 days (~6% remaining in 4 months). The water peak half-lives were ~1 day in a monitoring study (MRID 44711601). Based on available data, chlorpyrifos degrades slowly in soil under both aerobic and anaerobic conditions. Degradation begins with cleavage of the phosphorus ester bond to yield 3,5,6-trichloro-2-pyridinol (TCP). Field dissipation studies show that chlorpyrifos is moderately persistent under field conditions—dissipation half-life less than 60 days. Chlorpyrifos is only slightly soluble in water (1400 ppb). However, if it reaches aquatic environments the Log K_{ow} (4.7) indicates that chlorpyrifos may bioaccumulate in fish and other aquatic organisms. A fish bioaccumulation study shows that chlorpyrifos is absorbed by fish; however, it rapidly depurates when exposure ceases.

Oxidation of chlorpyrifos to chlorpyrifos oxon could potentially occur through photolysis, aerobic metabolism, and chlorination as well as other oxidative processes. Chlorpyrifos oxon is expected to have similar fate characteristics as chlorpyrifos except chlorpyrifos oxon is more soluble in water and undergoes hydrolysis faster. The hydrolysis half-life of chlorpyrifos oxon is significantly shorter than that observed for chlorpyrifos (5 days vs 81 days). Chlorpyrifos oxon hydrolyses to form TCP. For chlorpyrifos, water purification (chlorination) has been shown to be a major route of chlorpyrifos oxon formation and degradation.

3.3 Pesticide Use Pattern

Chlorpyrifos (0,0-diethyl-0-3,5,6-trichloro -2-pyridyl phosphorothioate) is a broad-spectrum, chlorinated OP insecticide. Registered use sites include a large variety of food crops (including fruit and nut trees, many types of fruits and vegetables, and grain crops), and non-food use settings (e.g., golf course turf, industrial sites, greenhouse and nursery production, sod farms, and wood products). Public health uses include aerial and ground-based fogger adulticide treatments to control mosquitoes. There are also residential uses of roach bait products and ant mound treatments. Permanent tolerances are established (40 CFR§180.342) for the residues of chlorpyrifos in/on a variety of agricultural commodities, including meat, milk, poultry and eggs. There are also tolerances for use in food handling/service establishments (FHE or FSE). Chlorpyrifos is manufactured as granular, microencapsulated liquid, soluble concentrate liquid, water dispersible granular in water soluble packets (WSP), wettable powders in WSPs, impregnated paints, cattle ear tags, insect bait stations and total release foggers. There is a wide range of application rates and methods. Registered labels generally require that handlers use normal work clothing/baseline attire (i.e., long sleeved shirt and pants, shoes and socks) and coveralls, chemical resistant gloves, and dust/mist respirators. The REIs on the registered chlorpyrifos labels range from 24 hours to 5 days. The master use table is provided in Appendix 5.

3.4 Anticipated Exposure Pathways

Chlorpyrifos applications may be made directly to growing crops (food and feedstuffs) which may result in human exposure to chlorpyrifos in food and to chlorpyrifos or chlorpyrifos oxon in drinking water (from surface and ground water sources). Registered uses that may result in residential (non-occupational) exposures to chlorpyrifos include aerial and ground-based fogger adult mosquitocide applications and golf course turf applications. There are also potential exposures for residential bystanders who live on, work in, or frequent areas adjacent to chlorpyrifos-treated agricultural fields from spray drift and volatilization. In occupational settings, exposure may occur while handling the pesticide prior to application, as well as during application. There is also a potential for post-application exposure for workers re-entering treated fields.

3.5 Consideration of Environmental Justice

Potential areas of environmental justice concerns, to the extent possible, were considered in this human health risk assessment, in accordance with U.S. Executive Order 12898, "Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations," (https://www.archives.gov/files/federal-register/executive-orders/pdf/12898.pdf). As a part of every pesticide risk assessment, OPP considers a large variety of consumer subgroups according to well-established procedures. In line with OPP policy, HED estimates risks to population subgroups from pesticide exposures that are based on patterns of that subgroup's food and water consumption, and activities in and around the home that involve pesticide use in a residential setting. Extensive data on food consumption patterns are compiled by the U.S. Department of Agriculture's National Health and Nutrition Examination Survey, What We Eat in America, (NHANES/WWEIA) and are used in pesticide risk assessments for all registered food uses of a pesticide. These data are analyzed and categorized by subgroups based on age and ethnic group. Additionally, OPP is able to assess dietary exposure to smaller, specialized subgroups and exposure assessments are performed when conditions or circumstances warrant. Whenever appropriate, non-dietary exposures based on home use of pesticide products and associated risks for adult applicators and for toddlers, youths, and adults entering or playing on treated areas post-application are evaluated. Spray drift can also potentially result in post-application exposure and it was considered in this analysis. Further considerations are also currently in development as OPP has committed resources and expertise to the development of specialized software and models that consider exposure to other types of possible bystander exposures and farm workers as well as lifestyle and traditional dietary patterns among specific subgroups.

4.0 Hazard Characterization and Dose-Response Assessment

The 2014 chlorpyrifos HHRA provided summary information and weight of evidence findings integrating multiple lines of evidence from experimental toxicology and epidemiology with respect to AChE/ChE inhibition (acetylcholinesterase/cholinesterase) and neurodevelopmental outcomes. The 2014 HHRA also describes the use of a robust PBPK-PD model for PODs and refined intra-species factors. Full details of the science and data analysis that support these

conclusions can be found in the 2014 chlorpyrifos HHRA (D. Drew *et al.,* D424485, 12/29/2014).

4.1 Safety Factor for Infants and Children (FQPA Safety Factor)[10]

The dietary, residential, aggregate, and non-occupational assessments have been conducted both with and without the retention of the 10X FQPA Safety Factor based on the following considerations:

- The toxicology database for chlorpyrifos is complete for deriving risk assessment PODs based on cholinesterase inhibition.
- Despite several years of study, the science addressing neurodevelopmental effects remains unresolved. Regulatory history of the scientific evaluation is contained in Appendix 2.
- Chlorpyrifos is an OP insecticide with an established neurotoxic MOA; neurotoxicity is the most sensitive effect in all species, routes, and lifestages. AChE inhibition is being used to derive the PODs for risk assessment. These PODs are protective for neurotoxic effects related to AChE inhibition and potential downstream neurotoxic effects. Although the dose response relationship of AChE inhibition across different lifestages is established quantitatively, the MOAs/AOPs for postulated neurodevelopmental effects occurring at doses below those eliciting cholinesterase inhibition have not been established.
- A literature search identified epidemiological studies with results suggesting an association between neurodevelopmental effects and exposure to chlorpyrifos even in the absence of AChE inhibition.
- There are no residual uncertainties in the exposure database. The chlorpyrifos residue chemistry database is robust. The exposure assessment in drinking water provides a conservative approach for estimating chlorpyrifos parent and oxon concentrations in ground and surface water sources of drinking water and is unlikely to underestimate exposure. The dietary (food) exposure analyses, although highly refined, incorporate conservative assumptions that are unlikely to underestimate exposures. Residue levels are based on either monitoring data reflecting actual residues found in the food supply, or high-end residues in foods. Furthermore, processing factors used were either those measured in processing studies, or default high-end factors representing the maximum concentration in the processed commodity. Residential exposure assessments use data from surrogate and chemical-specific sources and rely on the 2012 Residential Standard Operating Procedures (SOPs). Although some refinements have been incorporated into the exposure assessments, the exposure assumptions will not underestimate risks.

As discussed above and in Appendix 2, despite several years of study, the science addressing neurodevelopmental effects remains unresolved, the dietary, residential, aggregate, and non-occupational risk assessments have been conducted both with retention of the 10X Food Quality Protection Act (FQPA) safety factor (SF) and without retention of the 10X FQPA SF

[10] HED's standard toxicological, exposure, and risk assessment approaches are consistent with the requirements of EPA's children's environmental health policy (https://www.epa.gov/children/epas-policy-evaluating-risk-children).

(*i.e.*, FQPA SF reduced to 1X). Similarly, the occupational risk assessments have been conducted both with and without retention of a 10X Database Uncertainty Factor (UF_{DB}).

4.2 Dose Response Assessment

4.2.1 Durations of Exposure, Critical Windows of Exposure, & Temporality of Effects

In risk assessment, exposure is evaluated considering the toxicology profile. More specifically, a variety of toxicokinetic and toxicodynamic factors are considered when determining the appropriate exposure durations to assess for risk potential. In the case of chlorpyrifos, exposure can occur from a single event or on a single day (*e.g.*, eating a meal) or from repeated days of exposure (*e.g.*, worker, residential).

With respect to AChE inhibition, these effects can occur from a single exposure or from repeated exposures. For OPs, repeated exposures generally result in more AChE inhibition at a given administered dose compared to acute exposures. Moreover, AChE inhibition in repeated dosing guideline toxicology studies with most OPs show a consistent pattern of inhibition reaching steady state at or around 2-3 weeks of exposure in adult laboratory animals (U.S. EPA, 2002). This pattern observed with repeated dosing is a result of the amount of inhibition comes at equilibrium with production of new enzyme. As such, AChE studies of 2-3 weeks generally show the same degree of inhibition with those of longer duration (*i.e.*, up to 2 years of exposure). Thus, for most of the human health risk assessments for the OPs, the Agency is focusing on the critical durations ranging from a single day up to 21 days (*i.e.*, the approximate time to reach steady state for most OPs). As described below, PODs for various lifestages, routes, and scenarios have been derived at the acute and steady state durations.

With respect to effects on the developing brain, very little is known about the duration of chlorpyrifos exposure needed to precipitate adverse effects in the developing brain. There are critical windows of vulnerability (Rice & Barone, 2000; Rodier, 2004) with regard to toxicant effects on brain development. This vulnerable period in humans spans early pregnancy to adolescence (Rice & Barone, 2000). In fact, evidence shows that synapse formation peaks quite late in human brain development at 4-8 years of age (Glantz *et al.,* 2007). Within these vulnerable periods there are key neurodevelopmental processes (*e.g.* cell division, migration, differentiation, synaptogenesis, and myelination) and each of these is region and stage specific. Consequently, the time of toxicant exposure will be a major determinate in the spectrum of neurotoxic effects. Because of the dynamic processes in the developing brain (*i.e.*, vulnerable windows) it is difficult to determine if the effect or differences in effects is due to duration of exposure or if different vulnerable windows were affected. As such, it is impossible at this time to rule out even a single day of high exposure to chlorpyrifos having a potential adverse neurodevelopmental effect in humans.

For the chlorpyrifos risk assessment, PODs for various lifestages, routes, and scenarios have been derived at the acute and steady state durations.

4.2.2 Use of the PBPK-PD Model

Evaluation of PBPK-PD models intended for risk assessments includes a review of the model purpose, model structure, mathematical representation, parameter estimation (calibration), and computer implementation (USEPA, 2006b). The chlorpyrifos PBPK-PD model has been through several quality assurance reviews by various individuals or groups, including the Agency, and found that the model reasonably predicts both blood/urine dosimetry of chlorpyrifos and 3,5,6-trichloro-2-pyridinol (TCPy), and ChE inhibition in two controlled, deliberate oral human dosing studies (Nolan *et al.,* 1982; Kisicki *et al.,* 1999) and a dermal human study (Nolan *et al.,* 1984). The PBPK-PD model predictions for rats inhaled chlorpyrifos compare well with observed data (Hotchkiss *et al.,* 2013) with respect to chlorpyrifos, oxon, and TCPy concentrations in plasma, and ChE in plasma, RBC and brain (Poet *et al.,* 2014). Significant improvements have been made to the PBPK-PD model in response to the 2008, 2011, and 2012 SAPs, the Agency, and peer reviewers from academic journals. The Agency believes that the model is sufficiently robust for use in HHRA. Age-specific parameters are incorporated in the model to allow for lifestage-specific evaluations from infant through adulthood. Since the model accounts for human specific metabolism and physiology, using the human model obviates the need for the inter-species extrapolation factor. The deterministic model can be used to simulate an "average individual" for all age groups. As such, as described below, the Agency is using the PBPK-PD model to derive the scenario-specific PODs for all age groups (See Table 4.2.2.1.2 below).

At the 2011 SAP meeting, the Panel specifically noted the lack of maternal and fetal PK and PD compartments in the current PBPK-PD model to inform about tissue dosimetry and AChE inhibition during lactation (FIFRA SAP 2011). As described in detail below, the Agency has assessed exposure to bottle-feeding infants exposed to the oxon through water used with infant formula. With respect to chlorpyrifos or oxon exposure to infants through breast milk, any exposure to chlorpyrifos would be far lower than drinking water levels predicted by EFED. Thus, the Agency is already accounting for oral exposure to chlorpyrifos to infants via bottle-feeding and a lactation component in the PBPK-PD model is not necessary.

The SAP noted the lack of maternal and fetal PK and PD compartments in the PBPK-PD model to inform tissue dosimetry and AChE inhibition to pregnant women and their fetuses (FIFRA SAP 2011). With respect to exposure to the fetus during gestation, there are multiple studies on chlorpyrifos (Mattsson et al., 1998, 2000) and other OPs (U.S. EPA, 2006a) which show that the pregnant dam exhibits similar or more AChE inhibition than the fetus at a given dose to the dam. As such, for AChE inhibition, protecting against AChE inhibition in the pregnant female is expected to be protective for AChE inhibition in the fetus. Biomonitoring data from rats and humans support the findings of these AChE studies. Specifically, Whyatt *et al.* (2003) have shown that levels of chlorpyrifos in maternal blood are similar to the levels measured in human umbilical cord blood (Whyatt *et al.,* 2003). With respect to the pregnant dam during gestation, metabolic activities and physiological parameters can be altered during pregnancy (for citations, see Appendix 1 of D424485 (D. Drew *et al.,* 12/29/2014)). While the PBPK-PD model accounts for age-related growth from infancy to adulthood by using polynomial equations to describe tissue volumes and blood flows as a function of age, the model does not include any descriptions

on physiological, anatomical and biochemical changes associated with pregnancy. Due to the uncertainty in extrapolating the current model predictions among women who may be pregnant, **the Agency is applying the standard 10X intra-species extrapolation factor for women of childbearing age.**

4.2.2.1 Derivation of Human Equivalent Doses/Concentrations

In typical risk assessments, PODs are derived directly from laboratory animal studies and inter- and intra-species extrapolations are accomplished by use of 10X factors. In the case of chlorpyrifos and its oxon, PBPK-PD modeling is being used as a data-derived approach to estimate PODs for all age groups and Data-Derived Extrapolation Factors (DDEF) for intra-species extrapolation for some groups (USEPA, 2014). The Agency typically uses a 10% response level for AChE inhibition in human health risk assessment. This response level is consistent with the 2006 OP cumulative risk assessment (USEPA, 2006a) and other single chemical OP risk assessments. As such, the model has been used to estimate exposure levels resulting in 10% RBC AChE inhibition following single day (acute; 24 hours) and 21-day exposures for a variety of exposure scenarios (see Table 4.2.2.1.2 below).

The PBPK-PD model accounts for PK and PD characteristics to derive age, duration, and route specific PODs (Table 4.2.2.1.2 below). Separate PODs have been calculated for dietary (food, drinking water), residential, and occupational exposures by varying inputs on types of exposures and populations exposed. Specifically, the following characteristics have been evaluated: duration [acute, 21 day (steady state)]; route (dermal, oral, inhalation); body weights which vary by lifestage; exposure duration (hours per day, days per week); and exposure frequency [events per day (eating, drinking)].

For each exposure scenario, the appropriate body weight for each age group or sex was modeled as identified from the Exposure Factors Handbook (USEPA, 2011) for occupational and residential exposures and from the NHANES/What We Eat in America (WWEIA) Survey[11] for dietary exposures. All body weights used are consistent with those assumed for dietary, occupational, and residential exposure assessments. The Agency assesses dietary exposures for children 6-12 years old, and children between 6-11 years old for residential exposures. For purpose of aggregate assessment, these age groups are combined. The Agency assesses dietary exposures for youths 13-19 years old, and youths between 11-16 years old for residential exposures. For purpose of aggregate assessment, these age groups are combined. The body weights used in the chlorpyrifos PBPK model are summarized in Table 4.2.2.1.1.

[11] http://www.ars.usda.gov/Services/docs.htm?docid=13793

Table 4.2.2.1.1 Body Weight Assumptions Incorporated into PBPK Model for Chlorpyrifos.						
			Population & Body Weight (kg)			
Exposure Scenario	**Exposure Pathway**	**Infants (<1 year old)**	**Young Children (<1 - 2 years old)**	**Children (Residential:6 -11 years old; Dietary:6-12 years old)**	**Youths (Residential:1 1-16 years old; Dietary:13-19 years old)**	**Females (13 – 49 years old)**
Dietary	Food and Drinking Water	4.8[1]	12.6[2]	37.1[2]	67.3[2]	72.9[2]
Residential (Contact with Treated Turf from Mosquitocide Application)	Oral		11[3]			
	Dermal			32[5]	57[6]	69[4]
	Inhalation		11[3]			69[4]
Residential (Golfing)	Dermal			32[5]	57[6]	69[4]
Non-Occupational Spray Drift	Oral		11[3]			
	Dermal					69[4]
Occupational	Dermal, Inhalation					69[4]

1 For infants from birth to < 1 year old, the Agency has selected the body weight for the youngest age group, birth to < 1 month old, 4.8 kg (Exposure Factors Handbook, Table 8-3, mean body weight for the birth to < 1 month age group).
2 NHANES/WWEIA
3 Exposure Factors Handbook, Table 8-3, mean body weight for the 1 to < 2 year old age group.
4 Exposure Factors Handbook, Table 8-5, mean body weight for females 13 to < 49 years old.
5 Exposure Factors Handbook, Table 8-3, mean body weight for the 6 to < 11 year old age group.
6 (Exposure Factors Handbook, Table 8-3, mean body weight for the 11 to < 16 year old age group).

In order to derive the scenario specific PODs, assumptions were incorporated into the PBPK model on routes of exposure, surface area exposed, etc. The following scenarios were evaluated: dietary exposure to the oxon exposures via drinking water (24-hour and 21-day exposures for infants, children, youths, and female adults); exposure to chlorpyrifos exposures via food (24-hour and 21-day exposures for infants, children, youths, and female adults); 21-day residential exposures to chlorpyrifos via skin for children, youths, and female adults; 21-day residential exposures to chlorpyrifos via hand-to-mouth ingestion for children 1- 2 years old; 21-day residential exposures to chlorpyrifos via inhalation for children 1-2 years old and female adults.

Steady state dietary exposure was estimated daily for 21 days. For drinking water exposure, infants and young childrens (infants < 1 year old, children between 1-2 years old, and children between 6-12 years old) were assumed to consume water 6 times per day, with a total consumption volume of 0.69 L/day[12]. For youths and female adults, they were assumed to consume water 4 times per day, with a total consumption volume of 1.71 L/day[13].

[12] The daily volumes consumed and number of daily consumption events for all populations are mean values by age group based on USDA What We Eat in America, NHANES survey for dietary exposures. The mean daily water consumption values for children 1- 2 years old (0.35 L/day) and children 6-12 years old (0.58 L/day), were less than that for the infants (0.69 L/day); however, the infant daily water consumption volume was selected to be protective for PBPK-PD POD derivation for these age groups.
[13] For youths 13-19 years old, the mean daily water consumption (0.93 L/day), was less than that for the female adults (1.71 L/day); however, the adult daily water consumption was also selected to be protective.

All residential steady state exposures were set to be continuous for 21 days. For all residential dermal exposures to chlorpyrifos the dermal PODs were estimated assuming 50% of the skin's surface was exposed. Exposure times for dermal exposure assessment were consistent with those recommended in the 2012 Residential Standard Operating Procedures (SOPs)[14]. For residential inhalation exposures following public health mosquitocide application, the exposure duration was set to 1 hour per day for 21 days. The incidental oral PODs for children 1 to < 2 years old for other turf activities were estimated assuming that there were six events, 15 minutes apart, per day.

In addition to dietary and residential exposures, the PBPK-PD model was also used to estimate exposure levels resulting in 10% RBC AChE inhibition following steady state occupational exposures. For occupational handlers and post-application workers, the dermal PODs were estimated assuming a body weight of 69 kg (to represent a female aged 13-49), 100% of the skin's surface was exposed for 5 days/week and the exposure duration was 8 hours/day for 21 days. For occupational handlers, the inhalation PODs were estimated exposure for 8 hours/day, 5 days/week, for 21 days.

[14] https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/standard-operating-procedures-residential-pesticide

Table 4.2.2.1.2. Chlorpyrifos PBPK Modeled Doses (PODs) Corresponding to 10% RBC AChE Inhibition.

RA Type	Exposure Pathway (all chlorpyrifos unless noted)	Infants (< 1 yr old)		Young Children (1 - 2 years old)		Children (Residential: 6-11 years old; Dietary: 6-12 years old)		Youths (Residential: 11-16 years old; Dietary: 13-19 years old)		Females (13 – 49 years old)	
		Acute	Steady State (21 day)	Acute	Steady State (21 day)	Acute	Steady State (21 day)	Acute	Steady State (21 day)	Acute	Steady State (21 day)
Dietary	Drinking Water (oxon conc, ppb)	1,183	217	3,004	548	7,700	1,358	4,988	878	5,285	932
	Food (mg/kg/day)	0.60	0.103	0.581	0.099	0.53	0.09	0.475	0.080	0.467	0.078
Residential (Golfers)	Dermal (mg/kg/day)						25.75		13.95		11.89
Residential (Mosquitocide Application) and Spray Drift	Dermal (mg/kg/day)				134.25						23.6
	Oral (mg/kg/day)				0.101						
	Inhalation (concn. in air mg/m^3)				2.37						6.15
Occupational	Dermal (mg/kg/day)										3.63
	Inhalation (mg/kg/day)										0.138

*PODs and exposure and risk estimates for females 13-49 yrs covers all youths >13 yrs

4.2.2.2 Intra-species Extrapolation

With respect to intra-species extrapolation, the PBPK-PD model can be run in 'variation' mode which allows for age-specific parameters to vary across a distribution of values. The model will not be described in detail here as it is described in multiple recent publications, including a detailed report reviewed by the FIFRA SAP in 2011; summary information is provided here. All model code for the PBPK-PD variation model are available to the public.

Significant improvements have been made to the PBPK-PD model in response to the 2008, 2011, and 2012 SAPs, the Agency, and peer reviewers from academic journals in addition to the input of new data. At the 2011 SAP, the panel was critical of some aspects of how the registrant proposed to assess intra-species extrapolation. The registrant made multiple changes, including the addition of a global sensitivity analysis, improvements to the quantitative approach to evaluate population variability across individuals at a given age, and an uncertainty analysis on metabolism data from human hepatic microsomes to address variation in metabolic capabilities. .

Of the more than 120 parameters in the PBPK-PD model, 16 parameters were selected for varying in the DDEF intra-species analysis. They were selected using local and global sensitivity analyses (MRID 49248201, Dow, 2014a,b). The distributions for these 16 parameters are provided in Table 4.2.2.2.1 below. Inter-individual variations for the 16 sensitive parameters (listed above) were assumed to follow a lognormal distribution. The distributions are truncated at far extreme values only to permit the model to compute but functionally not truncated with respect to assessing human variability. References cited in the table are listed in the report "Development of Chemical Specific Adjustment Factors for Chlorpyrifos and Chlorpyrifos Oxon" (MRID number 49248201) and also provided in Dow, 2014a,b,c.

Table 4.2.2.2.1. Sixteen parameters in variation model. Extracted from Dow, 2014c.				
Parameter	**Mean value**	**Standard Deviation**	**CV**	**Variability Reference**
Total Blood Volume (L/kg body	0.08	0.0022	0.027	P^{3}M; Price *et al.,* 2003
Plasma PON1 (µmol/hr×L)	162,000	92,000	0.57	Smith et al., 2011
Hepatic Blood Flow (L/hr×kg tissue)	50	14	0.27	Materne et al., 2000
RBC ChE Inhibition Rate (l/µmol×hr)	100	17	0.17	Dimitriadis and Syrmos,
Hepatic PON1 (µmol/hr×kg tissue)	154,000	88,000	0.57	Smith et al., 2011
Hematocrit (%)	0.45	0.031	0.068	P^{3}M; Price *et al.,* 2003
RBC ChE Degradation Rate (l/hr)	0.01	0.0014	0.14	Chapman *et al.,* 1968
Hepatic P450 Bioactivation to Oxon (µmol/hr×kg tissue)	690	410	0.59	Smith et al., 2011
Hepatic P450 Detoxification to TCPy (µmol/hr×kg tissue)	1500	800	0.53	Smith et al., 2011
RBC ChE Reactivation Rate (l/hr)	0.014	0.0050	0.36	Mason et al., 2000
Intestinal CYP Bioactivation to Oxon (µmol/hr×kg tissue)	82	43	0.52	Obach *et al.,* 2001
Intestinal CYP Detoxification to TCPy (µmol/hr×kg tissue)	53	28	0.52	Obach *et al.,* 2001
Transfer Rate to Intestine (hr-1)	0.31	0.081	0.26	Singh et al., 2006
Volume of the Liver (L/kg body weight)	0.032	0.0010	0.032	P^{3}M; Price *et al.,* 2003
Hepatic Carboxyl Basal Activity Rate (l/hr/kg tissue)	1,270,000	460,000	0.36	Pope *et al.,* 2005
Hepatic Carboxyl Reactivation Rate (l/hr)	0.014	0.0050	0.36	Mason et al., 2000

Of these 16 parameters, four metabolism-related parameters (hepatic CYP450 activation of chlorpyrifos to chlorpyrifos oxon, hepatic CYP450 detoxification of chlorpyrifos oxon to TCPy, hepatic PON1 detoxification of chlorpyrifos oxon to TCPy, PON1 detoxification of chlorpyrifos oxon to TCPy in plasma) were found to drive more than 80% of the total variation in RBC AChE inhibition (Table 4.2.2.2.2). The human variability for these four parameters were assessed using *in vitro* data from 30 human hepatic microsome samples and 20 human plasma samples (Smith et al., 2011). Twenty of the hepatic microsome samples came from individuals < 12 years of age; and 10 of the samples came from adults > 17 years old. Ten of the plasma sample came from individuals < 2 years of age; and 10 of the samples came from adults. Because the findings from Smith et al (2011) account for more than 80% of the total variation in RBC AChE inhibition, it was determined that evaluating the uncertainty associated with the data (i.e., small number of samples compared to the large U.S. population) from this study was important to having confidence in the DDEFs derived from the variation model. Although some other *in vitro* studies shown in Table 4.2.2.2.1 also have small numbers of samples, these parameters make relatively small contributions to the overall variability. As such, additional quantitative uncertainty analysis on these *in vitro* studies is not needed.

Table 4.2.2.2.2. Four Metabolism Related Parameters in Variation Model. Extracted from Dow, 2014c.			
hepatic CYP450 activation of chlorpyrifos to chlorpyrifos oxon	total blood volume	RBC ChE degradation rate	transfer rate of chlorpyrifos or oxon from the stomach to the intestine
hepatic PON1 detoxification of chlorpyrifos oxon to TCPy	hepatic blood flow	RBC ChE reactivation rate	volume of the liver
PON1 detoxification of chlorpyrifos oxon to TCPy in plasma	RBC AChE inhibition rate	intestinal CYP bioactivation to chlorpyrifos oxon	hepatic carboxyl basal activity rate
hepatic PON1 detoxification of chlorpyrifos oxon to TCPy	hematocrit	intestinal CYP detoxification to TCPy	hepatic carboxyl reactivation rate

The uncertainty associated with these four critical parameters were incorporated in the subsequent Monte Carlo analysis by generating 50 sets of unbounded parametric distributions using the following approach. First, the parametric bootstrap approach was used to sample 1000 values, with replacement, from the *in vitro* data. Then, this process was repeated for 50 iterations, and the resulting 50 sets of distribution all have equally probable sets of means and coefficient of variation as the observed data, except for the coefficient of variation of the plasma PON1 metabolism rate. Since the liver is the origin of PON1 in plasma, the variation of the plasma PON1 metabolism rate was set to be the same as the hepatic PON1 metabolism rate. Even though the distributions have similar means and coefficient of variation as the observed data, they included values outside of the range of the observed data because the distributions were assumed to be unbounded. These 50 sets of distributions, for each of the four parameters, were found to cover the entire range of the observed data; and the ratios of maximum value to minimum value in the simulated distributions were at least three times the ratios of maximum value to minimum value in the observed data.

According to EPA's Data-Derived Extrapolation Factor guidance, when calculating a DDEF intra-species extrapolation (USEPA, 2014), administered doses leading to the response level of interest (10% change in RBC AChE inhibition) are compared between a measure of average response and response at the tail of the distribution representing sensitive individuals. Oral doses that cause 10% RBC AChE inhibition in both adults and 6-month old infants (example provided in Figure 1 a,b) were estimated using the model. The ratio of the adult ED_{10} to the infant ED_{10} was then used to derive intraspecies extrapolation factors. In the subsequent Monte Carlo simulations, the target age group is six-month-old individuals. Some model parameters are specific to this age group (e.g., PON1 metabolism in plasma), and some parameters are scaled by body weight that reflect this age group (e.g., tissue volume). Based on the 5th percentile of the distributions, the DDEF for intraspecies extrapolation is 2.8X for chlorpyrifos and 3.1X for the oxon (Dow, 2014b). Based on the 99th percentile of the distributions, the DDEF for intraspecies extrapolation is 4X for chlorpyrifos and 5X for the oxon (Dow, 2014b). For this revised HHRA, the 99th percentile is being used to account for sensitivities (i.e., the intra-species factor is 4X for chlorpyrifos and 5X for the oxon for all groups except women who are pregnant or may become pregnant). As shown in Figure 1b, at the 99th-ile, only 1% of infants will experience 10% or greater RBC AChE inhibition at the POD.

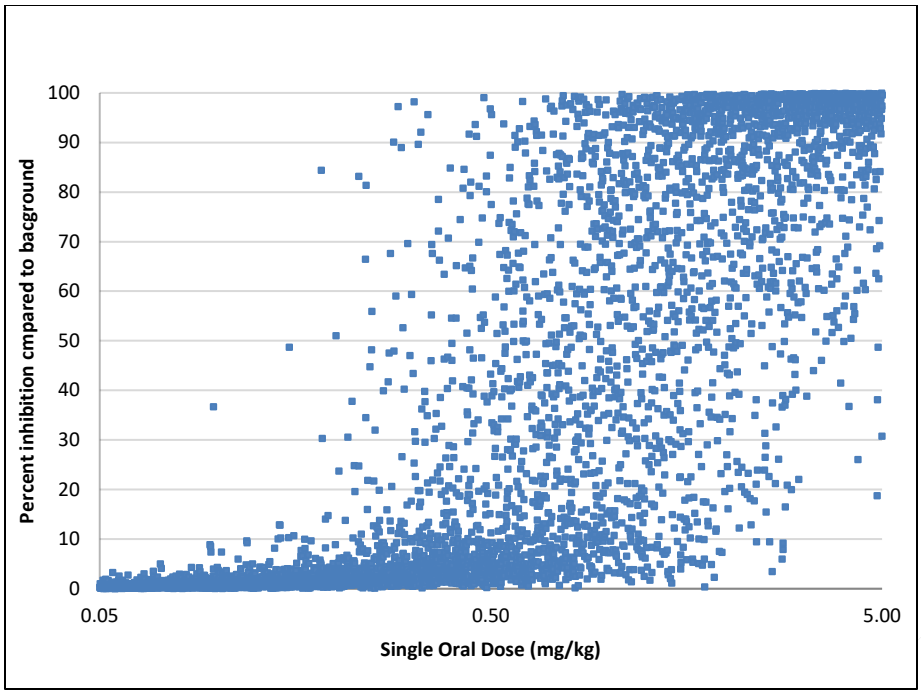


Figure 1a. Simulated population of 6 month olds for intra-species extrapolation DDEF derivation. Percent RBC AChE inhibition from exposure to single oral doses of chlorpyrifos ranging from 0.05 to 5.0 mg/kg/day (X and Y axes provided on the log scale).

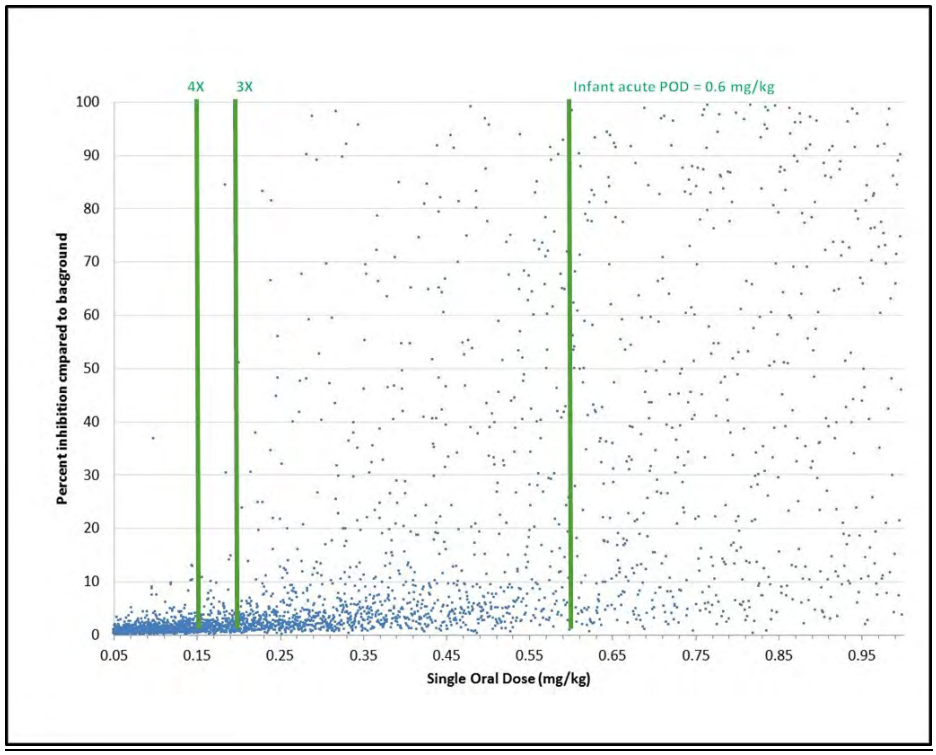


Figure 1b. Simulated population of 6 month olds for intra-species extrapolation DDEF derivation. Percent RBC AChE inhibition from exposure to single oral doses of chlorpyrifos ranging from 0.05 to 1.0 mg/kg/day. Green lines represent the infant acute POD for chlorpyrifos, the POD adjusted for the 3X and 4X intraspecies factors for the 95 and 99th-%ile, respectively.

In summary, for the chlorpyrifos HHRA, the human PBPK-PD model has been used to derive PODs for RBC AChE inhibition for various populations, durations, and routes (Table 4.2.2.1.2). As such, the interspecies factor is not needed. To account for variations in sensitivities, an intra-species factor of 4X for chlorpyrifos and 5X for the oxon is applied for all groups except women of childbearing age. For women of childbearing age, the typical 10X intra-species factor is being applied due the lack of appropriate information and algorithms to characterize physiological changes during pregnancy. Risks are being presented throughout the document assuming both the 10X FQPA SF is being retained for all subpopulations and reduced to 1X for all subpopulations. The individual and total uncertainty factors are summarized in Table 4.2.2.2.3.

Table 4.2.2.2.3 Uncertainty Factor Summary.

Uncertainty Factor	FQPA 10X Retained			FQPA 10X Reduced to 1X		
	Females	All other Subpopulations		Females	All other Subpopulations	
		Food (parent)	Drinking Water (oxon)		Food (parent)	Drinking Water (oxon)
Interspecies	1	1	1	1	1	1
Intraspecies	10	4	5	10	4	5
FQPA	10	10	10	1	1	1
Total	**100**	**40**	**50**	**10**	**4**	**5**

4.3 Endocrine Disruptor Screening Program

As required by the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and the Federal Food, Drug, and Cosmetic Act (FFDCA), EPA reviews numerous studies to assess potential adverse outcomes from exposure to chemicals. Collectively, these studies include acute, subchronic and chronic toxicity, including assessments of carcinogenicity, neurotoxicity, developmental, reproductive, and general or systemic toxicity. These studies include endpoints which may be susceptible to endocrine influence, including effects on endocrine target organ histopathology, organ weights, estrus cyclicity, sexual maturation, fertility, pregnancy rates, reproductive loss, and sex ratios in offspring. For ecological hazard assessments, EPA evaluates acute tests and chronic studies that assess growth, developmental and reproductive effects in different taxonomic groups. As part of its reregistration decision for chlorpyrifos, EPA reviewed these data and selected the most sensitive endpoints for relevant risk assessment scenarios from the existing hazard database. However, as required by FFDCA section 408(p), chlorpyrifos is subject to the endocrine screening part of the Endocrine Disruptor Screening Program (EDSP).

EPA has developed the EDSP to determine whether certain substances (including pesticide active and other ingredients) may have an effect in humans or wildlife similar to an effect produced by a "naturally occurring estrogen, or other such endocrine effects as the Administrator may designate." The EDSP employs a two-tiered approach to making the statutorily required determinations. Tier 1 consists of a battery of 11 screening assays to identify the potential of a chemical substance to interact with the estrogen, androgen, or thyroid (E, A, or T) hormonal systems. Chemicals that go through Tier 1 screening and are found to have the potential to interact with E, A, or T hormonal systems will proceed to the next stage of the EDSP where EPA will determine which, if any, of the Tier 2 tests are necessary based on the available data. Tier 2 testing is designed to identify any adverse endocrine-related effects caused by the substance and establish a dose-response relationship between the dose and the E, A, or T effect.

Under FFDCA section 408(p), the Agency must screen all pesticide chemicals. Between October 2009 and February 2010, EPA issued test orders/data call-ins for the first group of 67 chemicals, which contains 58 pesticide active ingredients and 9 inert ingredients. A second list of chemicals identified for EDSP screening was published on June 14, 2013[15] and includes some pesticides scheduled for registration review and chemicals found in water. Neither of these lists should be construed as a list of known or likely endocrine disruptors.

Chlorpyrifos is on List 1 for which EPA has received all of the required Tier 1 assay data. The Agency has reviewed all of the assay data received for the appropriate List 1 chemicals and the conclusions of those reviews are available in the chemical-specific public dockets (see Docket # EPA-HQ-OPP-2008-0850 for chlorpyrifos)."For further information on the status of the EDSP, the policies and procedures, the lists of chemicals, future lists, the test guidelines and the Tier 1 screening battery, please visit our website.[16]

5.0 Dietary Exposure and Risk Assessment

HED had previously conducted both acute and steady state dietary (food only) exposure analyses for chlorpyrifos using DEEM and Calendex software with the Food Commodity Intake Database (FCID) (D. Drew *et al.,* D424486, 11/18/2014), respectively.

For the current assessment, the resulting acute and steady state food exposure values are compared to the PBPK-derived aPAD or ssPAD. When the dietary exposure exceeds 100% of the aPAD or ssPAD there is a potential risk concern.

All details pertaining to the assumptions, data inputs, and exposure outputs for the dietary analysis may be found in the 2014 dietary assessment memorandum (D. Drew *et al.,* D425586, 11/18/2014).

[15] See https://www.regulations.gov/document?D=EPA-HQ-OPPT-2009-0477-0074 for the final second list of chemicals.
[16] https://www.epa.gov/endocrine-disruption

Table 5.0.1. Chlorpyrifos Population Adjusted Doses (PADs) Derived from PBPK Modeled Doses Corresponding to 10% RBC AChE Inhibition – FQPA SF 10X Retained[1].

RA Type	Infants (< 1 year old)			Children (1 – 2 Years old)			Children (6-12 Years Old)			Youths (13-19 Years Old)			Females (13-49 Years Old)		
	LOC	Acute	Steady State	LOC	Acute	Steady State	LOC	Acute	Steady State	LOC	Acute	Steady State	LOC	Acute	Steady State
Drinking Water (oxon conc, ppb)	50	23.66	4.34	50	60.08	10.96	50	154	27.16	50	99.76	17.56	100	52.85	9.32
Food (µg/kg/day)	40	15	2.6	40	15	2.5	40	13	2.3	40	12	2.0	100	4.7	0.78

1. Population Adjusted Dose (PAD) = POD ÷ LOC (including all applicable uncertainty factors). PODs for each scenario and subpopulation are provided in Table 4.2.2.1.2.

Table 5.0.2. Chlorpyrifos Population Adjusted Doses (PADs) Derived from PBPK Modeled Doses Corresponding to 10% RBC AChE Inhibition – FQPA SF Reduced to 1X[1].

RA Type	Infants (< 1 year old)			Children (1 – 2 Years old)			Children (6-12 Years Old)			Youths (13-19 Years Old)			Females (13-49 Years Old)		
	LOC	Acute	Steady State	LOC	Acute	Steady State	LOC	Acute	Steady State	LOC	Acute	Steady State	LOC	Acute	Steady State
Drinking Water (oxon conc, ppb)	5	236	43.4	5	600.8	109.6	5	1540	271.6	5	997.6	175.6	10	528.5	93.2
Food (µg/kg/day)	4	150	26	4	150	25	4	130	23	4	120	20	10	47	7.8

1. Population Adjusted Dose (PAD) = POD ÷ LOC (including all applicable uncertainty factors). PODs for each scenario and subpopulation are provided in Table 4.2.2.1.2.

5.1 Residues of Concern Summary and Rationale

The qualitative nature of the residue in plants and livestock is adequately understood based on acceptable metabolism studies with cereal grain (corn), root and tuber vegetable (sugar beets), and poultry and ruminants. The residue of concern, for tolerance expression and risk assessment, in plants (food and feed) and livestock commodities is the parent compound chlorpyrifos.

Based on evidence (various crop field trials and metabolism studies) indicating that the metabolite chlorpyrifos oxon would be not be present in edible portions of the crops (particularly at periods longer than the currently registered PHIs), it is not a residue of concern in food or feed at this time. Also, the chlorpyrifos oxon is not found on samples in the U.S. Department of Agriculture's Pesticide Data Program (USDA PDP) monitoring data. In fact, from 2007 to 2012, out of several thousand samples of various commodities, only one sample of potato showed presence of the oxon at trace levels, 0.003 ppm where the LOD was 0.002 ppm, even though there are no registered uses of chlorpyrifos on potato in the U.S.

The oxon metabolite was not found in milk or livestock tissues in cattle and dairy cow feeding studies, at all feeding levels tested, and is not a residue of concern in livestock commodities.

Oxidation of chlorpyrifos to chlorpyrifos oxon could potentially occur through photolysis, aerobic metabolism, and chlorination as well as other oxidative processes. Because of the toxicity of the oxon and data indicating that chlorpyrifos rapidly converts to the oxon during typical drinking water treatment (chlorination), the drinking water risk assessment considers the oxon as the residue of concern in treated drinking water and assumes 100% conversion of chlorpyrifos to chlorpyrifos oxon (see DWA, R. Bohaty, 09/15/2020, D459269 and 09/15/2020, D459270).

Table 5.1. Summary of Metabolites and Degradates to be included in the Risk Assessment and Tolerance Expression.

Matrix		Residues included in Risk Assessment	Residues included in Tolerance Expression
Plants	Primary Crop	Chlorpyrifos	Chlorpyrifos
	Rotational Crop	Chlorpyrifos	Chlorpyrifos
Livestock	Ruminant	Chlorpyrifos	Chlorpyrifos
	Poultry	Chlorpyrifos	Chlorpyrifos
Drinking Water		Chlorpyrifos Oxon	Not Applicable

5.2 Food Residue Profile

Acute and steady state dietary (food only) exposure analyses for chlorpyrifos were conducted using the Dietary Exposure Evaluation Model (DEEM) and Calendex software with the Food Commodity Intake Database (FCID) (D. Drew, 11/18/2014, D424486, *Chlorpyrifos Acute and Steady State Dietary (Food Only) Exposure Analysis to Support Registration Review*). This software uses 2003-2008 food consumption data from the U.S. Department of Agriculture's (USDA's) National Health and Nutrition Examination Survey, What We Eat in America, (NHANES/WWEIA). These analyses were performed for the purpose of obtaining food exposure values for comparison to the chlorpyrifos doses predicted by the PBPK-PD model to cause RBC ChEI. The acute and steady state dietary exposure analyses do not include drinking

water which is assessed separately as discussed in Section 7 (Aggregate Exposure/Risk Characterization).

Both the acute and steady state dietary exposure analyses are highly refined. The large majority of food residues used were based upon PDP monitoring data except in a few instances where no appropriate PDP data were available. In those cases, field trial data or tolerance level residues were assumed. OPP's Biological and Economic Analysis Division (BEAD) provided estimated percent crop treated information. Food processing factors from submitted studies were used as appropriate.

5.3 Percent Crop Treated Used in Dietary Assessment

The acute and steady state dietary exposure assessment used percent crop treated (%CT) information from BEAD's Screening Level Usage Analysis **(**SLUA; May 2014). BEAD has recently issued an updated SLUA (March 2020) for chlorpyrifos which includes a comparison of the percent crop treated estimates of 2016 and 2020.[17] Those results indicate that there were no appreciable increases in estimated percent crop treated and that most reported crop commodities had a decrease in percent crop treated as well as a decrease in the average yearly amount of chlorpyrifos applied. The use of the 2014 crop treated estimates do not underestimate the dietary exposures.

5.4 Acute Dietary (Food Only) Risk Assessment

Chlorpyrifos acute (food only) dietary exposure assessments were conducted using the Dietary Exposure Evaluation Model software with the Food Commodity Intake Database DEEM-FCID™, Version 3.16, which incorporates consumption data from NHANES/WWEIA. This dietary survey was conducted from 2003 to 2008. Acute dietary risk estimates are presented below for the sentinel population subgroups for acute risk assessment: infants (< 1 year old), children (1-2 years old), youths (6-12 years old) and adults (females 13-49 years old). The assessment of these index lifestages will be protective for the other population subgroups.

Acute dietary (food only) risk estimates are all <100 % of the acute PAD for food ($aPAD_{food}$) at the 99.9th percentile of exposure and are not of concern. With the 10X FQPA SF retained, the population with the highest risk estimate is females (13-49 years old) at 3.2 % $aPAD_{food}$. With the FQPA SF reduced to 1X, the acute dietary risk estimates are <1% of the $aPAD_{food}$ for all populations.

Table 5.4. Acute Dietary (Food Only) Exposure and Risk Estimates for Chlorpyrifos.

Population Subgroup	Food Exposure[1] (µg/kg/day)	$aPOD_{food}$[2] (µg/kg/day)	10X FQPA SF		1X FQPA SF	
			$aPAD_{food}$[3] (µg/kg/day)	% of $aPAD_{food}$	$aPAD_{food}$[4] (µg/kg/day)	% of $aPAD_{food}$
Infants (< 1 yr)	0.273	600	15	1.8	150	<1

[17] L. Hendrick, 03/05/2020, Updated Chlorpyrifos (059101) Screening Level Usage Analysis (SLUA)

Table 5.4. Acute Dietary (Food Only) Exposure and Risk Estimates for Chlorpyrifos.						
Population Subgroup	**Food Exposure[1] (µg/kg/day)**	**$aPOD_{food}$[2] (µg/kg/day)**	**10X FQPA SF**		**1X FQPA SF**	
			$aPAD_{food}$[3] (µg/kg/day)	**% of $aPAD_{food}$**	**$aPAD_{food}$[4] (µg/kg/day)**	**% of $aPAD_{food}$**
Children (1-2 yrs)	0.423	581	15	2.8	150	<1
Youths (6-12 yrs)	0.189	530	13	1.4	130	<1
Adults (Females 13-49 yrs)	0.150	467	4.7	3.2	47	<1

[1] Acute food only exposure estimates from DEEM (at 99.9th percentile). Refined with monitoring data and %CT.
[2] Acute point of departure; daily dose predicted by PBPK-PD model to cause RBC ChEI of 10% for acute dietary (food) exposures. Table 4.8.4.1.2.
[3]aPAD= acute population adjusted dose = PoD (Dose predicted by PBPK-PD model to cause 10% RBC ChEI) ÷ total UF; Total uncertainty factor =100X for females 13-49 yrs (10X intraspecies factor and 10X FQPA uncertainty factor) and 40X for other populations (4X intraspecies factor and 10X FQPA uncertainty factor). Table 5.0.1.
[4]aPAD= acute population adjusted dose = PoD (Dose predicted by PBPK-PD model to cause 10% RBC ChEI) ÷ total UF; Total uncertainty factor =10X for females 13-49 yrs (10X intraspecies factor and 1X FQPA uncertainty factor) and 4X for other populations (4X intraspecies factor and 1X FQPA uncertainty factor). Table 5.0.2.

5.5 Steady State Dietary (Food Only) Exposure and Risk Estimates

A chlorpyrifos steady state dietary (food only) exposure analysis was conducted using Calendex-FCID™. HED's steady state assessment considers the potential risk from a 21-day exposure duration using a 3-week rolling average (sliding by day) across the year. For this assessment, the same food residue values used in the acute assessment were used for the 21-day duration. In the Calendex software, one diary for each individual in the WWEIA is selected to be paired with a randomly selected set of residue values for each food consumed. The steady state analysis calculated exposures for the sentinel populations for infant, child, youths, and adult (infants <1 yr, children 1-2 yrs, youths 6-12 yrs, females 13-49 yrs). The assessment of these index lifestages will be protective for the other population subgroups.

Calendex reported dietary exposures for each population subgroup at several percentiles of exposure ranging from 10th percentile to 99.9th percentile. The dietary (food only) exposures for chlorpyrifos were all <100% $ssPAD_{food}$ (all populations, at all percentiles of exposure). Only the 99.9th percentile of exposure is presented in Table 5.5 below. Calendex exposure results for other percentiles of exposure can be found in D424486.

Steady state dietary (food only) risk estimates are all <100 % of the steady state PAD for food ($ssPAD_{food}$) at the 99.9th percentile of exposure and are not of concern. With the 10X FQPA SF retained, the population with the highest risk estimate is children (1-2 years old) at 9.7 % $ssPAD_{food}$. With the FQPA SF reduced to 1X, the steady state dietary risk estimates are <1% of the $ssPAD_{food}$ for all populations.

Table 5.5. Steady State Dietary (Food Only) Exposure and Risk Estimates for Chlorpyrifos.						
Population Subgroup	**Food Exposure[1] (µg/kg/day)**	**ssPoD$_{food}$[2] (µg/kg/day)**	**10X FQPA SF**		**1X FQPA SF**	
			ssPAD$_{food}$[3] (µg/kg/day)	**% of ssPAD$_{food}$**	**ssPAD$_{food}$[4] (µg/kg/day)**	**% of ssPAD$_{food}$**
Infants (< 1 yr)	0.186	103	2.6	7.2	26	<1
Children (1-2 yrs)	0.242	99	2.5	9.7	25	<1
Youths (6-12 yrs)	0.128	90	2.3	5.6	23	<1
Adults (Females 13-49 yrs)	0.075	78	0.78	9.6	7.8	<1

[1] Steady state food only exposure estimates from DEEM (at 99.9th percentile). Refined with monitoring data and %CT.
[2] Steady state point of departure; daily dose predicted by PBPK-PD model to cause RBC ChEI of 10% for acute dietary (food) exposures. Table 4.8.4.1.2.
[3]ssPAD= steady state population adjusted dose = POD (Dose predicted by PBPK-PD model to cause 10% RBC ChEI) ÷ total UF; Total uncertainty factor =100X for females 13-49 yrs (10X intraspecies factor and 10X FQPA uncertainty factor) and 40X for other populations (4X intraspecies factor and 10X FQPA uncertainty factor). Table 5.0.1.
[4] ssPAD= steady state population adjusted dose = POD (Dose predicted by PBPK-PD model to cause 10% RBC ChEI) ÷ total UF; Total uncertainty factor =10X for females 13-49 yrs (10X intraspecies factor and 1X FQPA uncertainty factor) and 4X for other populations (4X intraspecies factor and 1X FQPA uncertainty factor). Table 5.0.2.

5.6 Dietary Drinking Water Risk Assessment

The total dietary exposure to chlorpyrifos is through both food and drinking water. EFED has provided a revised drinking water assessment (DWA) for chlorpyrifos (R. Bohaty, 09/15/2020, D459269 and 09/15/2020, D459270) which includes the updated EDWCs for dietary risk assessment. A DWLOC approach is used to calculate the amount of exposure available in the total dietary 'risk cup' for chlorpyrifos in drinking water after accounting for chloropyrifos exposure from food and from residential uses. This DWLOC can be compared to the EDWCs to determine if there is a risk of concern for drinking water exposures (See D. Drew, D424485, 12/29/2014 for details on the DWLOC approach and calculations). The acute and steady state dietary exposure analyses discussed above only include food and do not include drinking water; the aggregate assessment, which does incorporate drinking water, is discussed in Section 7 (Aggregate Exposure/Risk Characterization).

6.0 Residential Exposure/Risk Characterization

Residential exposures to chlorpyrifos are currently expected from chlorpyrifos use in residential settings. Formulations/use sites registered for use in residential areas include a granular ant mound use and roach bait in child-resistant packaging. Additionally, chlorpyrifos is labeled for public health aerial and ground-based fogger ULV mosquito adulticide applications and for golf course turf applications. All residential exposures and risks were previously assessed in support of the 2014 HHRA (W. Britton, D424484, 12/29/2014) and 2016 HHRA (W. Britton, D436317, 11/3/2016). The previous assessments included evaluation of residential post-application risks from playing golf on chlorpyrifos-treated courses and from exposures which can occur following aerial and ground-based ULV mosquito adulticide usage. The potential for residential exposures

from the roach bait product was determined to be negligible. Further, residential exposures from the ant mound use were also determined to be negligible since these products can only be applied professionally and direct exposure with treated ant mounds is not anticipated.

The previously assessed residential post-application assessments have been updated to incorporate the approach applied for PBPK-derivation of PODs for infants, children, and adults based on 10% RBC AChE inhibition. The results have been summarized assuming both that the FQPA SF has been retained at 10X and has been reduced to 1X. If the FQPA SF is retained, the total LOC for residential exposure assessment is 100X for adults (represented by females 13-49) and 40X for all other subpopulations, including children.

6.1 Residential Handler Exposure/Risk Estimates

HED uses the term "handlers" to describe those individuals who are involved in the pesticide application process. HED believes that there are distinct tasks related to applications and that exposures can vary depending on the specifics of each task. Residential handlers are addressed somewhat differently by HED as homeowners are assumed to complete all elements of an application without use of any protective equipment.

Based upon review of all chlorpyrifos registered uses, only the roach bait products can be applied by a homeowner in a residential setting, but the application of roach bait products has not quantitatively assessed because these exposures are negligible. The roach bait product is designed such that the active ingredient is contained within a bait station which eliminates the potential for contact with the chlorpyrifos containing bait material. Therefore, updated residential handler risks are not required for these uses.

6.2 Residential Post-Application Exposure/Risk Estimates

Residential post-application exposures are likely from being in an environment that has been previously treated with chlorpyrifos. Chlorpyrifos can be used on golf courses and as an aerial and ground based ULV mosquito adulticide application in residential areas. Post-application exposure from residential ant mount treatment was assessed qualitatively because post-application exposures to treated ant mounts are expected to be negligible.

All of the residential post-application exposure scenarios, data and assumptions, and algorithms used to assess exposures and risks from activities on golf course turf following chlorpyrifos application and from aerial and ground based ULV mosquito adulticide applications are the same as those used in the 2016 HHRA. Additionally, this updated assessment makes use of the same chemical-specific turf transferable residue (TTR) data to assess exposures and risks. In the 2016 HHRA (W. Britton, D436317, 11/03/2016), the residential post-application exposures and risks resulting from aerial and ground-based ULV mosquito adulticide applications were updated to reflect 1) the current default deposition fraction recommended for ground applied ULV mosquitocides (i.e., 8.7 percent of the application rate vs the previous 5 percent) and 2) several iterations of aerial applications modeled assuming differing winds speeds and release heights allowed by chlorpyrifos mosquitocide ULV labels. The previously assessed residential post-application assessment has been updated to incorporate the approach applied for PBPK-derivation of PODs for infants, children, and adults based on 10% RBC AChE inhibition and

assuming both that the FQPA SF has been retained at 10X and has been reduced to 1X. The AgDISP (v8.2.6) model input parameters, outputs, and the algorithms used to estimate residential post-application exposures following aerial and ground based ULV mosquitocide application can be found in Appendix 7.

Combining Exposure and Risk Estimates

Since dermal, incidental oral, and inhalation exposure routes share a common toxicological endpoint, RBC AChE inhibition, risk estimates have been combined for those routes. The incidental oral scenarios (i.e., hand-to-mouth and object-to-mouth) should be considered inter-related and it is likely that they occur interspersed amongst each other across time. Combining these scenarios with the dermal and inhalation exposure scenarios would be unrealistic because of the conservative nature of each individual assessment. Therefore, the post-application exposure scenarios that were combined for children 1 < 2 years old are the dermal, inhalation, and hand-to-mouth scenarios (the highest incidental oral exposure expected). This combination should be considered a protective estimate of children's exposure to pesticides.

Summary of Residential Post-Application Non-Cancer Exposure and Risk Estimates

Whether the FQPA SF is retained at 10X or reduced to 1X, there are no residential post-application risk estimates of concern for the registered uses of chlorpyrifos. If the FQPA SF is retained at 10X, the assessment of steady state residential golfing post-application exposures (dermal only) to chlorpyrifos treated turf results in no risks of concern for adults or children/youths [i.e., MOEs $\geq$ 40 for children 6 to < 11 years old and youths 11 to < 16 years old and MOEs $\geq$ 100 for adults (females 13-49)]. Additionally, the steady state post-application exposures from public health mosquitocide applications results in no combined risk estimates of concern for adults (females 13-49; dermal and inhalation exposures) and children 1 to < 2 years old (dermal, incidental oral, and inhalation exposures) (i.e., MOEs $\geq$ 40 for children 1 to < 2 years old and MOEs $\geq$ 100 for adults). If the FQPA SF is reduced to 1X, there are also no residential post-application risk estimates of concern for adults (females 13-49) or children/youths [MOEs > 4 for children 1 to < 2 years old, children 6 to < 11 years old, and children 11 to < 16 years old; and MOEs > 10 for adults (females 13-49 years old)].

The risk estimates are presented in Table 6.2.1 – Table 6.2.8.

Table 6.2.1. Steady State Residential Post-Application Exposure and Risk Estimates for Chlorpyrifos - Golf Course Uses.

Lifestage	Post-application Exposure Scenario		Application Rate[1]	State (TTR Data)	Dose (mg/kg/day)[2]	MOEs[3]
	Use Site	Route of Exposure				
Adult (Females 13-49 years old)	Golf Course Turf	Dermal	1.0 (Emulsifiable Concentrate)	CA	0.010	1,200
				IN	0.0069	1,700
				MS	0.012	1,000
				Mean	0.0095	1,200
Youths 11 to < 16 years old				CA	0.010	1,400
				IN	0.0069	2,000
				MS	0.012	1,200
				Mean	0.0096	1,500
Children 6 to < 11 years old				CA	0.012	1,900

Table 6.2.1. Steady State Residential Post-Application Exposure and Risk Estimates for Chlorpyrifos - Golf Course Uses.						
Lifestage	**Post-application Exposure Scenario**		**Application Rate[1]**	**State (TTR Data)**	**Dose (mg/kg/day)[2]**	**MOEs[3]**
	Use Site	**Route of Exposure**				
				IN	0.0082	2,800
				MS	0.014	1,600
				Mean	0.011	2,000
Adult (Females 13-49 years old)			1.0 (Granular)	CA	0.0088	1,400
Youths 11 to < 16 years old					0.0088	1,600
Children 6 to < 11 years old					0.010	2,200

1 Based on the maximum application rates registered for golf course turf.
2 Dose (mg/kg/day) equations for golfing applications are provided in Appendix B of the occupational and residential exposure assessment (W. Britton, D424484, 12/29/2014). For dose estimation from exposures to golfing on treated turf, the TTR data were used. Doses have been presented for all State sites, including the mean of all state sites.
3 MOE = POD (mg/kg/day) ÷ Dose (mg/kg/day). LOC = if the FQPA SF is retained at 10X, the total LOC for residential exposure assessment is 100X for adults (females 13-49) and 40X for all other subpopulations, including children. If the FQPA SF is reduced to 1X, the total LOC for residential exposure assessment is 10X for adults (females 13-49) and 4X for all other subpopulations, including children. See Table 4.2.2.1.2 for PODs.

Table 6.2.2. Residential Post-Application Inhalation Steady State Exposure Estimates from Chlorpyrifos ULV Aerial Mosquitocide Application - AgDISP Model.			
Application Parameters	**Population**	**Air Concentration Estimate (mg/m^3)[1]**	**MOE[2]**
1 mph Wind Speed Dv 0.5 = 60 µm 75 Foot Release Height	Adults	0.0047	1,300
	Children 1 to <2 years old		500
10 mph Wind Speed Dv 0.5 = 40 µm 300 Foot Release Height	Adults	0.00070	8,800
	Children 1 to <2 years old		3,400

1 Air concentration estimate modeled using AGDISP v8.2.6 at breathing height of adults and children.
2 MOE = POD (mg/m^3) ÷ Dose (mg/m^3). See Table 4.2.2.1.2 for PODs.

Table 6.2.3. Residential Post-Application Inhalation Steady State Exposure Estimates from Chlorpyrifos ULV Ground Mosquitocide Application – Well Mixed Box (WMB) Model.		
Population	**Air Concentration Estimate (mg/m^3)[1]**	**MOE[2]**
Adults	0.0051	1,200
Children 1 to <2 years old		460

1 Air concentration estimate modeled using the well mixed box model. The inputs and algorithms used are presented in Appendix C of D424484 (W. Britton, 12/29/2014).
2 MOE = POD (mg/m^3) ÷ Dose (mg/m^3). See Table 4.2.2.1.2 for PODs.

Table 6.2.4. Residential Post-Application Dermal Steady State Exposure Estimates Resulting from Chlorpyrifos Aerial ULV Mosquitocide Application.

Application Parameters	Lifestage	Application Rate (lb ai/A)	AgDISP Deposition Fraction[1]	Adjusted TTR[2] (µg/cm^2)	Dermal Dose[3] (mg/kg/day)	MOE[4]
1 mph Wind Speed Dv 0.5 = 60 µm 75 Foot Release Height	Adults	0.010	1.0	0.00038	0.0015	16,000
	Children 1 to < 2 Years Old				0.0026	53,000
10 mph Wind Speed Dv 0.5 = 40 µm 300 Foot Release Height	Adults	0.010	0.086	0.000033	0.00013	180,000
	Children 1 to < 2 Years Old				0.00022	610,000

1 The fraction of chlorpyrifos residue deposited following aerial mosquitocide application was determined with use of the AgDISP (v8.2.6) model.
2 TTR_t (µg/cm^2) = [(Day 0 Residue from MS TTR study (µg/cm^2) × Application Rate (0.010 lb ai/A)) ÷ Application Rate of MS TTR Study (3.83 lb ai/A))] × AgDISP Deposition Fraction. The MS TTR data was selected for use because it is the worst case and, as a result, most protective of human health.
3 Dermal Dose (mg/kg/day) = [(TTR_t (µg/cm^2) × CF1 (0.001 mg/µg) × Transfer Coefficient (180,000 cm^2/hr, adults; 49,000 cm^2/hr, children) * ET (1.5 hrs))] ÷ BW (kg).
4 MOE = POD (mg/kg/day) ÷ Dose (mg/kg/day). See Table 4.2.2.1.2 for PODs.

Table 6.2.5. Residential Post-Application Dermal Steady State Exposure Estimates Resulting from Chlorpyrifos ULV Ground Mosquitocide Application.

Lifestage	Application Rate (lb ai/A)	Deposition Fraction[1]	Adjusted TTR[2] (µg/cm^2)	Dermal Dose[3] (mg/kg/day)	MOE[4]
Adults	0.010	1.0	0.00038	0.00013	180,000
Children 1 to < 2 Years Old				0.00022	610,000

1 Ground fraction of mosquitocide application rate deposited on turf as determined using eight published studies on ground ULV application in which deposition was measured.
2 TTR_t (µg/cm^2) = [(Day 0 Residue from MS TTR study (µg/cm^2) × Application Rate (0.010 lb ai/A)) ÷ Application Rate of MS TTR Study (3.83 lb ai/A))] × AgDISP Deposition Fraction
3 Dermal Dose (mg/kg/day) = [(TTR_t (µg/cm^2) × CF1 (0.001 mg/µg) × Transfer Coefficient (cm^2/hr - 180,000, adults; 49,000, children) × ET (1.5 hrs))] ÷ BW (kg)
4 MOE = POD (mg/kg/day) ÷ Dose (mg/kg/day). See Table 4.2.2.1.2 for PODs.

Table 6.2.6. Residential Post-Application Steady State Incidental Oral Exposure Estimates Resulting from Chlorpyrifos ULV Aerial Mosquitocide Application.

Application Parameters	Lifestage	Application Rate (mg ai)	Dermal Exposure (mg/day)[1]	Incidental Oral Dose (mg/kg/day)[2]	MOE[3]
1 mph Wind Speed Dv 0.5 = 60 µm 75 Foot Release Height	Children 1 to < 2 Years Old	0.010	0.028	$5.2x10^{-5}$	1,900
10 mph Wind Speed			0.0022	$4.5x10^{-6}$	22,000

Dv 0.5 = 40 µm 300 Foot Release Height					

1 Dermal exposure (mg/day) as calculated for children's aerial based ULV applications using the algorithms as described in Appendix C of D424484 (W. Britton, 12/29/2014).
2 Incidental Oral Dose estimated using the algorithms as described below in Appendix C of the 2014 HHRA.
3 MOE = POD (mg/kg/day) ÷ Dose (mg/kg/day). See Table 4.2.2.1.2 for PODs.

Table 6.2.7. Residential Post-Application Steady State Incidental Oral Exposure Estimates Resulting from Chlorpyrifos ULV Ground Mosquitocide Application.

Lifestage	Application Rate (mg ai)	Dermal Exposure (mg/day)[1]	Incidental Oral Dose (mg/kg/day)[2]	MOE[3]
Children 1 to < 2 Years Old	0.010	0.0024	$4.5x10^{-6}$	22,000

1 Dermal exposure (mg/day) as calculated for children's ground based ULV applications using the algorithms described in Table 6.2.5 above, and as described below in Appendix C of D424484 (W. Britton, 12/29/2014).
2 Incidental Oral Dose estimated using the algorithms as described in Appendix C of the 2014 HHRA.
3 MOE = POD (mg/kg/day) ÷ Dose (mg/kg/day). See Table 4.2.2.1.2 for PODs.

Table 6.2.8. Combined Residential Post-Application Steady State Exposure Estimates from Chlorpyrifos Mosquitocide Applications.						
Population	**Application Parameter**	**Route of Exposure**	**Dermal or Incidental Oral Dose (mg/kg/day) or Air Concentration estimate (mg/m^3)[1]**	**MOE[2]**	**Combined Routes[3]**	**Combined MOEs[4]**
Adults (Females 13-49 years old)	Aerial ULV Mosquitocide Application 1 mph Wind Speed Dv 0.5 = 60 µm 75 Foot Release Height	Inhalation	0.0047	1,300	X	1,200
		Dermal	0.0015	16,000		
	Aerial ULV Mosquitocide Application 10 mph Wind Speed Dv 0.5 = 40 µm 300 Foot Release Height	Inhalation	0.00070	8,800	X	8,400
		Dermal	0.00013	180,000		
	Ground Mosquitocide Application – WMB	Inhalation	0.0051	1,200	X	1,200
		Dermal	0.00013	180,000		
Children 1 to < 2 years old	Aerial ULV Mosquitocide Application 1 mph Wind Speed Dv 0.5 = 60 µm 75 Foot Release Height	Inhalation	0.0047	500	X	400
		Dermal	0.0026	53,000		
		Incidental Oral	$5.2x10^{-5}$	1,900		
	Aerial ULV Mosquitocide Application 10 mph Wind Speed Dv 0.5 = 40 µm 300 Foot Release Height	Inhalation	0.00070	3,400	X	2,900
		Dermal	0.00022	610,000		
		Incidental Oral	$4.5x10^{-6}$	22,000		
	Ground Mosquitocide Application – WMB	Inhalation	0.0051	460	X	450
		Dermal	0.00022	610,000		
		Incidental Oral	$4.54x10^{-6}$	22,000		

1. See Tables 6.2.3 – 6.2.7 for route-specific exposure inputs and risk estimates.
2. MOE = POD (mg/m^3) ÷ Dose (mg/m^3). See Table 4.2.2.1.2 for PODs.
3. X indicates the exposure scenarios included in the combined MOE.

4. Combined MOE = 1 ÷ [(1/dermal MOE) + (1/inhalation MOE) + (1/incidental oral MOE)], where applicable.

6.3 Residential Risk Estimates for Use in Aggregate Assessment

Table 6.3 reflects the residential risk estimates that are recommended for use in the aggregate assessment for chlorpyrifos.

- Adults (females 13-49 years old): post-application dermal exposures from golfing on treated turf using MS TTR data.
- Children 11 to < 16 years old: post-application dermal exposures from golfing on treated turf using MS TTR data.
- Children 6 to < 11 years old: post-application dermal exposures from golfing on treated turf using MS TTR data.

Exposures to treated turf from mosquitocide applications are completed as stand-alone assessments since mosquitocide applications are typically only made as a result of/in response to a public health need, and require a risk mitigation/risk management determination significantly different from an assessment without a large public health benefit. Therefore, these exposures are not aggregated with exposures from food and drinking water.

Table 6.3. Recommendations for the Residential Exposures for the Chlorpyrifos Aggregate Assessment.

Lifestage	Exposure Scenario	Dose[1]			MOE[2]			
		Dermal (mg/kg/day)	Inhalation (mg/m^3)	Oral (mg/kg/day)	Dermal	Inhalation	Oral	Total
Adults (Females 13-49 Years Old)	Golf Course Turf – MS TTR Data	0.012	N/A	N/A	1,000	N/A	N/A	1,000
Children 11 to < 16 Years Old		0.012	N/A		1,200	N/A		1,200
Children 6 to < 11 Years Old		0.014	N/A		1,600	N/A		1,600

1 Dose = the highest dose for each applicable lifestage of all residential scenarios assessed. Total = dermal + incidental oral (where applicable).

2 MOE = the MOEs associated with the highest residential doses. Total = 1 ÷ [(1/Inhalation MOE) + (1/Dermal MOE) + (1/Incidental Oral MOE)], where applicable.

7.0 Aggregate Exposure/Risk Characterization

In accordance with the FQPA, HED must consider and aggregate (add) pesticide exposures and risks from three major sources: food, drinking water, and residential exposures. In an aggregate assessment, exposures from relevant sources are added together and compared to quantitative estimates of hazard, or the risks themselves can be aggregated. The durations of exposure identified for chlorpyrifos uses are acute and steady state. The acute aggregate assessment includes food and drinking water only. The steady state aggregate assessment includes food, drinking water, and residential exposures.

A drinking water level of comparison (DWLOC) approach to aggregate risk was used to calculate the amount of exposure available in the total 'risk cup' for chlorpyrifos oxon in drinking water after accounting for any chloropyrifos exposures from food and/or residential uses. This DWLOC can then be compared to the EDWCs to determine if there is an aggregate risk of concern. EFED has provided an updated drinking water assessment (DWA) for chlorpyrifos which includes the EDWCs for aggregate risk assessment. For chlorpyrifos,

DWLOCs were calculated for both the acute and steady state aggregate assessments for infants, children, youths and adult females.

For complete details on the assumptions, results, and characterization of the drinking water analysis refer to EFED's DWA (R. Bohaty, 09/15/2020, D459269 and 09/15/2020, D459270).

7.1 Acute Aggregate Risk – DWLOC Approach

The acute aggregate assessment includes only food and drinking water. Acute DWLOCs were calculated for infants, children, youths, and adults. The DWLOCs were calculated assuming both that the FQPA SF has been retained at 10X and has been reduced to 1X. With the 10X FQPA SF retained, the lowest acute DWLOC calculated was for infants (<1 year old) at 23 ppb. With the FQPA SF reduced to 1X, the lowest acute DWLOC calculated was for infants (<1 year old) at 230 ppb.

Table 7.1.1. Acute Aggregate (Food and Drinking Water) Calculation of DWLOCs with FQPA 10X SF.[1,2]

Population	Food Exposure (chlorpyrifos)[3]		Drinking Water Exposure (chlorpyrifos oxon)[4]		Acute DWLOC with FQPA 10X[5] (ppb chlorpyrifos oxon)
	MOE	ARI	MOE	ARI	
Infants[1] (<1 yr)	2200	55	51	1.0	23
Children[1] (1-2 yrs)	1400	35	52	1.0	58
Youths[1] (6-12 yrs)	2800	70	51	1.0	150
Adults[2] (Females 13-49 yrs)	3100	31	103	1.0	51

[1] DWLOCs for infants, children and youths are calculated using the ARI (Aggregate Risk Index) approach since target MOEs are different for drinking water (chlorpyrifos oxon target MOE=50 with 10X FQPA SF retained) and for food and residential (chlorpyrifos target MOE= 40 with FQPA SF retained) exposures.
[2] DWLOCs for adults (females 13-49 yrs) are calculated using the reciprocal MOE approach since the target MOEs are the same for drinking water (chlorpyrifos oxon target MOE=100 with 10X FQPA SF retained) and for food and residential (chlorpyrifos target MOE= 100 with 10X FQPA SF retained) exposures.
[3] **FOOD:** MOE_{food} = POD_{food} (µg/kg/day) (from Table 4.2.2.1.2) ÷ Food Exposure (µg/kg/day) (from Table 5.4). ARI_{food} = [(MOE_{food})/(MOE_{target})].
[4] **WATER (ARI approach):** ARI_{water}= 1/[(1/ARI_{agg}) – ((1/ARI_{food}) + (1/ARI_{dermal}))]; Where ARI_{agg}=1 (Note:HED is generally concerned when calculated ARIs are less than 1).
MOE_{water} = ARI_{water} x MOE_{target}.
WATER (Reciprocal MOE approach): MOE_{water} = 1 ÷ [(1/MOE_{agg}) – ((1/MOE_{food}) + (1/MOE_{dermal}))]; Where MOE_{agg} =Target MOE.
[5] **DWLOC:** DWLOC ppb= POD_{water} (ppb; from Table 4.2.2.1.2) ÷ MOE_{water}

Table 7.1.2. Acute Aggregate (Food and Drinking Water) Calculation of DWLOCs with FQPA SF Reduced to 1X.[1,2]

Population	Food Exposure (chlorpyrifos)[3]		Drinking Water Exposure (chlorpyrifos oxon)[4]		Acute DWLOC with FQPA 1X[5] (ppb chlorpyrifos oxon)
	MOE	ARI	MOE	ARI	
Infants[1] (<1 yr)	2200	55	51	1.0	230

Table 7.1.2. Acute Aggregate (Food and Drinking Water) Calculation of DWLOCs with FQPA SF Reduced to 1X.[1,2]					
Population	**Food Exposure (chlorpyrifos)[3]**		**Drinking Water Exposure (chlorpyrifos oxon)[4]**		**Acute DWLOC with FQPA 1X[5] (ppb chlorpyrifos oxon)**
	MOE	**ARI**	**MOE**	**ARI**	
Children[1] (1-2 yrs)	1400	35	52	1.0	600
Youths[1] (6-12 yrs)	2800	70	51	1.0	1,500
Adults[2] (Females 13-49 yrs)	3100	31	10	1.0	530

[1] DWLOCs for infants, children and youths are calculated using the ARI (Aggregate Risk Index) approach since target MOEs are different for drinking water (chlorpyrifos oxon target MOE= 5 with FQPA SF reduced to 1X) and for food and residential (chlorpyrifos target MOE= 4 with FQPA SF reduced to 1X) exposures.
[2] DWLOCs for adults (females 13-49 yrs) are calculated using the reciprocal MOE approach since the target MOEs are the same for drinking water (chlorpyrifos oxon target MOE= 10 with FQPA SF reduced to 1X) and for food and residential (chlorpyrifos target MOE= 10 with FQPA SF reduced to 1X) exposures.
[3] **FOOD:** $MOE_{food} = POD_{food}$ (µg/kg/day) (from Table 4.2.2.1.2) ÷ Food Exposure (µg/kg/day) (from Table 5.4).
$ARI_{food} = [(MOE_{food})/(MOE_{target})]$.
[4] **WATER (ARI approach):** $ARI_{water} = 1/[(1/ARI_{agg}) – ((1/ARI_{food}) + (1/ARI_{dermal}))]$; Where $ARI_{agg}=1$ (Note:HED is generally concerned when calculated ARIs are less than 1).
MOE_{water} = ARI_{water} x MOE_{target}.
WATER (Reciprocal MOE approach): $MOE_{water} = 1 ÷ [(1/MOE_{agg}) – ((1/MOE_{food}) + (1/MOE_{dermal}))]$; Where MOE_{agg} =Target MOE.
[5] **DWLOC:** DWLOC ppb= POD_{water} (ppb; from Table 4.2.1.2) ÷ MOE_{water}

7.2 Steady State Aggregate Risk – DWLOC Approach

The steady state aggregate assessment includes dietary exposures from food and drinking water and dermal exposures from residential uses. Treated golf course turf represent the highest residential dermal exposures. Aggregate DWLOCs are presented below for the population subgroups of infants (< 1 year old), children (1-2 years old), youths (6-12 years old), and adults (females 13-49 years old). The assessment of these index lifestages is protective for the other population subgroups, including youths 11 to < 16 years old. The DWLOCs were calculated assuming both that the FQPA SF has been retained at 10X and has been reduced to 1X. The lowest steady state DWLOC calculated was for infants (<1 year old) at 4.0 ppb if the FQPA SF is retained at 10X and the lowest steady state DWLOC calculated was for infants (< 1 year old) at 43 ppb if the FQPA SF is reduced to 1X.

Table 7.2.1. Steady State Aggregate (Food, Drinking Water, Residential) Calculation of DWLOCs with FQPA 10X SF.[1,2]							
Population	**Food Exposure (chlorpyrifos)[3]**		**Residential Exposure (chlorpyrifos)[4]**		**Drinking Water Exposure (chlorpyrifos oxon)[5]**		**Steady State DWLOC with FQPA 10X[6] (ppb chlorpyrifos oxon)**
	MOE	**ARI**	**MOE**	**ARI**	**MOE**	**ARI**	
Infants[1] (<1 yr)	550	14	NA	NA	54	1.1	4.0
Children[1] (1-2 yrs)	410	10	NA	NA	55	1.1	9.9
Youths[1] (6-12 yrs)	700	18	1,600	40	44	1.1	21

Table 7.2.1. Steady State Aggregate (Food, Drinking Water, Residential) Calculation of DWLOCs with FQPA 10X SF.[1,2]

Population	Food Exposure (chlorpyrifos)[3]		Residential Exposure (chlorpyrifos)[4]		Drinking Water Exposure (chlorpyrifos oxon)[5]		Steady State DWLOC with FQPA 10X[6] (ppb chlorpyrifos oxon)
	MOE	ARI	MOE	ARI	MOE	ARI	
Adults[2] (Females 13-49 yrs)	1040	10	1,000	10	124	1.2	7.5

[1] DWLOCs for infants, children and youths are calculated using the ARI (Aggregate Risk Index) approach since target MOEs are different for drinking water (chlorpyrifos oxon target MOE=50 with 10X FQPA SF retained) and for food and residential (chlorpyrifos target MOE= 40) exposure.
[2] DWLOCs for adults (females 13-49 yrs) are calculated using the reciprocal MOE approach since the target MOEs are the same for drinking water (chlorpyrifos oxon target MOE=100 with 10X FQPA SF retained) and for food and residential (chlorpyrifos target MOE= 100 with 10X FQPA SF retained) exposure.
[3] **FOOD:** $MOE_{food} = POD_{food}$ (µg/kg/day) (from Table 4.2.2.1.2) ÷ Food Exposure (µg/kg/day) (from Table 5.5).
$ARI_{food} = [(MOE_{food})/(MOE_{target})]$.
[4] **RESIDENTIAL:** $MOE_{residential} = 1 \div (1/\text{Dermal MOE})$, (see Table 6.3).
[5] **WATER (ARI approach):** $ARI_{water} = 1/[(1/ARI_{agg}) – ((1/ARI_{food}) + (1/ARI_{residential}))]$; Where ARI_{agg}=1 (Note:HED is generally concerned when calculated ARIs are less than 1).
$MOE_{water} = ARI_{water} \times MOE_{target}$.
WATER (Reciprocal MOE approach): $MOE_{water} = 1/ [(1/MOE_{agg}) – ((1/MOE_{food}) + (1/MOE_{residential}))]$; Where MOE_{agg} =Target MOE.
[6] **DWLOC:** DWLOC ppb= PoD_{water} (ppb; from Table 4.2.2.1.2) /MOE_{water}

Table 7.2.2. Steady State Aggregate (Food, Drinking Water, Residential) Calculation of DWLOCs with FQPA SF Reduced to 1X.[1,2]

Population	Food Exposure (chlorpyrifos)[3]		Residential Exposure (chlorpyrifos)[4]		Drinking Water Exposure (chlorpyrifos oxon)[5]		Steady State DWLOC with FQPA 1X[6] (ppb chlorpyrifos oxon)
	MOE	ARI	MOE	ARI	MOE	ARI	
Infants[1] (<1 yr)	550	140	NA	NA	5.0	1.0	43
Children[1] (1-2 yrs)	410	102	NA	NA	5.0	1.0	110
Youths[1] (6-12 yrs)	700	180	1,600	400	4.0	1.0	230
Adults[2] (Females 13-49 yrs)	1040	104	1,000	100	10	1.0	91

[1] DWLOCs for infants, children and youths are calculated using the ARI (Aggregate Risk Index) approach since target MOEs are different for drinking water (chlorpyrifos oxon target MOE=5 with FQPA SF reduced to 1X) and for food and residential (chlorpyrifos target MOE= 4 with FQPA SF reduced to 1X) exposure.
[2] DWLOCs for adults (females 13-49 yrs) are calculated using the reciprocal MOE approach since the target MOEs are the same for drinking water (chlorpyrifos oxon target MOE= 10 with FQPA SF reduced to 1X) and for food and residential (chlorpyrifos target MOE= 10 with FQPA SF reduced to 1X) exposure.
[3] **FOOD:** $MOE_{food} = POD_{food}$ (µg/kg/day) (from Table 4.2.2.1.2) ÷ Food Exposure (µg/kg/day) (from Table 5.5).
$ARI_{food} = [(MOE_{food})/(MOE_{target})]$.
[4] **RESIDENTIAL:** $MOE_{residential} = 1 \div (1/\text{Dermal MOE})$, (see Table 6.3).
[5] **WATER (ARI approach):** $ARI_{water} = 1/[(1/ARI_{agg}) – ((1/ARI_{food}) + (1/ARI_{residential}))]$; Where ARI_{agg}=1 (Note:HED is generally concerned when calculated ARIs are less than 1).
$MOE_{water} = ARI_{water} \times MOE_{target}$.
WATER (Reciprocal MOE approach): $MOE_{water} = 1/ [(1/MOE_{agg}) – ((1/MOE_{food}) + (1/MOE_{residential}))]$; Where MOE_{agg} =Target MOE.
[6] **DWLOC:** DWLOC ppb= PoD_{water} (ppb; from Table 4.2.2.1.2) /MOE_{water}

8.0 Non-Occupational Spray Drift Exposure and Risk Estimates

Spray drift is a potential source of exposure to those nearby pesticide applications. This is particularly the case with aerial application, but, to a lesser extent, spray drift can also be a potential source of exposure from the ground application methods (e.g., groundboom and airblast) employed for chlorpyrifos. Sprays that are released and do not deposit in the application area end up off-target and can lead to exposures to those it may directly contact. They can also deposit on surfaces where contact with residues can eventually lead to indirect exposures (*e.g.*, children playing on lawns where residues have deposited next to treated fields). The potential risk estimates from these residues can be calculated using drift modeling coupled with methods employed for residential risk assessments for turf products.

In the 2011 occupational and residential exposure assessment, the potential risks to bystanders from spray drift and exposure from volatilization were identified as possible concerns. Spray drift is the movement of aerosols and volatile components away from the treated area during the application process. The potential risks from spray drift and the impact of potential risk reduction measures were assessed in July 2012 (J. Dawson *et al.,* D399483, 07/13/2012). This evaluation supplemented the 2011 assessment where limited monitoring data indicated risks to bystanders. To increase protection for children and other bystanders, chlorpyrifos technical registrants voluntarily agreed to lower application rates and to other spray drift mitigation measures (R. Keigwin, 2012). As of December 2012, spray drift mitigation measures and use restrictions appear on all chlorpyrifos agricultural product labels (including a restriction to nozzles and pressures that produce a medium to coarse droplet size). Spray drift risk estimates have been re-presented here for children and adults using endpoints based on 10% RBC AChE inhibition and PODs derived with a PBPK model; and assuming both that the FQPA SF has been retained at 10X and has been reduced to 1X.

If the FQPA SF is retained at 10X, there were no dermal risk estimates of concern from indirect spray drift exposure to chlorpyrifos at the field edge for adults (females 13-49 years old) (MOEs $\geq$ 100). For children 1 to < 2 years old, there were no combined (dermal + incidental oral) risk estimates of concern from indirect spray drift exposure to chlorpyrifos (MOEs $\geq$ 40), except for two scenarios. For aerial applications at 2.3 lb ai/A, a distance of 10 feet results in MOEs not of concern. However, the 2012 agreement between EPA and the technical registrants (R. Keigwin, 2012) indicates that buffer distances of 80 feet for coarse or very coarse droplets and 100 feet for medium droplets for aerial applications are required for application rates $\geq$ 2.3 lb ai/A. For airblast applications > 3.76 lb ai/A, distances of 10 to 25 feet results in MOEs not of concern (LOC = 40). However, the 2012 agreement between EPA and the technical registrants (R. Keigwin, 2012) indicates that buffer distances of $\geq$ 25 feet and medium to coarse drops are required for airblast applications at rates >3.76 lb ai/A. Therefore, there are no risk estimates of concern incorporating the agreed-upon buffer distances and droplet sizes/nozzle types by the EPA and the technical registrants in 2012.

If the FQPA SF is reduced to 1X, there were no dermal risk estimates of concern from indirect spray drift exposure to chlorpyrifos at the field edge for adults (females 13-49 years old) (MOEs $\geq$ 10) and no combined (dermal + incidental oral) risks for children 1 to < 2 years old at the field edge (MOEs $\geq$ 4).

Table 8.1. Summary of Spray Drift Distances from the Field Edge for Chlorpyrifos MOEs to be > LOCs with 10X FQPA SF Retained.[1]

Application Rate (lb ai/A)	Nozzle Droplet Type/ Canopy Density	Adult Buffer Summary			Children 1 to < 2 Years Old Buffer Summary (Dermal + Incidental Oral)		
		Distance (Feet) from the Field Edge Needed For MOE > LOC of 100			Distance (Feet) from the Field Edge Needed for MOE > LOC of 40		
		Aerial[2]	Groundboom[2]	Airblast	Aerial[2]	Groundboom[2]	Airblast
6.0	Medium/ Coarse for Aerial and Ground-boom	NA	NA	0	NA	NA	25
4.3			0			0	10
4.0							10
3.76							10
3.0							0
2.3	Sparse for Airblast	0			10		
2.0					0		
1.5							
1.0							

1 Per December 2012 spray drift mitigation memorandum, aerial application of greater than 2 lb ai/A is only permitted for Asian Citrus Psylla control, up to 2.3 lb ai/A.
2 NA = not allowable.

Table 8.2. Summary of Spray Drift Distances from the Field Edge for Chlorpyrifos MOEs to be > LOCs with FQPA SF Reduced to 1X.[1]

Application Rate (lb ai/A)	Nozzle Droplet Type/ Canopy Density	Adult Buffer Summary			Children 1 to < 2 Years Old Buffer Summary (Dermal + Incidental Oral)		
		Distance (Feet) from Field Edge Needed for MOE > LOC of 10			Distance (Feet) From Field Edge Needed for MOE > LOC of 4		
		Aerial[2]	Groundboom[2]	Airblast	Aerial[2]	Groundboom[2]	Airblast
6.0	Medium/ Coarse for Aerial and Ground-boom	NA	NA	0	NA	NA	0
4.3			0			0	
4.0							
3.76							
3.0							
2.3	Sparse for Airblast	0			0		
2.0							
1.5							
1.0							

1 Per December 2012 spray drift mitigation memorandum, aerial application of greater than 2 lb ai/A is only permitted for Asian Citrus Psylla control, up to 2.3 lb ai/A.
2 NA = not allowable.

9.0 Non-Occupational Bystander Post-Application Inhalation Exposure and Risk Estimates

In January 2013, a preliminary assessment of the potential risks from volatilization was conducted.[18] The assessment evaluated the potential risks to bystanders, or those who live and/or work in proximity to treated fields, from inhalation exposure to vapor phase chlorpyrifos and chlorpyrifos-oxon emitted from fields following application of chlorpyrifos. The results of the January 2013 assessment indicated that offsite concentrations of chlorpyrifos and

[18] R. Bohaty, C. Peck, A. Lowit, W. Britton, N. Mallampalli, A. Grube. Chlorpyrifos: Preliminary Evaluation of the Potential Risks from Volatilization. 1/31/13. U.S. EPA Office of Chemical Safety and Pollution Prevention. D399484, D400781.

chlorpyrifos-oxon may exceed the target concentration based on the toxicological endpoints used at that time.[19]

One significant area of uncertainty described in the preliminary assessment was the use of the aerosolized chlorpyrifos inhalation toxicity study -- as opposed to chlorpyrifos vapor -- for evaluation of lung AChE resulting from field volatilization. Because field volatilization is the production and release of vapor into the atmosphere after sprays have settled on treated soils and plant canopies, the vapor, rather than the aerosol, is the relevant form for evaluation of bystander volatilization exposures. However, EPA lacked chlorpyrifos vapor toxicity data at the time it conducted the preliminary volatilization assessment in 2013. Following the release of the preliminary volatilization assessment, DAS conducted, high quality nose-only vapor phase inhalation toxicity studies for both chlorpyrifos and chlorpyrifos-oxon[20] to address this uncertainty.

In June 2014, a reevaluation of the 2013 preliminary volatilization assessment was conducted to present the results of the vapor studies and their impact. In the vapor studies, female rats were administered a saturated vapor, meaning that the test subjects received the highest possible concentration of chlorpyrifos or chlorpyrifos-oxon which can saturate the air in a closed system. At these saturated concentrations, no statistically significant inhibition of AChE activity was measured in RBC, plasma, lung, or brain at any time after the six-hour exposure period in either study. Under actual field conditions, indications are that exposures to vapor phase chlorpyrifos and its oxon would be much lower as discussed in the January 2013 preliminary volatilization assessment.

Because these new studies demonstrated that no toxicity occurred even at the saturation concentration, which is the highest physically achievable concentration, then there are no anticipated risks of concern from exposure to the volatilization of either chlorpyrifos or chlorpyrifos oxon. In June 2014, the January 2013 volatilization assessment was revised to reflect these findings.[21]

10.0 Cumulative Exposure/Risk Characterization

OPs, such as chlorpyrifos, share the ability to inhibit AChE through phosphorylation of the serine residue on the enzyme leading to accumulation of acetylcholine and ultimately cholinergic

[19]EPA MRID# 48139303**:**Acute Inhalation Exposure of Adult Crl:CD(SD) Rates to Particulate Chlorpyrifos Aerosols: Kinetics of Concentration-Dependent Cholinesterase (ACHE) Inhibition in Red Blood Cells, Plasma, Brain and Lung; Authors: J. A. Hotchkiss, S. M. Krieger, K. A. Brzak, and D. L. Rick; Sponsor: Dow AgroSciences LLC.

[20]W. Irwin. Review of Nose-Only Inhalation of Chlorpyrifos Vapor: Limited Toxicokinetics and Determination of Time-Dependent Effects on Plasma, Red Blood Cell, Brain and Lung Cholinesterase Activity in Femal CD(SD): Crl Rats. U.S. EPA Office of Chemical Safety and Pollution Prevention. 6/25/14. D411959. TXR# 0056694. EPA MRID# 49119501.

W. Irwin. Review of Nose-Only Inhalation of Chlorpyrifos-Oxon Vapor: Limited Toxicokinetics and Determination of Time-Dependent Effects on Plasma, Red Blood Cell, Brain, and Lung Cholinesterase Activity in Female CD(SD):Crl Rats. U.S. EPA Office of Chemical Safety and Pollution Prevention. 6/25/14. D415447. TXR# 0056869. EPA MRID# 49210101.

[21] W. Britton. W. Irwin. J. Dawson. A. Lowit. E. Mendez. Chlorpyrifos:Reevaluation of the Potential Risks from Volatilization in Consideration of Chlorpyrifos Parent and Oxon Vapor Inhalation Toxicity Studies. 6/25/2014. U.S. EPA Office of Chemical Safety and Pollution Prevention. D417105.

neurotoxicity. This shared MOA/AOP is the basis for the OP common mechanism grouping per OPP's *Guidance For Identifying Pesticide Chemicals and Other Substances that have a Common Mechanism of Toxicity* (USEPA, 1999). The 2002 and 2006 CRAs used brain AChE inhibition in female rats as the source of dose response data for the relative potency factors and PODs for each OP, including chlorpyrifos. Prior to the completion of Registration Review, OPP will update the OP CRA on AChE inhibition to incorporate new toxicity and exposure information available since 2006.

OPP has conducted the chlorpyrifos human health risk assessment both with retention of the 10X FQPA SF and without retention of the 10X FQPA SF (*i.e.*, FQPA SF reduced to 1X) due to uncertainties associated with neurodevelopmental effects in children and exposure to OPs. There is a lack of an established MOA/AOP for the neurodevelopment outcomes which precludes the Agency from formally establishing a common mechanism group per the *Guidance For Identifying Pesticide Chemicals and Other Substances that have a Common Mechanism of Toxicity* (USEPA, 1999) based on that outcome. Moreover, the lack of a recognized MOA/AOP and other uncertainties with exposure assessment in the epidemiology studies prevent the Agency from establishing a causal relationship between OP exposure and neurodevelopmental outcomes. As part of an international effort, the ORD has been developing a battery of NAMs for evaluating developmental neurotoxicity. Information from these NAMs may be used in the future as part of the weight of evidence evaluation of neurodevelopmental toxicity potential for OPs. These NAMs will be presented, using the OPs as a case study, to the Federal Insecticide, Fungicide, and Rodenticide (FIFRA) Scientific Advisory Panel (SAP) in September 2020. The Agency will also continue to evaluate the epidemiology studies associated with neurodevelopmental outcomes and OP exposure prior to the release of the revised DRA. During this period, the Agency will determine whether or not it is appropriate to apply the guidance document entitled, *Pesticide Cumulative Risk Assessment: Framework for Screening Analysis* for the neurodevelopment outcomes.

11.0 Occupational Exposure/Risk Characterization

11.1 Occupational Handler Exposure and Risk Estimates

The term handlers is used to describe those individuals who are involved in the pesticide application process. There are distinct job functions or tasks related to applications and exposures can vary depending on the specifics of each task. Job requirements (amount of a chemical used in each application), the kinds of equipment used, the target being treated, and the level of protection used by a handler can cause exposure levels to differ in a manner specific to each application event. Based on the anticipated use patterns and current labeling, types of equipment and techniques that can potentially be used, occupational handler exposure is expected from chlorpyrifos use. For purpose of occupational handler assessment, the parent chlorpyrifos is the relevant compound.

Current labels generally require that handlers use normal work clothing (i.e., long sleeved shirt and pants, shoes and socks) and coveralls, chemical resistant gloves, and dust/mist respirators. Also, some products are marketed in engineering controls such as water-soluble packets. In order to determine what level of personal protection is required to alleviate risk concerns and to ascertain if label modifications are needed, steady state exposure and risk estimates were updated

for occupational handlers of chlorpyrifos for a variety of scenarios at differing levels of personal protection including engineering controls.

The previously assessed occupational handler assessments have been updated to incorporate the approach applied for PBPK-derivation of PODs for adults based on 10% RBC AChE inhibition. The results have been summarized assuming both that the database uncertainty factor has been retained at 10X and has been reduced to 1X. If the database uncertainty factor is retained, the total LOC for occupational exposure assessment is 100X for adults (represented by females 13-49). If the database uncertainty SF is reduced to 1X, the total LOC for occupational exposure assessment is 10X for adults (represented by females 13-49). The occupational handler scenarios, exposure assumptions and inputs have not changed since the previous assessment[22].

Combining Exposures/Risk Estimates:

Dermal and inhalation risk estimates were combined in this assessment, since the toxicological endpoint, RBC AChE inhibition, is the same for these exposure routes.

Summary of Occupational Handler Non-Cancer Exposures and Risk Estimates

Detailed result tables are provided in Appendix 10.

In this assessment for the non-seed treatment scenarios, a total of 288 occupational handler exposure scenarios were assessed. Using the updated PBPK-derived steady state PODs based on 10% RBC AChE inhibition and assuming the database uncertainty 10X SF has been retained (LOC = 100), 119 scenarios are of concern with label-specified personal protective equipment (PPE; baseline attire, chemical resistant gloves, coveralls, and a PF10 respirator) (MOEs < 100). Risks of concern for 45 additional exposure scenarios could potentially be mitigated if engineering controls are used. If the database uncertainty 10X SF is reduced to 1X (LOC = 10), 19 scenarios are of concern with label-specified PPE (baseline attire, chemical resistant gloves, coveralls, and a PF10 respirator) (MOEs < 10). Risks of concern for 15 additional scenarios could potentially be mitigated if engineering controls are used.

For the seed treatment scenarios, a total of 93 scenarios were assessed (40 short-term primary handler scenarios + 40 intermediate-term primary handler scenarios + 13 short- and intermediate-term planting scenarios). Assuming the 10X database uncertainty factor has been retained (LOC = 100), 12 short-term exposure and 10 intermediate-term scenarios are of concern with label-specified PPE (baseline attire, chemical resistant gloves, coveralls, and a PF10 respirator) (MOEs < 100) for primary handlers; there are no short- or intermediate scenarios of concern for seed planters. Assuming the 10X database uncertainty factor has been reduced to 1X (LOC = 10), there are no short- or intermediate-term risk estimates of concern with label-specified PPE (baseline attire, chemical resistant gloves, coveralls, and a PF10 respirator) (MOEs > 10) for primary handlers or seed planters.

[22] Some occupational handler exposure inputs have changed since the previous ORE assessments were completed in 2011 (W. Britton, D388165, 06/27/2011), 2014 (W. Britton, D424484, 12/29/2014), and 2016 (W. Britton, D436317, 11/03/2016) (e.g., amount of seed treated per day, seed planted per day). The changes to the inputs are not expected to result in significant changes to the risk estimates and have not been updated at this time.

11.2 Occupational Post-Application Exposure and Risk Estimates

11.2.1 Dermal Post-Application Exposure and Risk Estimates

Detailed result tables are provided in Appendix 11.

A series of assumptions and exposure factors served as the basis for completing the occupational post-application risk assessments; these assumptions and exposure factors remain unchanged from the previous assessment (W. Britton, D424484, 12/29/2014).

The 2011 and 2014 occupational and residential exposure assessments incorporated 7 Chemical-specific DFR studies. These studies used 5 different formulations and were conducted on 12 different crops. Specifically, the DFR studies examined the use of 1) emulsifiable concentrate formulations on sugarbeets, pecans, citrus, sweet corn, cotton, and turf; 2) wettable powder formulations on almonds, apples, pecans, cauliflower, tomato and turf; 3) granular formulations on sweet corn and turf; 4) a total release aerosol formulation on ornamentals; and 5) a microencapsulated liquid formulation on ornamentals. The submitted studies were reviewed by HED. Despite limitations, HED recommended the use of all or some of the data in the studies to assess post-application risks to chlorpyrifos except for the tomato DFR data. Summaries for all DFR studies can be referenced in Appendix I of D424484 (W. Britton, 12/29/2014).

The current assessment uses the same DFR data and crop pairings as the previous occupational and residential exposure assessments. For example, DFR data for an individual crop was applied to that specific crop, as well as to crops in the same crop grouping (e.g., cauliflower data was used for cauliflower and all other cole crops). For other crops in which no crop-specific or crop group-specific data are available, the DFR data for the crop deemed the closest match were used as surrogates to calculate potential exposure (e.g., cauliflower data were also used for strawberries, cranberries, and leafy vegetables). Additionally, whenever possible, a label use was assessed using DFR data for the same formulation type. A full description of the criteria for selection of DFR data for assessment of post-application exposures to individual crops/crop groupings can be referenced in Section 2.4.3 of D388165 (W. Britton, 06/27/2011).

Summary of Occupational Post-Application Dermal Exposure and Risk Estimates

Current labels require a Restricted Entry Interval (REI) of 24 hours from most crops and activities, but in some cases such as tree fruit, REIs are up to 5 days after application. Using the updated PBPK-derived steady state PODs based on 10% RBC AChE inhibition and assuming the UF_{DB} of 10X has been retained, the majority of the post-applications scenarios are not of concern 1 day after application (REI = 24 hours). However, for some activities such as irrigation, hand harvesting, scouting, and thinning result in risks of concern up to as many as 10 days following application for the non-microencapsulated formulations and > 35 days for the microencapsulated formulation.

Using the updated PBPK-derived steady state PODs based on 10% RBC AChE inhibition and assuming the UF_{DB} has been reduced to 1X, the majority of the post-application risk estimates are not of concern 1 day after application (REI = 24 hours).

Table 11.2.1. Chlorpyrifos Occupational Post-application Exposure and Risk Summary.						
Crop Group	**Crop**	**App. Rate (lbs ai/A)**	**DFR Data Source**	**DFR Study Location**	**Estimated REI Range (days) (Dermal LOC = 10)**	**Estimated REI Range (days) (Dermal LOC = 100)**
Berry: Low	Strawberry	1.0	MRID 42974501 (cauliflower WP)	AZ	0	0 - 4
	Cranberry	1.5			0	0 - 5
Field and Row Crops: Low to Medium	Clover (Grown for Seed)	1.9	MRID 44748102 (sugar beet EC)	MN	1	1
				OR	0	1
	Perennial Grass Seed Crops	1.0	MRID 44748102 (sugar beet EC)	MN	0	1
				OR	0	1
	Alfalfa	1.0	MRID 44748102 (cotton EC)	TX	0 – 1	1
	Cotton[1]	1.0	MRID 44748102 (cotton EC)	CA	0	0
				MS	0	0 – 1
				TX	0	0 – 1
	Peppermint/ Spearmint	2.0	MRID 44748102 (sugar beet EC)	MN	0 - 1	1
				OR	0	0 – 1
	Wheat	1.0	MRID 44748102 (sugar beet EC)	CA	0	0 - 1
				MN	0	0 - 1
	Soybean	1.0	MRID 44748102 (cotton EC)	MS	0	0 – 1
	Sugar Beet	1.0	MRID 44748102 (sugar beet EC)	CA	0	0 – 1
				MN	0	0 – 1
				OR	0	0 – 1
Field and Row Crops: Tall	Corn: Sweet; Corn: Field, Including Grown for Seed	1.5	MRID 44748102 (sweet corn EC)	IL	0 – 1	0 – 3
				MN	0 – 1	0 – 3
				OR	0 – 1	0 – 2
	Corn: Sweet; Corn: Field, Including Grown for Seed	1.0	MRID 44748102 (sweet corn EC)	IL	0 – 1	0 – 2
				MN	0 – 1	0 – 2
				OR	0 – 1	0 – 2
	Sorghum	1.0	MRID 44748102 (sweet corn EC)	IL	0	0 – 1
				MN	0	0 – 1
	Sunflowers	1.5	MRID 44748102 (sweet corn EC)	IL	0	1
				MN	0	1
Tree Fruit: Deciduous	Apples, Cherries, Peaches, Pears, Plums, Prunes, Nectarines	2.0	MRID 44748101 (apple WP)	CA	0	1
				WA	0	1 – 2
				NY	0	1 – 2

Table 11.2.1. Chlorpyrifos Occupational Post-application Exposure and Risk Summary.						
Crop Group	**Crop**	**App. Rate (lbs ai/A)**	**DFR Data Source**	**DFR Study Location**	**Estimated REI Range (days) (Dermal LOC = 10)**	**Estimated REI Range (days) (Dermal LOC = 100)**
	(Dormant and Delayed Dormant)					
	Nectarine & Peaches (Dormant and Delayed Dormant)	3.0	MRID 44748101 (apple WP)	CA	0	1
				NY	0	2 - 3
	Cherries (Sour)	4.0	MRID 44748101 (apple WP)	CA	0 – 1	1 – 5
				WA	0 – 2	2 – 6
				NY	0 – 3	2 – 6
Tree Fruit: Evergreen	Conifer Trees and Christmas Tree Plantations	1.0	MRID 43062701 (citrus EC)	CA (scouting, harvesting seed cone, irrigation)	0	0 – 1
			MRID 44839601 (turf EC)	MS (harvesting/ seedling production)	0	0
	Citrus	6.0 (CA and AZ)	MRID 43062701 (citrus EC)	CA	0	0 – 2
		4.0	MRID 43062701 (citrus EC)	CA	0	0
Forestry	Hybrid Cottonwood/ Poplar Plantations (Dormant and Delayed Dormant)	2.0	MRID 44748101 (apple WP)	WA	0 – 1	2 – 4
				NY	0 – 1	2 – 4
	Deciduous Trees (Plantations and Seed Orchards)	1.0	MRID 44748101 (apple WP)	CA	0	0 – 1
				WA	0	0 – 1
				NY	0	0 – 1
Tree Nuts[2]	Almonds	2.0	MRID 44748101 (almond WP)	CA (arid)	0	1
	Almonds (Dormant and Delayed Dormant)	4.0	MRID 44748101 (almond WP)	CA (arid)	0	1 – 3
	Filberts, Pecans, Walnuts	2.0	MRID 44748101 (pecan EC)	GA	0	0
				LA	0	0
				TX	0	0

Table 11.2.1. Chlorpyrifos Occupational Post-application Exposure and Risk Summary.						
Crop Group	**Crop**	**App. Rate (lbs ai/A)**	**DFR Data Source**	**DFR Study Location**	**Estimated REI Range (days) (Dermal LOC = 10)**	**Estimated REI Range (days) (Dermal LOC = 100)**
	Filberts & Walnuts (Dormant and Delayed Dormant)[3]	2.0	MRID 44748101 (pecan EC)	GA	0	0
Ornamentals/ Nurseries (Outdoor Only)	Deciduous Trees in Nurseries and Orchards Except Apples (Dormant and Delayed Dormant) Non-bearing Apple Trees	1.0	MRID 44748101 (apple WP)	CA	0	0
				WA	0	1
				NY	0	0
Ornamentals/ Nurseries (Outdoor Only)	Non-bearing Fruit and Nut Trees (Almonds, Citrus, Filbert, Cherry, Pear, Plum/Prune)	4.0	MRID 43062701 (citrus EC)	CA	0	0
	Non-bearing Fruit Trees (Peach, Nectarine)	3.0	MRID 44748101 (apple WP)	CA	0	1
				NY	0	2
	Non-bearing Fruit Trees (Apple)	2.0	MRID 44748101 (apple WP)	CA	0	1
				NY	0	1
	Conifers in Nurseries	1.0	MRID 43062701 (citrus EC)	CA	0	0
Field and Row Crops: Low to Medium (Outdoor Only)	Ornamentals	2.0	MRID 44748102 (sugar beet EC)	CA	0 – 1	1 – 5
				MN	0 – 1	1 – 3
				OR	0 – 1	1 – 2
Vegetable: Root and Tuber	Carrot	0.94	MRID 44748102 (sugar beet EC)	CA	0	0 – 1
				MN	0 – 1	0 – 1
	Radish	1.0	MRID 44748102 (sugar beet EC)	MN	0 – 1	0 – 1
Vegetable: Fruiting	Pepper	1.0	MRID 44748102 (cotton EC)	CA	0	0 – 2
				MS	0 – 1	1
				TX	0 – 1	1
Vegetable: Head and Stem Brassica	Broccoli, Brussel Sprouts, Cabbage, and Cauliflower	1.0	MRID 42974501 (cauliflower WP)	AZ	0	0 – 10
Vegetable: Leafy	Bok Choy, Collards, Kale, Kohlrabi	1.0	MRID 42974501 (cauliflower WP)	AZ	0	0 – 6
	Asparagus	1.0	MRID 44748102 (sugar beet EC)	CA	0	0 – 1

Table 11.2.1. Chlorpyrifos Occupational Post-application Exposure and Risk Summary.						
Crop Group	**Crop**	**App. Rate (lbs ai/A)**	**DFR Data Source**	**DFR Study Location**	**Estimated REI Range (days) (Dermal LOC = 10)**	**Estimated REI Range (days) (Dermal LOC = 100)**
Stalk and Stem: Vegetable				MN	0 – 1	1
				OR	0	0 – 1
	Non-bearing Pineapple	2.0	MRID 44748102 (cotton EC)	MS	0	1
Vine/ Trellis	Grapes (Dormant and Delayed Dormant) Grapes (Post-harvest and Prior to Budbreak)	2.0	MRID 43062701 (citrus EC)	CA	0	1
Turf	Turf for Sod and Seed	3.76	MRID 44829601 (turf EC and WP)	CA	0	1
				IN	0	1
				MS	0	1
	Turf for Golf Course	1.0	MRID 44829601 (turf EC and WP)	CA	0	0
				IN	0	0
				MS	0	0
Granular Applications						
Field and Row Crops: Low to Medium	Soybeans	1.0	MRID 44748102 (sweet corn G)	IL	0	0
	Sugar Beet	2.0	MRID 44748102 (sweet corn G)	IL	0	0
				OR	0	0 – 1
	Peanuts	4.0	MRID 44748102 (sweet corn G)	IL	0	0 – 1
Field and Row Crops: Tall	Corn, Sweet; Corn, Field; Corn, Grown for Seed	2.0	MRID 44748102 (sweet corn G)	IL	0	0 – 1
				OR	0 – 1	0 – 1
Nursery	Woody Ornamentals (In Container and Field Grown) – Preharvest	6.0 (Note: all other ornamental application rates are either 1.1 or 1.0 lb ai/A)	MRID 44748102 (sweet corn G)	IL	0	0
				OR	0	0
Turf	Turf for Sod or Seed	1.0	MRID 44829601 (turf G and fertilizer)	CA	0	0
	Golf Course				0	0
Microencapsulated Formulation Application						

Table 11.2.1. Chlorpyrifos Occupational Post-application Exposure and Risk Summary.						
Crop Group	**Crop**	**App. Rate (lbs ai/A)**	**DFR Data Source**	**DFR Study Location**	**Estimated REI Range (days) (Dermal LOC = 10)**	**Estimated REI Range (days) (Dermal LOC = 100)**
Nursery (Microencap. Formulations)	Ornamentals – Nurseries and Greenhouses	1.4	MRID 46722702 (smooth ornamentals ME)	Greenhouse	0 - 3	1 to > 35
Greenhouse						
Greenhouse (Total Release Fogger and. Liquid Concentrate Formulations)	Ornamentals – *Liquid Concentrates*	2	MRID 46722701 (hairy ornamentals ME)	Greenhouse	0 – 1	1 – 5
	Commercial Ornamentals, Greenhouse Production: Bedding Plants, Cut Flowers, Flowering Hanging Baskets, Potted Flowers, Ornamentals, Trees and Shrubs – *Total Release Foggers*	0.29	MRID 46722701 (hairy ornamentals ME)	Greenhouse	0	0 – 2

1. Mechanical harvesting (tramper) activities are not anticipated to result in significant chlorpyrifos exposures due to the 14-day pre-harvest interval (PHI).
2. Exposure during nut sweeping and windrowing results from contact with soil, for which transfer coefficients are currently unavailable. Assessment options include requesting exposure data or a qualitative comparison with a post- application exposure scenario assumed to result in higher exposure. Note that dislodgeable soil residue would be needed for an exposure assessment, as this would be the media contacted by worker's performing this activity. A study monitoring such exposure is available (Exposure of Workers During Reentry into Pecan Groves Treated with Super-Tim 80WP, Griffin Corporation, 1994; EPA MRID 43557401), however has yet to be evaluated for derivation of transfer coefficients.
2. Transfer coefficients for dormant pruning are unavailable. Assessment options include requesting exposure data or a qualitative comparison with a post-application exposure scenario assumed to result in higher exposure. Note that dislodgeable branch or bark residue would be needed for an exposure assessment, as this would be the surface contacted by workers performing this activity.

11.2.2 Dermal Post-Application Exposure and Risk Estimates: Chlorpyrifos Oxon

Chlorpyrifos is activated by desulfuration, reacting in bioactivation to the more toxic and potent AChE inhibitor, chlorpyrifos oxon. The oxon is highly unstable due to rapid deactivation through hydrolytic cleavage by a process called dearylation which releases TCP. Workers reentering an indoor environment (i.e., greenhouses) previously treated with chlorpyrifos could potentially be exposed to the oxon as chlorpyrifos degrades. Available exposure data indicate chlorpyrifos oxon may form in indoor environments.[23] Toxicity adjustment factors (TAFs) were used to estimate the potency of chlorpyrifos oxon relative to chlorpyrifos. HED determined the oxon to be between 11.9 (acute) and 18 (chronic) times more toxic than the parent.

Dermal exposure to the oxon on foliar surfaces from reentry into an outdoor environment (e.g., field crops and orchards) previously treated with chlorpyrifos is not anticipated and, therefore, has not been assessed. No occupational exposure studies (handler, post-application, or DFR) were identified that quantified the levels of oxon present in the environment. However, a search of open literature for the 2011 assessment resulted in 4 plant metabolism studies which measured surface residues. Three plant metabolism studies[24] measured leaf surface residues of the oxon in outdoor environments that were either well below the parent, not detectable, or detected at a level just above the level of detection (LOD). The potential for exposure to the oxon is further minimized due to rapid deactivation of the oxon to TCP. Further, the dietary exposure risk assessment[25] conducted in support of registration review concludes the following, "all residues in food are assumed to be parent chlorpyrifos since the chlorpyrifos oxon is not typically found in foods in monitoring data or crop field trials."

The 4th plant metabolism study, a tomato and green bean metabolism study conducted in a greenhouse, was less definitive than the other three plant metabolism studies regarding oxon presence; therefore, there is concern that the formation of the oxon may be greater and its deactivation to TCP slower in greenhouses when compared to the outdoor environment. The study results indicate that oxon residue is from 9 to 14X less than the parent from fruit analyzed on the day of application in flat and asymmetric roof greenhouses. The proportion of oxon to parent is less for all days which measurable levels were observed (all but 8 and 15 days after application). The oxon was detected until day 5 with levels between 5 and 6X below that of the parent. It should be noted that residues of chlorpyrifos and oxon were measured from analysis of whole fruit samples. HED typically assesses occupational post-application exposure and risk based upon the potential for transfer from surface residues. The whole fruit samples, which include surface residues, as well as residues which may have been contained within the fruit

[23] J.L. Martinez Vidal, et al. 1998. Diminution of Chlorpyrifos and Chlorpyrifos Oxon in Tomatoes and Green Beans Grown in Greenhouses. J. of Agric. and Food Chem. 46 (4), 1440–1444.

[24] Iwata, Y. et al. 1983. Chlorpyrifos Applied to California Citrus: Residue Levels on Foliage and On and In Fruit. J. Agric. Food Chem. 31(3), 603-610.

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R. Putnam, et al. 2003. The Persistence and Degradation of Chlorthalonil and Chlorpyrifos in a Cranberry Bog. J. Agric. Food Chem. 51(1), 170-176.

[25] D. Drew. Chlorpyrifos: Acute and Steady State Dietary (Food Only) Exposure Analysis to Support Registration Review. 11/18/2014. U.S. EPA Office of Chemical Safety and Pollution Prevention. D424486.

sample, may overestimate the amount of oxon on the fruit surface. Regardless, the 2011 occupational and residential exposure assessment recommended additional data to measure the chlorpyrifos and oxon residues on leaf surfaces following treatment with a liquid formulation in greenhouses in order to address these uncertainties and more accurately address the risk potential for exposure from occupational reentry into greenhouses treated with chlorpyrifos. To date, no data have been submitted to address these uncertainties. As a result, HED has assessed occupational dermal post-application exposures in greenhouses using conservative assumptions of oxon formation.

In order to account for the formation of and potential increased toxicity from exposure to chlorpyrifos oxon, a total toxic residue approach was applied which combines chlorpyrifos and chlorpyrifos oxon (expressed as toxicity equivalents). The total toxic residue approach[26] estimates the chlorpyrifos oxon equivalent residues by 1) assuming a specific fraction of the measured chlorpyrifos dislodgeable foliar residues are available as the oxon and 2) factoring in the relative potency of chlorpyrifos oxon with use of a TAF. It was conservatively assumed that 5% (0.05) of the total chlorpyrifos present as DFR in greenhouses is available for worker contact during post-application activities. This assumption is based on a review of available TTR and DFR data for other OPs where both the parent and metabolite were measured in residue samples. Five percent was found to be the high-end value for the percent of parent that metabolized during the course of the residue studies. The chronic TAF (which is appropriate for steady state assessment) of 18 was derived from BMD analysis of inhibition of RBC AChE in adult female rats (adult male rats not examined) observed in the repeated phase of the CCA study. Once predicted, these total toxic (dislodgeable foliar) residues are used to estimate exposures from post-application activities in greenhouse and risks are estimated with used of the steady state POD for occupational exposures, 3.63 mg/kg/day.

Summary of Occupational Post-Application Dermal Exposure and Risk Estimates with Use of Total Toxic Residue Approach

Due to uncertainty regarding the formation of chlorpyrifos oxon in greenhouses, HED also estimated risks for reentry into treated greenhouses (all 4 formulations) for the parent chlorpyrifos plus chlorpyrifos oxon using a total toxic residue approach. When the total toxic residue approach is used and with the updated PBPK-derived steady state PODs based on 10% RBC AChE inhibition and assuming a 10X UF_{DB} has been retained, MOEs are not of concern 0 to 6 days after treatment for non-microencapsulated formulations. For the microencapsulated formulation, MOEs are not of concern 3 to > 35 days after treatment (the completion of the monitoring period), depending on the exposure activity considered.

When the total toxic residue approach is used and with the updated PBPK-derived steady state PODs based on 10% RBC AChE inhibition and assuming the 10X UF_{DB} has been reduced to 1X, there are no risk estimates of concern with the current labeled REI (24 hours), except for the microencapsulated formulation. For the microencapsulated formulation, MOEs are of concern 0 to > 35 days after treatment (the completion of the monitoring period), depending on the exposure activity considered.

[26] Total DFR ($\mu g/cm^2$) = [Chlorpyrifos DFR ($\mu g/cm^2$) * TAF] + [Chlorpyrifos DFR ($\mu g/cm^2$)]

Table 11.2.2.1. All Formulations - Summary of Post-Application Risk Assessment for Total Toxic Residue (Chlorpyrifos + Chlorpyrifos Oxon) Using Chlorpyrifos -Specific DFR Data.						
Crop Group	**Crop**	**App Rates (lbs. ai/ acre)**	**DFR Data Source**	**DFR Study Location**	**Estimated REI Range (days) (Dermal LOC = 10)**	**Estimated REI Range (days) (Dermal LOC = 100)**
Nursery	Ornamentals – Nurseries and Greenhouses	0.0070 lb ai/gal 1.4 lb ai/A	MRID 46722702 (smooth ornamentals ME)	Greenhouse	0 to >35	3 to > 35
Field and Row Crops – Low to Medium	Ornamentals – Nurseries and Greenhouses	2.0	MRID 44748102 (sugar beet EC)	CA	0 – 1	1 – 6
				OR	0 – 1	1 – 2
				MN	0 – 1	1 – 5
Nursery	Ornamentals - Greenhouse	0.29	DFR: MRID 46722701 (hairy ornamentals -aerosol)	Greenhouse	0 – 1	0 – 5

Restricted Entry Interval

Chlorpyrifos is classified as Toxicity Category II via the dermal route and Toxicity Category IV for skin irritation potential. It is not a skin sensitizer. There were some risk estimates of concern related to contacting chlorpyrifos treated foliage both outdoors and in greenhouses; therefore, HED is recommending that the REI be revised on the label to address those concerns.

Table 11.2.2.2. Acute Toxicity Profile: Chlorpyrifos.				
Guideline No.	**Study Type**	**MRID(s)**	**Results**	**Toxicity Category**
870.1100	Acute Oral (rat)	44209101	LD_{50} = 223 mg/kg (M & F)	II
870.1200	Acute Dermal (rabbit)	44209102	$LD_{50} \geq$ 5000 mg/kg (M & F)	IV
870.1300	Acute Inhalation (rat)	00146507	LC_{50} > 0.2 mg/L (M & F)	II[1,2]
870.2400	Primary Eye Irritation (rabbit)	44209103	Minimum to mild irritant	IV
870.2500	Primary Skin Irritation (rabbit)	44209104	Mild irritant	IV
870.2600	Dermal Sensitization (guinea pig)	44209105	Non-Sensitizing (Buehler Method)	N/A

[1] Study classified as Supplementary (TXR 0004633, S. Saunders, 08/26/1985)
[2] Study requirement waived and Toxicity Category II assigned (TXR 5001957, M. Hashim, 12/20/1997)

11.2.3 Inhalation Post-Application Exposure and Risk Estimates

There are multiple potential sources of post-application inhalation exposure to individuals performing post-application activities in previously treated fields. These potential sources include volatilization of pesticides and resuspension of dusts and/or particulates that contain pesticides. The Agency sought expert advice and input on issues related to volatilization of

pesticides from its Federal Insecticide, Fungicide, and Rodenticide Act Scientific Advisory Panel (SAP) in December 2009, and received the SAP's final report on March 2, 2010 (http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OPP-2009-0687-0037). The Agency has evaluated the SAP report and has developed a Volatilization Screening Tool and a subsequent Volatilization Screening Analysis (https://www.regulations.gov/#!docketDetail;D=EPA-HQ-OPP-2014-0219). During Registration Review, the Agency will utilize this analysis to determine if data (i.e., flux studies, route-specific inhalation toxicological studies) or further analysis is required for chlorpyrifos.

In addition, the Agency is continuing to evaluate the available post-application inhalation exposure data generated by the Agricultural Reentry Task Force. Given these two efforts, the Agency will continue to identify the need for and, subsequently, the way to incorporate occupational post-application inhalation exposure into the Agency's risk assessments.

The Worker Protection Standard for Agricultural Pesticides contains requirements for protecting workers from inhalation exposures during and after greenhouse applications through the use of ventilation requirements. [40 CFR 170.110, (3) (Restrictions associated with pesticide applications)].

A post-application inhalation exposure assessment is not required as exposure is expected to be negligible. Seed treatment assessments provide quantitative inhalation exposure assessments for seed treaters and secondary handlers (i.e., planters). It is expected that these exposure estimates would be protective of any potential low-level post-application inhalation exposure that could result from these types of applications. As described in Section 4, a quantitative occupational post-application inhalation risk assessment is not required for chlorpyrifos or chlorpyrifos oxon due to the lack of toxicity from the vapor phase of these chemicals, even at the saturation concentration.

12.0 References

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13.0 List of Appendices

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Appendix 1: Summary of OPP's ChE Policy and Use of BMD Modeling

OPP's ChE policy (USEPA, 2000[27]) describes the way ChE data are used in human health risk assessment. The following text provides a brief summary of that document to provide context to points of departure selected.

AChE inhibition can be inhibited in the central or peripheral nervous tissue. Measurements of AChE or cholinesterase (ChE) inhibition in peripheral tissues (e.g., liver, diaphragm, heart, lung etc) are rare. As such, experimental laboratory studies generally measure brain (central) and blood (plasma and red blood cell, RBC) ChE. Blood measures do not represent the target tissue, per se, but are instead used as surrogate measures for peripheral toxicity in studies with laboratory animals or for peripheral and/or central toxicity in humans. In addition, RBC measures represent AChE, whereas plasma measures are predominately BuChE. Thus, RBC AChE data may provide a better representation of the inhibition in target tissues. As part of the dose response assessment, evaluations of neurobehavior and clinical signs are performed to consider the dose response linkage between AChE inhibition and apical outcomes.

Refinements to OPP's use of ChE data have come in the implementation of BMD approaches in dose response assessment. Beginning with the OP CRA, OPP has increased its use of BMD modeling to derive PODs for AChE inhibiting compounds. Most often the decreasing exponential empirical model has been used.

OPP does not have a defined benchmark response (BMR) for OPs. However, the 10% level has been used in the majority of dose response analyses conducted to date. This 10% level represents a 10% reduction in AChE activity (i.e., inhibition) compared to background (i.e., controls). Specifically, the BMD_{10} is the estimated dose where ChE is inhibited by 10% compared to background. The $BMDL_{10}$ is the lower confidence bound on the BMD_{10}.

The use of the 10% BMR is derived from a combination of statistical and biological considerations. A power analysis was conducted by the Office of Research and Development (ORD) on over 100 brain AChE datasets across more than 25 OPs as part of the OP CRA (USEPA, 2002). This analysis demonstrated that 10% is a level that can be reliably measured in the majority of rat toxicity studies. In addition, the 10% level is generally at or near the limit of sensitivity for discerning a statistically significant decrease in ChE activity in the brain compartment and is a response level close to the background brain ChE level. With respect to biological considerations, a change in 10% brain AChE inhibition is protective for downstream cholinergic clinical signs and apical neurotoxic outcomes. With respect to RBC AChE inhibition, these data tend to be more variable than brain AChE data. OPP begins its BMD analyses using the 10% BMR for RBC AChE inhibition but BMRs up to 20% could be considered on a case by case basis as long as such PODs are protective for brain AChE inhibition, potential peripheral inhibition, and clinical signs of cholinergic toxicity.

[27] USEPA (2000) Office of Pesticide Programs, US Environmental Protection Agency, Washington DC 20460. August 18, 2000 Office of Pesticide Programs Science Policy of The Use of Data on Cholinesterase Inhibition for Risk Assessments of Organophosphorous and Carbamate Pesticides.

Appendix 2: Summary of Regulatory and Scientific Activities to Address Uncertainty Around Neurodevelopmental Effects

1. Regulatory Context & History:

Historically, data on the AChE inhibition has been the critical effect used to derive points of departure (PODs) for OPs, including chlorpyrifos. The Registration Eligibility Decision (RED) for chlorpyrifos was completed in 2006 and relied on AChE inhibition results from laboratory animals to derive PODs but retained the FQPA 10X Safety Factor due to concerns over age-related sensitivity and uncertainty associated with potential neurodevelopmental effects observed in laboratory animals. Since that time, numerous epidemiology, laboratory animal, and mechanistic studies have evaluated the hypothesis that chlorpyrifos exposure results in adverse effects on the developing brain. This body of studies has raised concerns that EPA's historical practice of using AChE inhibition as the critical effect for deriving PODs may not be protective of neurodevelopmental outcomes.

EPA-OPP initiated a science evaluation of the potential effects on neurodevelopment in 2007 following the receipt of a petition from Pesticide Action Network of North America (PANNA) and Natural Resources Defense Council (NRDC) seeking revocation of all tolerances and cancellation of all FIFRA registrations of products containing chlorpyrifos. EPA has three times presented approaches and proposals to the Federal Insecticide, Fungicide, Rodenticide Act (FIFRA) Scientific Advisory Panel (SAP)[28] for evaluating epidemiologic, laboratory animal, and mechanistic data exploring the possible connection between *in utero* and early childhood exposure to chlorpyrifos and adverse neurodevelopmental effects. The SAP's reports have rendered numerous recommendations for additional study and sometimes conflicting advice for how EPA should consider (or not consider) the epidemiology data in conducting EPA's registration review human health risk assessment for chlorpyrifos. For over a decade, EPA has evaluated the scientific evidence surrounding the different health effects associated with chlorpyrifos. Despite these efforts, unresolved scientific questions remain. EPA has continued to pursue some aspects of these uncertainties but has not found resolution.

2. Previous Risk Assessments, Peer Review & Public Process:

The public process surrounding science issues on chlorpyrifos and in the PANNA/NRDC petition has been extensive and began with the September 2008 FIFRA SAP. The 2008 SAP evaluated the Agency's preliminary review of available literature and research on epidemiology in mothers and children following exposures to chlorpyrifos and other OPs, laboratory studies on animal behavior and cognition, AChE inhibition, and mechanisms of action (USEPA, 2008). The 2008 FIFRA SAP recommended that AChE inhibition remain as the source of data for the PODs but noted that despite some uncertainties, the Columbia Center for Children's Environmental Health (CCCEH) epidemiologic studies were "indeed quite strong and provided extremely valuable information (p. 35, FIFRA SAP, 2008)" and "concluded that the Columbia

[28] FIFRA SAP is a federal advisory committee created by Congress through FIFRA and is the primary venue for external, independent scientific advice to the EPA on major health and safety issues related to pesticides:

study is epidemiologically sound and that there is minimal selection and information bias (p. 32, FIFRA SAP, 2008)."

In 2010, EPA developed the Draft "Framework for Incorporating Human Epidemiologic & Incident Data in Health Risk Assessment" which describes the use of the Bradford Hill Criteria as modified in the Mode of Action Framework to integrate epidemiology information with other lines of evidence. The draft epidemiology framework was reviewed favorably by the FIFRA SAP in 2010. As suggested by the FIFRA SAP, EPA did not immediately finalize the draft epidemiology framework but instead used the document in several pesticide evaluations prior to making revisions and finalizing. OPP's epidemiology framework was finalized in December 2016.[29] (USEPA, 2016).

In 2011, EPA released the preliminary human health risk assessment for chlorpyrifos.[30]. The preliminary assessment used red blood cell (RBC) AChE inhibition from laboratory rats as the critical effect for extrapolating risk. The preliminary assessment also used the standard 10X factors for inter- and intra-species extrapolation. The 10X FQPA SF was removed with a note to the public that a weight of evidence (WOE) as described in the Draft "Framework for Incorporating Human Epidemiologic & Incident Data in Health Risk Assessment" evaluation would be forthcoming.

In 2011, EPA convened a meeting of the FIFRA SAP to review the PBPK-PD model for chlorpyrifos. The panel made numerous recommendations for the improvement of the model for use in regulatory risk assessment, including the inclusion of dermal and inhalation routes. From 2011-2014, Dow AgroSciences, in consultation with EPA, refined the PBPK-PD model for use in the revised human health risk assessment.

In 2012, the Agency convened another meeting of the FIFRA SAP to review the latest experimental data related to AChE inhibition, cholinergic and non-cholinergic adverse outcomes, including neurodevelopmental studies on behavior and cognition effects. The Agency also performed an in-depth analysis of the available chlorpyrifos biomonitoring data and of the available epidemiologic studies from three major children's health cohort studies in the U.S., including those from the CCCEH, Mt. Sinai and CHAMACOS. The Agency explored plausible hypotheses on mode of actions/adverse outcome pathways (MOAs/AOPs) leading to neurodevelopmental outcomes seen in the biomonitoring and epidemiology studies. The 2012 Panel described the Agency's epidemiology review as "very clearly written, accurate" and "very thorough review". The 2012 Panel went further to note that "The Panel believes that the [Agency's] epidemiology review *appropriately concludes* that the studies show some consistent associations relating exposure measures to abnormal reflexes in the newborn, pervasive development disorder at 24 or 36 months, mental development at 7-9 years, and attention and behavior problems at 3 and 5 years of age….." [*italics added*]. Although the 2012 Panel noted that the RBC AChE inhibition remained the most robust dose-response data, the 2012 Panel expressed significant concerns about the degree to which 10% AChE inhibition is protective for neurodevelopmental effects pointing to evidence from epidemiology, *in vivo* animal studies, and

[29] https://www3.epa.gov/pesticides/EPA-HQ-OPP-2008-0316-DRAFT-0075.pdf
[30] https://www.regulations.gov/document?D=EPA-HQ-OPP-2008-0850-0025

in vitro mechanistic studies, and urged the EPA to find ways to use the CCCEH cord blood data (pp. 50-52, FIFRA SAP, 2012).

In 2014, EPA released the revised human health risk assessment. The revised assessment used the chlorpyrifos PBPK-PD model for deriving human PODs for RBC AChE inhibition, thus obviating the need for the inter-species extrapolation factor and providing highly refined PODs which accounted for gender, age, duration and route specific exposure considerations. The PBPK-PD model was also used to develop data derived intra-species factors for some lifestages. The 10X FQPA SF was retained based on the outcome of the 2012 FIFRA SAP and development of a WOE analysis on potential for neurodevelopmental outcomes according to OPP's *Framework for Incorporating Human Epidemiologic & Incident Data in Risk Assessments for Pesticides*.

Based on the aggregate human health risks identified in 2014, a proposed rule (PR) for revoking all tolerances of chlorpyrifos was published in the Federal Register on November 6, 2015 (80 FR 69079). The 2014 human health risk assessment (HHRA), which used the 10% RBC AChE inhibition endpoint, was the basis for the proposed tolerance revocation for chlorpyrifos since a determination of 'reasonable certainty of no harm' could not be met due to risks identified from drinking water using a national-scale assessment.

In 2015, EPA conducted additional hazard analyses using data on chlorpyrifos levels in fetal cord blood reported by the CCCEH study investigators. The Agency convened another meeting of the FIFRA SAP in April 2016 to evaluate a proposal of using cord blood data from the CCCEH epidemiology studies as the source of data for PODs. The 2016 SAP did not support the "direct use" of the cord blood and working memory data for deriving the regulatory endpoint due in part to lack of raw data from the epidemiology study, insufficient information about timing and magnitude of chlorpyrifos applications in relation to cord blood concentrations at the time of birth, uncertainties about the prenatal window(s) of exposure linked to reported effects, and lack of a second laboratory to reproduce the analytical blood concentrations.

Despite their critiques regarding uncertainties in the CCCEH studies, the 2016 SAP expresses concern throughout the report that 10% RBC AChE inhibition is not sufficiently protective of human health. Specifically, the Panel stated that it "agrees that both epidemiology and toxicology studies suggest there is evidence for adverse health outcomes associated with chlorpyrifos exposures below levels that result in 10% red blood cell (RBC) acetylcholinesterase (AChE) inhibition (i.e., toxicity at lower doses) (p. 18, FIFRA SAP, 2016)." This statement is repeated multiple times throughout the 2016 SAP report (e.g., pp. 22, 25, 39-40, and 53, FIFRA SAP, 2016).

The 2016 SAP was supportive of the EPA's use of the PBPK model as a tool for assessing internal dosimetry from typical OPP exposure scenarios using peer reviewed exposure assessment approaches (e.g., food, water, residential, occupational). The 2016 SAP recommended the use of a time weighted average (TWA) blood concentration of chlorpyrifos for the CCCEH study cohort as the PoD for risk assessment (p. 36, 42, 45, FIFRA SAP, 2016) and EPA's 2016 chlorpyrifos HHRA followed this approach.

3. Regulatory and Scientific Activities Since 2016

In March 2017, EPA denied the NRDC/PANNA petition to revoke all tolerances and cancel all FIFRA registrations of products containing chlorpyrifos. In the 2017 denial, EPA noted that "further evaluation of the science is warranted to achieve greater certainty as to whether the potential exists for adverse neurodevelopmental effects to occur from current human exposures to chlorpyrifos." The denial went on to state that EPA "will not complete the human health portion of the registration review or any associated tolerance revocation of chlorpyrifos without first attempting to come to a clearer scientific resolution on those issues." Since that time, EPA has continued to pursue acquisition of the raw data from new laboratory animal studies and the epidemiology studies conducted by Columbia University; evaluated the new laboratory animal studies with results suggesting effects on the developing brain occur at doses lower than does that cause AChE inhibition; and evaluated whether or not additional statistical analysis, including bias analysis, would be useful in characterizing the epidemiology results.

3.1 Transparency in Regulatory Decision Making: Availability of Raw Data

For conventional pesticides, like chlorpyrifos, EPA receives numerous toxicology studies in laboratory animals conducted according to OCSPP[1] and OECD[2] guidelines to comply with pesticide registration data requirements listed in the 40CFR Part 158. Most of these studies are conducted in accordance with Good Laboratory Practice (GLP), as set forth in 40 CFR Part 160. In accordance with GLP regulations, registrants certifying compliance with Good Laboratory Practice are required to retain the raw data from these toxicology studies. Raw data must also be retained by pesticide producers pursuant to EPA's Books and Records regulations (40 CFR section 169.2(k)) and EPA must, upon request, be furnished with (or given access to) such records (see sections 160.15 and 169.3). These toxicology studies (including the raw data, if it is in EPA's possession) used by EPA in human health risk assessment can, in turn, be obtained through a Freedom of Information Act request as long as the person affirms under FIFRA section 10(g) that he or she will not provide the data to a multinational pesticide producer. As such, EPA and stakeholders interested in pesticide risk assessment have high expectations with regard to the transparency of data used to develop hazard assessment and characterization. Although for most conventional pesticides, EPA uses the guideline studies submitted by pesticide registrants, there are some cases where studies from the open scientific literature are used. In those situations, in line with EPA's commitment to transparency, EPA often makes an effort to obtain the raw data from the investigators. EPA will often, but not always, receive such requested information.

- With regard to the new laboratory animal studies (reviewed by Mendez, 2020, D457378), EPA contacted the primary investigators in July-August 2018. Dr. Russell Carr from Mississippi State University kindly provided the requested information. However, none of the others provided EPA with the raw data.

- With regard to the raw data from CCCEH, EPA has a history of requesting this information as detailed on EPA's website (https://www.epa.gov/ingredients-used-

[1] https://www.epa.gov/test-guidelines-pesticides-and-toxic-substances
[2] http://www.oecd.org/env/ehs/testing/oecdguidelinesforthetestingofchemicals.htm

pesticide-products/chlorpyrifos-epas-seven-year-quest-columbias-raw-data). Throughout 2018, EPA continued to pursue the raw data from CCCEH but to no avail. See Attachment 1.

3.2 Review of New Laboratory Animal Studies

Chlorpyrifos has numerous studies in laboratory animals evaluating effects on behavior and learning in young animals exposed during gestation and/or post-natal period. Beginning with the 2008 preliminary evaluation, EPA evaluated the open literature studies in 2008 in a preliminary evaluation, in 2012 in a comprehensive systematic review of the literature, and again in 2016 with additional studies. EPA has consistently concluded, with support from the FIFRA SAP, that these studies provide evidence of the potential effects on the developing brain from exposure to chlorpyrifos but that they lack robustness for using as PODs for extrapolating human health risk. Moreover, until recently, the dose levels used in these animal behavior studies typically were only high enough to elicit AChE inhibition. The newest studies have used lower doses, including some below doses required to elicit 10% AChE inhibition.

In 2018, the California Department of Pesticide Regulation (CDPR) proposed to adopt a regulation designating chlorpyrifos as a toxic air contaminant (TAC) in California[31]. As part of this determination, CDPR developed its "Final Toxic Air Contaminant Evaluation of Chlorpyrifos Risk Characterization of Spray Drift, Dietary, and Aggregate Exposures to Residential Bystanders[32]." The CDPR risk characterization document cites five new laboratory animal studies not previously reviewed by EPA (Gomez-Gimenez *et al.,* 2017, 2018; Silva *et al*., 2017; Lee *et al.,* 2015; Carr *et al.,* 2017). CDPR is using these studies as the main source of information for their new POD for acute oral exposure (Table 23 in CDPR, 2018). EPA-OPP in consultation with the Office of Research and Development, has reviewed these five studies (Mendez, 2020, D457378) in accordance with OPP's Guidance for Considering and Using Open Literature Toxicity Studies to Support Human Health Risk Assessment.[33]
In short, EPA concludes that the Gomez-Gimenez et al (2017, 2018) and Silva et al (2017) papers are of unacceptable quality due to a number of deficiencies described in Mendez, 2020, D457378. Lee et al (2015) is considered acceptable but only for use qualitatively as some key deficiencies surrounding the assignment of pups from litters were noted. EPA finds the Carr et al (2017) study to be of high quality and provides strong support for the conclusion that effects on the developing brain may occur below a dose eliciting 10% AChE inhibition. Using the raw data provided by Dr. Carr, EPA conducted an independent statistical analysis of these results[34]. EPA's statistical analysis confirms the conclusions of Carr et al (2017) that young rats exposed to chlorpyrifos, at doses lower than those eliciting brain AChE inhibition, spent significantly less time in the dark container prior to emerging as compared to the control group.

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[31] https://www.cdpr.ca.gov/docs/emon/pubs/tac/tacpdfs/chlorpyrifos/proposed_determination_chlorpyrifos.pdf

[32] https://www.cdpr.ca.gov/docs/emon/pubs/tac/tacpdfs/chlorpyrifos/final_eval_chlorpyrifos_tac.pdf

[33] https://www.epa.gov/sites/production/files/2015-07/documents/lit-studies.pdf

[34] https://www.regulations.gov/document?D=EPA-HQ-OPP-2008-0850-0939

EPA-OPP continues to view the laboratory animal studies as part of the weight of the evidence surrounding the effects on the developing brain. Despite the strength of the new Carr paper, EPA continues to conclude these studies are not robust enough for deriving a POD.

3.3 Potential for Additional Statistical Analysis of CCCEH Studies

One of the areas of additional evaluation by EPA was a consideration of whether additional statistical analyses would be useful in characterizing the epidemiology results.

As described by Lash et al (2014[35]), quantitative bias analysis (QBA) evaluates nonrandom errors that may affect the results and interpretation of epidemiological studies. The purpose is to estimate the potential magnitude and direction of biases and to quantify the uncertainty about these biases. EPA held a series of conference calls with Dr. Timothy Lash at Emory University about the CCCEH studies. Dr. Lash is a recognized expert in this area. These conference calls and associated activities are described in the docket[36]. Some stakeholders have identified the limited blood lead testing in the CCCEH cohort to be an area of uncertainty and potential unresolved confounder in the epidemiology results. Dr. Lash noted that given that lead abatement was conducted by New York City prior to the start of the CCCEH study that this was not a major concern for him. Dr. Lash initially identified potential selection bias in the interpretation of working memory IQ from Rauh et al (2011) as a possible area for QBA. Upon further evaluation of this issue, it was determined that a QBA would not be useful or possible since working memory was only evaluated in children at age 7 but not at other ages.

EPA has recently pursued some additional questions about the statistical analysis conducted in CCCEH papers[37]. In Rauh et al (2011), CCCEH investigators log-transformed the working memory composite score but not log-transforming the chlorpyrifos exposure in the data analysis. EPA asked the investigators why this was done. The researchers explained that the natural log-transformation was applied to the outcome variables to stabilize the variance and improve the linear model fit. EPA inquired about further sensitivity analysis and if any model-fit diagnostics were available. CCCEH investigators responded that they did perform various transformations of the data in an exploratory mode but did not publish or further detail these results or share the results of these exploratory analyses with EPA.

EPA also recently asked CCCEH investigators about the impact of including/excluding extremely high exposure data points. The CCCEH investigators noted that there are three subjects with non-missing data had chlorpyrifos levels above 25 pg/g. These three subjects were not included in the final model because one subject with 63 pg/mg was a highly influential observation (outlier) and drastically impacted inference and the data from the two other subjects were too sparse and the splines too unstable in this region. The CCCEH investigators did not share the results of these exploratory analyses with EPA.
Although EPA does not have a specific reason to believe that CCCEH have inappropriately handled the data or statistical analysis, without the availability of the raw data, EPA remains

[35] Lash TL, Fox MP, MacLehose RF, Maldonado G, McCandless LC, Greenland S. 2014. Good practices for quantitative bias analysis. Int J Epidemiol. 2014 Dec;43(6):1969-85. doi: 10.1093/ije/dyu149. Epub 2014 Jul 30.
[36] https://www.regulations.gov/document?D=EPA-HQ-OPP-2008-0850-0939
[37] https://www.regulations.gov/document?D=EPA-HQ-OPP-2008-0850-0939

unable to verify the reported findings of the CCCEH papers. Moreover, EPA and interested stakeholders are unable to conduct alternative statistical analyses to evaluate the robustness and appropriateness of the approaches used by the investigators.

4. FQPA 10X Safety Factor for the 2020 Human Health Risk Assessment

The Food Quality Protection Act (FQPA, 1996) requires EPA in making its "reasonable certainty of no harm" finding, that in "the case of threshold effects, *an additional tenfold margin of safety* for the pesticide chemical residue and other sources of exposure shall be applied for infants and children to take into account *potential pre- and postnatal toxicity and completeness of data with respect to exposure and toxicity to infants and children*." The statute goes on to state that "the Administrator may use a different margin of safety for the pesticide chemical residue only if, on the basis of reliable data, such margin will be safe for infants and children."

Over the last decade, EPA has used several different approaches for assessing the human health risk to chlorpyrifos. EPA began registration review with a 2011 preliminary assessment using a traditional risk assessment based on laboratory animal data with standard 10X inter- and inter-species extrapolation factors but without the FQPA 10X SF. The 2014 revised human health risk assessment applied the PBPK-PD model to derive PODs for 10% RBC AChE inhibition which obviated the need for the inter-species factor and applied the FQPA 10X SF based on uncertainty identified regarding the potential for chlorpyrifos to effect neurodevelopment. In 2016, EPA used the PBPK model to derive an internal human POD based on the TWA for blood concentrations to women potentially exposed to chlorpyrifos from residential uses voluntarily cancelled in 2000. Despite the distinct differences in approach, EPA's acute and chronic population adjusted doses (PADs) in the 2011 and 2014 risk assessments are quite similar. Specifically, in the 2011 preliminary assessment, the acute and chronic PADs were 0.0036 mg/kg/day and 0.0003 mg/kg/day respectively, whereas in the 2014 revised assessment, the acute and chronic PADs are 0.005 mg/kg/day and 0.0008 mg/kg/day for females ages 13-49, respectively. In the 2016 assessment and using a PBPK model to derive a TWA for blood concentrations to women potentially exposed to chlorpyrifos from residential uses voluntarily cancelled, a PAD of 0.00005 mg/kg/day was calculated which is approximately an order of magnitude lower than the 2011 and 2014 assessments.

In conclusion, despite several years of study, peer review, and public process, the science addressing neurodevelopmental effects remains unresolved. Therefore, the dietary, residential, aggregate, and non-occupational risk assessments have been conducted with retention of the 10X Food Quality Protection Act (FQPA) safety factor (SF) and without retention of the 10X FQPA SF (*i.e.*, FQPA SF reduced to 1X). Similarly, the occupational risk assessments have been conducted both with and without retention of a 10X UF_{DB}.

Appendix 2 Attachment 1: Summary of Regulatory and Scientific Activities to Address Uncertainty Around Neurodevelopmental Effects

Despite a stated public commitment to "share all data gathered," CCCEH has not provided EPA with the data used in the CCCEH epidemiology studies. In the summer of 2015, Dr. Dana Barr of Emory University (formerly of CDC) provided the EPA with limited raw urine and blood data in her possession from the three cohorts. However, the files provided from Dr. Barr are not useful for the EPA's current purpose of assessing risk to chlorpyrifos. The EPA does not have any of the other measurements of the children in the cohort (e.g., chlorpyrifos blood data, interviews, test or IQ scores). CCCEH researchers have asserted that the pesticide component of the cohort study was privately funded, not federally funded, and therefore disclosure of underlying data is not required. EPA has described its efforts to acquire the CCCEH data on its website (https://www.epa.gov/ingredients-used-pesticide-products/chlorpyrifos-epas-seven-year-quest-columbias-raw-data).

Some recent requests include[38].

- April 19, 2016: EPA letter to Linda P. Fried, Dean, Mailman School of Public Health
- May 18, 2016: Linda P. Fried, Dean, Mailman School of Public Health letter to EPA
- June 27, 2016: EPA letter to Linda P. Fried, Mailman School of Public Health
- January 17, 2017: USDA letter to EPA citing Scientific Integrity Policy
- January 2, 2018: EPA letter to Linda Fried, once again requesting dataset
- January 8, 2018: Email from Linda Fried saying EPA needs to "clarify the information requests"

Throughout 2018, EPA continued to request the raw data from Columbia University:

- February 1, 2018: Teleconference and email to Howard Andrews regarding continued interest in reviewing the raw data and questions regarding statistical analysis of the Columbia dataset[39]
- February 6, 2018: Email from Howard Andrews requesting additional details on EPA's questions regarding the statistical analysis of the Columbia dataset
- March 26, 2018: Email to Howard Andrews with additional questions regarding statistical analysis of the Columbia dataset
- May 31, 2018: Teleconference with Howard Andrews regarding statistical analysis of Columbia dataset and reiterated request for the raw dataset
- June 27, 2018: Teleconference with Howard Andrews regarding raw dataset and CCCEH concern about the identification of study participants[40]

Following the June 2018 conference call with CCCEH, EPA contacted the CDC in July 2018 to discuss HIPAA and data de-identification issues as it relates to the CCCEH. The CDC

[38] Links to each letter can be found on https://www.epa.gov/ingredients-used-pesticide-products/chlorpyrifos-epas-seven-year-quest-columbias-raw-data.
[39] https://www.regulations.gov/document?D=EPA-HQ-OPP-2008-0850-0939
[40] https://www.regulations.gov/document?D=EPA-HQ-OPP-2008-0850-0937

representative noted that even after taking out personally identifiable information (PII) from the dataset, the data that remain can still pose identification issues because of the possibility of linking it with information currently in the public domain. The CDC representative further noted there are some datasets that cannot be deidentified given the nature of the data and specified that geographic location is one of the variables that makes something highly identifiable. In the case of CCCEH, the study participants live within a small geographical range with New York City. The CDC representative noted that for those cases, there is the possibility of allowing the data to be viewed in a secure data center[41].

Since June 2018, EPA has not made further attempts at obtaining or viewing the raw data from CCCEH.

[41] https://www.regulations.gov/document?D=EPA-HQ-OPP-2008-0850-0936

Appendix 3: Physical/Chemical Properties

Physical/Chemical Properties of Chlorpyrifos.		
Parameter	Value	Reference
Melting point/range	41.5-42.5 ºC	Chlorpyrifos IRED
pH	NR	
Density (21ºC)	1.51 g/mL	
Water solubility (25°C)	1.05 mg/L	
Solvent solubility (20°C)	Acetone >400 g/L Dichloromethane >400 g/L Methanol 250 g/L Ethyl acetate >400 g/L Toluene >400 g/L n-hexane >400 g/L	
Vapor pressure, (25°C)	1.87×10^{-5} torr[1]	
Dissociation constant, pK_a	NR	
Octanol/water partition coefficient, Log(K_{OW})	4.7	
UV/visible absorption spectrum	NR	

NR – not reported.

[1] R. Bohaty, June 2011, D368388 and D389480, *Chlorpyrifos Drinking Water Assessment for Registration Review* (CRF assessment, Oct. 16, 2009 product chemistry BC 2062713)

Appendix 4: Current U.S. Tolerances and International Residue Limits for Chlorpyrifos

Summary of US and International Tolerances and Maximum Residue Limits				
Residue Definition:				
US	**Canada**		**Mexico[2]**	**Codex[3]**
40CFR180.342 chlorpyrifos *per se* (*O,O* -diethyl *O* -(3,5,6-trichloro-2-pyridyl) phosphorothioate	*O,O*-diethyl-*O*-(3,5,6-trichloro-2-pyridyl) phosphorothioate (apples, grapes, tomatoes) *O,O*-diethyl-*O*-(3,5,6- trichloro-2-pyridyl) phosphorothioate, including the metabolite 3,5,6-trichloro-2-pyridinol (citrus fruits; fat, kidney, and liver of cattle; kiwifruit; peppers; rutabagas; green onion subgroup (crop subgroup 3-07B); meat and meat byproducts of cattle (calculated on the fat content))			Chlorpyrifos. The residue is fat soluble.
Commodity[1,]	Tolerance (ppm) /Maximum Residue Limit (mg/kg)			
	US	Canada	Mexico[2]	Codex[3]
Alfalfa, forage	3.0			
Alfalfa, hay	13			5 alfalfa fodder
Almond	0.2			0.05
Almond, hulls	12			
Apple	0.01	0.01		1 pome fruits
Apple, wet pomace	0.02			
Banana	0.1			2
Beet, sugar, dried pulp	5.0			
Beet, sugar, molasses	15			
Beet, sugar, roots	1.0			0.05
Beet, sugar, tops	8.0			
Cattle, fat	0.3	1		
Cattle, meat	0.05	1		1 (fat)
Cattle, meat byproducts	0.05	1		0.01 cattle, kidney and liver
Cherry, sweet	1.0			
Cherry, tart	1.0			
Citrus, dried pulp	5.0			
Citrus, oil	20			
Corn, field, forage	8.0			
Corn, field, grain	0.05	0.05		0.05 maize
Corn, field, refined oil	0.25			0.2 maize oil, edible
Corn, field, stover	8.0			10 maize fodder (dry)
Corn, sweet, forage	8.0			

Summary of US and International Tolerances and Maximum Residue Limits				
Residue Definition:				
US	**Canada**		**Mexico[2]**	**Codex[3]**
Corn, sweet, kernel plus cob with husk removed	0.05	0.05		0.01 sweet corn (corn-on-the-cob)
Corn, sweet, stover	8.0			
Cotton, undelinted seed	0.2			0.3 cotton seed
Cranberry	1.0			1
Cucumber	0.05	0.05		
Egg	0.01			0.01 (*)
Fig	0.01			
Fruit, citrus, group 10	1.0	1		1
Goat, fat	0.2			
Goat, meat	0.05			
Goat, meat byproducts	0.05			
Hazelnut	0.2			
Hog, fat	0.2			
Hog, meat	0.05			0.02 (fat)
Hog, meat byproducts	0.05			0.01 (*) pig, edible offal
Horse, fat	0.25			
Horse, meat	0.25			
Horse, meat byproducts	0.25			
Kiwifruit	2.0	2		
Milk, fat (Reflecting 0.01 ppm in whole milk)	0.25			0.02 milk
Nectarine	0.05	0.05		
Onion, bulb	0.5	0.2		0.2
Peach	0.05	0.05		0.5
Peanut	0.2			
Peanut, refined oil	0.2			
Pear	0.05			1 pome fruits
Pecan	0.2			0.05 (*)
Pepper	1.0	1		2 peppers sweet including pimento or pimiento); 20 peppers chili, dried
Peppermint, tops	0.8			
Peppermint, oil	8.0			
Plum, prune, fresh	0.05			0.5 plums (including prunes)
Poultry, fat	0.1			
Poultry, meat	0.1			0.01 (fat)
Poultry, meat byproducts	0.1			0.01 (*) poultry, edible offal
Pumpkin	0.05			
Radish	2.0			
Rutabaga	0.5	0.5		
Sheep, fat	0.2			

Summary of US and International Tolerances and Maximum Residue Limits				
Residue Definition:				
US	**Canada**		**Mexico[2]**	**Codex[3]**
Sheep, meat	0.05			1 (fat)
Sheep, meat byproducts	0.05			0.01 sheep, edible offal
Spearmint, tops	0.8			
Spearmint, oil	8.0			
Sorghum, grain, forage	0.5			
Sorghum, grain, grain	0.5			0.5
Sorghum, grain, stover	2.0			2 sorghum straw and fodder, dry
Soybean, seed	0.3			0.1 soya bean (dry)
Strawberry	0.2			0.3
Sunflower, seed	0.1	0.1		
Sweet potato, roots	0.05			
Turnip, roots	1.0			
Turnip, tops	0.3			
Vegetable, brassica, leafy, group 5	1.0			2 Broccoli 1 Cabbages, head 0.05 Cauliflower 1 Chinese cabbage (type pe-tsai)
Vegetable, legume, group 6 except soybean	0.05	0.05 lentils		0.01 common bean (pods and/or immature seeds); peas (pods and succulent=immature seeds)
Walnut	0.2			0.05 (*)
Wheat, forage	3.0			
Wheat, grain	0.5			0.5
Wheat, straw	6.0			5 wheat straw and fodder, dry
Prepared 05/19/2020 D. Drew				

[1] Includes commodities listed in the CFR as of 5/19/2020. The 40CFR 180.342 (a) (3) also stipulates that "a tolerance of 0.1 part per million is established for residues of chlorpyrifos, per se, in or on food commodities (other than those already covered by a higher tolerance as a result of use on growing crops) in food service establishments where food and food products are prepared and served, as a result of the application of chlorpyrifos in microencapsulated form."

[2] Mexico adopts US tolerances and/or Codex MRLs for its export purposes.

[3] * = absent at the limit of quantitation. (fat) = to be measured on the fat portion of the sample.

Tolerances with regional registrations

Commodity	Parts per million	Canada	Codex
Asparagus	5.0		
Grape	0.01	0.01	0.5

Appendix 5: Master Use Summary Document

Table A.5. Summary of Current Chlorpyrifos Usage

Crop/Site	Residential	Agricultural	Forestry	Timing; Application Type	Method/ Equipment	Maximum Single Application Rate by Formulation[1] (lb a.i./A)	Maximum Application Rate		Maximum Application Number		PHI (days)[3]	REI (hours)[3]	MRI (days)[3]	Geographic Restrictions	Comments
							Per Year lb a.i./A	Per CC[2] lb a.i./A	Per Year	Per CC[2]					
AGRICULT-URAL FARM PREMISES Livestock housing and holding areas (such as hog barns, empty chicken houses, dairy areas, milkrooms, calf hutches, calving pens and parlors).		✓		Indoor general surface spray	backpack sprayer; high and low sprayer (pressure or volume)	0.075 lb a.i./ 1000 ft sq 1.2 EC, ME	[14.4] NS	NA	12	NA	NA	NS	NS		Only permitted for use in poultry houses
ALFALFA		✓		At plant	groundboom	1.0 G	1.0	1.0	[1] NS	1	21	24	[10] NS	Missouri only	Lower PHI permitted for EC rates 0.33 lb a.i./A (7 d) and 0.67 lb a.i./A (14 d) e.g. Reg. No. 62719-591 Stand is in production 3-5 years. Planted ¼" to ½" deep.

Table A.5. Summary of Current Chlorpyrifos Usage															
Crop/Site	**Residential**	**Agricultural**	**Forestry**	**Timing; Application Type**	**Method/ Equipment**	**Maximum Single Application Rate by Formulation[1] (lb a.i./A)**	**Maximum Application Rate**		**Maximum Application Number**		**PHI (days)[3]**	**REI (hours)[3]**	**MRI (days)[3]**	**Geographic Restrictions**	**Comments**
							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
		✓		Foliar	aerial or ground/ broadcast, chemigation	1.0 EC	[4.0] NS	4.0	[4] NS	4	21	24	10		Lower PHI permitted for EC rates 0.33 lb a.i./A (7 d) and 0.67 lb a.i./A (14 d) *e.g.*, Reg. No. 62719-591 Multiple harvests (or cuttings) per year when used for feed/fodder and 1 harvest per year when grown for seed. Cuttings occur about every 30 days. Only 1 crop cycle per year but up to 9 cuttings, varies by geography.
				Total		**1.0**	**5.0**	**5.0**	**[5] NS**	**5**	**21**	**24**	**[10] NS**		Represents Missouri scenario otherwise 4.0 lb a.i./A per is max.

Table A.5. Summary of Current Chlorpyrifos Usage															
Crop/Site	**Residential**	**Agricultural**	**Forestry**	**Timing; Application Type**	**Method/ Equipment**	**Maximum Single Application Rate by Formulation[1] (lb a.i./A)**	**Maximum Application Rate**		**Maximum Application Number**		**PHI (days)[3]**	**REI (hours)[3]**	**MRI (days)[3]**	**Geographic Restrictions**	**Comments**
							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
ALMOND		✓		**dormant/ delayed dormant**; broadcast	aircraft, airblast	2.0 WDG, WP	2.0	NA	1	NA	NA		10	Restricted use in California.	
		✓		**foliar**; broadcast	aircraft, airblast	2.0 WDG,WP	6.0	NA	3	NA	14		10		
		✓		pre-plant, foliar; **trunk spray/drench or pre-plant dip**	handheld, backpack, drench/dip, handgun, and low-pressure hand wand	2.5 (3.0/100 gal) WDG	2.5	NA	1	NA	14	24	NS		
		✓		Dormant/ delayed dormant; foliar; **orchard floors** broadcast	ground boom, handgun, chemigation	4.0 EC*	4.0	NA	2	NA	14		10	Restricted use in California. Only one dormant application can be made.	
				Total	**--**	**4.0**	**14.5**	**NA**	**7**	**NA**	**14**		**NS**		Excludes nursery applications (See general "Fruits" listing)
APPLE		✓		**dormant/ delayed dormant**; broadcast	aircraft, airblast	2.0 EC 2.0 WDG 1.5 WP	2	2.0	1	1	NA	24/ 4 d	10d		Reflects spray drift mitigation measures.

Table A.5. Summary of Current Chlorpyrifos Usage															
Crop/Site	**Residential**	**Agricultural**	**Forestry**	**Timing; Application Type**	**Method/ Equipment**	**Maximum Single Application Rate by Formulation[1] (lb a.i./A)**	**Maximum Application Rate**		**Maximum Application Number**		**PHI (days)[3]**	**REI (hours)[3]**	**MRI (days)[3]**	**Geographic Restrictions**	**Comments**
							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
		✓		pre-plant, foliar; **trunk spray/drench or pre-plant dip**; ground	handheld, backpack, drench/dip, handgun, and low-pressure hand wand	1.5 (1.5 lb ai/100 gal) WDG	1.5	NA	1	1	28	4d	NS	Use permitted in states east of the Rockies except Mississippi.	
				Total		**2.0**	**3.5**		**2**						
ASPARAGUS		✓		Foliar, pre-harvest; broadcast	aircraft, ground boom	1.0 EC, WDG	1.0	1.0	1	1	1	24	10		
		✓		Postharvest, broadcast	aircraft, ground boom	1.0 EC, WDG	2.0	2.0	2	1	1	24	10		
					granular soil band treatment ground boom	1.5 G	3.0	3.0	2	2	180	24	[10] NS	Permitted in California, the Midwest, and the Pacific Northwest 19713-505, 19713-521, 5481-525, 62719-34, 83222-34	Do not apply more than 3.0 lb a.i./A between harvests.
				Total		**1.5 G**	**3.0 G 2.0**	**3.0 G 2.0**	3	3	1	24	10		

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							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
BEANS		✓		Preplant; Seed treatment	Seed Treatment	*0.016-0.348* 0.000798 lb ai/lb seed ME *0.013-0.272* 0.000625 lb ai/lb seed WP *0.012-0.253* 0.00058 lb ai/lb seed EC	NS	[0.348] NS	NS	[1] NS	NS	NS	NS	ME is SLN only for ID	Italics highlight the range of application rates depending on the number of seeds per lb and the number of seeds planted per acre. Seeding rate information provide by BEAD.[4]
BEEF/RANGE/ FEEDER CATTLE (MEAT)/ DAIRY CATTLE (NON-LACTATING)				Summer, late fall, spring; impregnated collar/tag	Animal treatment (ear tag)	0.0066 lb/animal	[0.0099] NS	NA	3	NA	NS	NS	NS		Reg. No. 39039-6 Cattle ear tags are assumed to last 4-6 months Two tags per animal at 0.0033 lb a.i./tag in the summer and one tag per animal at 0.0033 lb a.i./A.
BEETS (UNSPECIFIED; TABLE OR SUGAR)		✓		At plant, soil band treatment	Ground boom	1.0 EC	NS	1	NS	1		24		Allowed in Oregon Court ordered	Minimum Incorporation: 2 inches

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							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
"grown for seed"														buffer of 60 ft for ground chlorpyrifos application is required for "affected waterways".	
		✓		Preplant, soil incorporated treatment	Broadcast/ ground boom	1.9 EC	NS (2.8 ID)	NS	1	NS				Allowed in Oregon and Idaho	OR-09007; 62719-591 ID-090002; 62719-591
				Total		**1.9**	**NS**	**NS**	**NS**	**NS**		**24**			One or the other type of application.
SUGAR BEETS		✓		Preplant, soil incorporated treatment	Broadcast/ ground boom	1.0 EC 2.0 G	3.0	2.0	1	1	NA	24	10		Minimum Incorporation: 1 inch
		✓		At plant, soil band treatment	Broadcast/ ground boom	1.0 EC, WDG 2.0 G	3.0	2.0	1	1	30	24	10		
		✓		Post plant, soil band	Broadcast/ ground boom	2.0 G	3.0	2.0	1	1	30	24	10		
		✓		Post-emergence band treatment; broadcast	Broadcast/ ground boom	1.0 EC, WDG	3.0	1.0	3	1	30	24	10		

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							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
		✓		broadcast	Aircraft, ground boom, chemigation	1.0 EC, WDG	3.0	1.0	3	1	30	24	10		EC is not for use in MS
				Total		**1.0 EC 2.0 G**	**4.0**	**[4.0] NS**	**3**	**[3] NS**	**30**	**24**	**10**		One granular application at 2.0 a.i./A and two liquid applications at 1.0 a.i./A per year. Also assumed per crop cycle.
CARROT Grown for Seed (INCLUDING TOPS)		✓		Foliar pre-bloom broadcast	aircraft, ground boom	0.94 EC	0.94	1	1	1	7	24	NA	Oregon and Washington Court ordered buffer of 60 ft for ground and 300 ft for aerial application is required for "affected waterways".	OR090011 SLN Expires: 12/31/2018 WA090011 SNL Expires: 12/31/2016 Carrots take two years to produce seed. All commercial production of the carrot (vegetable) takes place in the first year when the plant

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							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
															is nowhere near blooming.
CHERRIES		✓		**dormant/ delayed dormant**; broadcast	aircraft, airblast	2.0 WDG, EC 1.5 WP	2.0	NA	1	NA	NS	24	10		
		✓		**foliar**; broadcast	airblast	4.0 EC	10.0	NA	5	NA	14	24	10		Tart cherry only
					aircraft	2.0									Reflects spray drift mitigation
		✓		Foliar, post-harvest; **trunk spray/drench**	handheld, backpack, drench/dip, handgun, and low-pressure hand wand	2.5 (3.0/100 gal) WDG, EC	2.5	NA	1	NA	2	24	[10] NS		Only some labels specify a 10 d MRI.
				Total	**--**	**4.0**	**4.5 (sweet)** **14.5 (tart only)**		**6**						Excludes nursery applications (See general "Fruits" listing) The foliar applications only apply to tart cherries, thus, sweet cherry scenarios (*e.g.*, Pacific NW) annual

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							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
															application rate would be 4.5 lb total a.i./year.
CHRISTMAS TREE PLANTATIONS		✓		**foliar**; broadcast	helicopter, orchard blast	1.0 EC, WDG, WP	3.0	NA	3	NA	[0] NS	24	7	Aerial applications via helicopter are only permitted in Washington and Oregon.	
		✓		post-harvest; **Stump Treatment**	handheld, backpack, drench/dip, handgun, and low-pressure hand wand	2.5 (3.0/100 gal) EC, WDG	2.5	NA	1	NA	NA		7		
				Total		**2.5**	**5.5**		**4**						
CITRUS		✓		**foliar**; broadcast	airblast, ground boom	6.0 WP, WSP, EC	7.5	NA	2	NA	35 (21 for low rates)	5d	30 (10 for low rates)	6.0 lb a.i. /A is only permitted in California and Arizona. The max single rate in other states is restricted to 4 lb a.i./A.	
		✓			aircraft	2.3 WP, WSP, EC					21	5	10	Florida, California,	Aerial application used

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							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
														and potentially Texas	to control psyllid, the vector for citrus greening. Reflects spray drift mitigation
		✓		foliar; **orchard floors broadcast**	ground boom, chemigation, handheld, backpack, drench/dip, handgun, and low-pressure hand wand	1.0 G*, WSP, EC	3.0	NA	3	NA	28	24/ 5 d	10		
				Total	**--**	**6.0**	**10.5**		**5**						Registered labels permit both foliar and soil applications in the same orchard. Total excludes nursery applications (See general "Fruits" listing)
CLOVER (GROWN FOR SEED)		✓		Preplant	Ground boom	1.9 EC	1.9	1.9	1	1	NS	24	NA	Use only permitted in Oregon.	OR-0900100; master label: 62719-591

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							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
		✓		Post-Plant Foliar	aircraft and ground boom										Either a preplant or post plant application is allowed.
COLE CROPS (EXCLUDES CAULIFLOWER AND BRUSSELS SPROUTS)		✓		Preplant, soil incorporated treatment	Ground boom	2.0 EC, WDG, G	4.0	2.0	2	1	30	24	10		Min. incorporation: 2 inches
		✓		At plant, soil band treatment	Ground boom					1					One granular application permitted per year.
		✓		Post plant	Ground boom					1					
		✓		Foliar Established Plantings, soil sidedress treatment	Ground boom					1					
		✓		Foliar, broadcast	Aircraft, ground boom, chemigation	1.0 EC, WDG, WP	4.0	3.0	4	3	21		10		Multiple crops per year are possible in some locations.
				Total			**8.0**	**5**	**6**	**4**					Some labels restrict the yearly application rate to 3 lb a.i./A.

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Crop/Site	**Residential**	**Agricultural**	**Forestry**	**Timing; Application Type**	**Method/ Equipment**	**Maximum Single Application Rate by Formulation[1] (lb a.i./A)**	**Maximum Application Rate**		**Maximum Application Number**		**PHI (days)[3]**	**REI (hours)[3]**	**MRI (days)[3]**	**Geographic Restrictions**	**Comments**
							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
															The maximum number of crops per year is 2.
BRUSSELS SPROUTS		✓		At plant, soil band treatment	Ground boom	2.0 EC; G	2.0	[2.0] NS	2	1	21	24	10		
		✓		Preplant, soil incorporated treatment	Ground boom										Minimum incorporation is 2 inches
		✓		Post plant, soil application	Ground boom	2.25 EC, G	2.25	[2.25] NS							
		✓		Foliar broadcast	Aircraft, Ground boom	1.0 EC	[5.3] NS	3.0	NS	3			10		83222-20, 84930-7, 86363-3 specify a 7-day MRI. All other labels specify a 10-day MRI. The PHI stated 84930-7 is conflicting [p. 4 (21 days and p. 19 (30 days)]
				Total		**2.3**	**5.3**		**NS**		**21**	**24**	**7**		Assume one application of either at plant, preplant, or post plant followed with additional

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Crop/Site	**Residential**	**Agricultural**	**Forestry**	**Timing; Application Type**	**Method/ Equipment**	**Maximum Single Application Rate by Formulation[1] (lb a.i./A)**	**Maximum Application Rate**		**Maximum Application Number**		**PHI (days)[3]**	**REI (hours)[3]**	**MRI (days)[3]**	**Geographic Restrictions**	**Comments**
							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
															foliar applications.
CAULI-FLOWER		✓		At plant, soil band treatment	Ground boom	2.0 EC 2.3 G	2.0 EC 2.25 G	NS	[1] NS	1	21	3d	10		Only one granular application.
		✓		Preplant, soil incorporated treatment	Ground boom	2.3 G 2.0 EC	2.3	NS	[1] NS	1	30, EC, 21 G				Minimum incorporation is 2 inches
		✓		Post plant, soil application	Ground boom										
		✓		Foliar broadcast	aircraft, ground boom	1.0 EC	[5.3] NS	3.0	NS	3	21		10		
				Total		**2.3**	**5.3**	**[5.3] NS**	**NS**	**[4] NS**	**21**	**24**	**10**		Assume one application at either plant, preplant, or post plant followed with additional foliar applications.
COMMERCIAL /INSTITUTION-AL/ INDUSTRIAL PREMISES/ EQUIP. (INDOOR)				Broadcast	Product Container	0.4373 lb a.i./100 sq ft 190.5 G	NS	NA	NS	NA	NA	NS	NS		For treatment of fire ants
				Crack and Crevice/Void	Sprayer/ Injection	0.0625 lb a.i./1000 sq ft	NS	NA	NS	NA	NA	NS	NS		499-419

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							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
Non-food areas of manufacturing, industrial, and food processing plants; warehouses; ship holds; railroad boxcars.						2.7 ME									
				Crack and Crevice/Spot	Sprayer/ Injection	0.0424 lb/gal ME	NS	NA	NS	NA	NA	NS	7		
COMMERCIAL /INSTITUTIONAL /INDUSTRIAL PREMISES/EQUIP. (OUTDOOR) Outdoor commercial use around non-food areas of manufact-uring, industrial, and food processing plants; warehouses; ship holds; railroad boxcars				Soil broadcast	Low and High Pressure, Backpack, Handgun Sprayers	0.0247 lb a.i./1000 sq ft 1.1 ME	NS	NA	NS	NA	NA	NS	NS		
				Directed spray		0.1132 lb a.i./1000 sq ft 4.9 ME	NS	NA	NS	NA	NA	NS	NS		Specific to: Inside and outside dumpsters and other trash holding containers, trash corrals and other trash storage areas.
				Crack and Crevice/void/ general outdoor		0.0424 lb/gal ME	NS	NA	NS	NA	NA	NS	7		
CONIFERS AND DECIDUOUS TREES;		✓	?	**foliar**; broadcast	Ground boom	1.0 EC	3	NA	6	NA	7	24	7		

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Crop/Site	**Residential**	**Agricultural**	**Forestry**	**Timing; Application Type**	**Method/ Equipment**	**Maximum Single Application Rate by Formulation[1] (lb a.i./A)**	**Maximum Application Rate**		**Maximum Application Number**		**PHI (days)[3]**	**REI (hours)[3]**	**MRI (days)[3]**	**Geographic Restrictions**	**Comments**
							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
PLANTATION, NURSERY		✓	?	foliar; **stump treatment**	backpack, drencher, low pressure hand wand	0.3 EC	0.3	NA	1	NA	7	24	7		
				Total		**1.0**	**3**	**NA**	**6**	**NA**	**7**	**24**	**7**		The total number of applications assumed is either 3 foliar applications or 2 foliar applications with one stump treatment.
CORN (ALL)		✓		Preplant	ground/ **soil incorporated** conservation tillage, in furrow, broadcast, chemigation, soil band	3.0 EC 2.0 G	3.0	3.0	NS	3	NA	24/ 5 EC	10		19713-520, 19713-599, 33658-26, 34704-857, 72693-11, 83222-20 The minimum incorporation depth is 2 inches.
					soil incorporated aerial conservation tillage	2.0 EC, G									

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							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
		✓			ground/ conservation tillage, in furrow, broadcast, chemigation, soil band	1.0 EC 2.0 G	3.0	3.0	NS	3	21		10		19713-520
		✓		Storage or preplant seed treatment	Seed treatment	*0.001-0.021* 0.000625 lb a.i./ lb seed WP *0.1-1.9* 0.058 lb a.i./ lb seed FC	[?] NS	[1.9] NS	[?] NS	1	NS	NS	NS		Italics highlight the range of application rates depending on the number of seeds per lb and the number of seeds planted per acre. Seeding rate information provide by BEAD.[4]
		✓		At plant	soil incorporated, conservation tillage	2.0 G	[?] NS	3.0	[?] NS	3	21	24	10		
		✓		Post emergence	Aerial or ground, broadcast, chemigation	1.5 EC 1.0 WDG	NS	3.0	NS	3	21	24/ 5d (EC	10		A brush on max single rate is permitted at 1.0 lb ai/a (72693-11)

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							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
		✓		Foliar	Aerial or ground/ broadcast, granule, seed and chemigation	1.5 EC	3.0	3.0	NS	3	21		10		
				Total		**3.0**	**8.1**	**8.1**	**NS**	**4**	**21**		**10**		Two granular applications are allowed with a maximum single rate of 1.0 lb a.i./A or one granular application at 2 lb a.i./A. Total with seed treatment PHI: 21 d except Delaware and Florida (7 d)
COTTON		✓		Storage or preplant seed treatment	Seed treatment	*0.8-2.2* 0.00116 lb/lb seed EC	[2.2] NS	[2.2] NS	[1] NS	1	NS	NS	NS		264-932 Rates in italics highlight the potential range of application rates depending on the number of seeds per lb and the number

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							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
															of seeds planted per acre. Seeding rate information provide by BEAD.[2]
		✓		Foliar	aerial, chemigation, ground boom	1.0 EC, WDGP	3	3.0	3	3	14	24	10		Except MS
				Total		**1.0**	**3.2**	**3.2**	**3**	**3**	**14**	**24**	**10**		1.6 lb a.i./A is max single rate (seed treatment) **Total with seed treatment** 1 crop cycle per year assumed
CRANBERRY		✓		Foliar	aircraft, ground boom/ broadcast and chemigation	1.5 EC, WDG	3.0	NA	2	NA	60	24	10	Not for use in Mississippi.	Do not apply to bogs when flooded.
CUCUMBER		✓		Storage or preplant seed treatment	Commercial seed treatment	*0.4* 0.00058 lb/lb seed EC	NS	0.1	2	1	NS	NS	NS		Seeding rate information provide by BEAD.[2] 264-932, 62719-221, CA040004 Per registrant 2 CCs per year

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							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
FIGS		✓		**dormant/ delayed dormant**; soil application	ground boom	2.0 WDG, EC	2.0	NA	1	NA	217	4 d	NS	Use is restricted to California only.	Incorporation to 3 inches is suggested but not required following application.
FILBERTS/ HAZELNUT		✓		**dormant/ delayed dormant**; broadcast	aircraft, airblast	2.0 WP	2.0	NA	1	NA	14	24	10		
		✓		**foliar**; broadcast	aircraft, airblast	2.0 WDG, WP, EC	6.0	NA	3	NA	14		10		Some labels specify a retreatment interval of 10 days.
				Total		**2.0**	**6.0**	**NS**	**3.0**	**NA**	**14**	**24**	**10**		Excludes nursery applications (See general "Fruits" listing)
FOOD PROCESSING PLANT PREMISES (NONFOOD CONTACT)				When needed, crack and crevice treatment, spot treatment		0.0424 lb/ gal ME	NS	NA	NS	NA	NA	NS	7		53883-264, 84575-3 Spot Treatment: Do not exceed two square feet per individual spot.
FOREST PLANTINGS (REFORESTAT			✓	Foliar, broadcast	ground boom	1.0 EC	6.0	NA	6	NA		24	7		

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							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
ION PROGRAMS) (TREE FARMS, TREE PLANTATION, ETC.)															
			✓	Foliar, stump treatment	direct spray, drencher	0.34 EC	6.0	NA	[18] NS	NA			7		
FOREST TREES (SOFTWOODS, CONIFERS)			✓	Foliar, broadcast	ground boom, drencher	0.61 EC	3.6	NA	NS	NA	24		7		
			✓	Foliar, stump treatment	direct spray	[3.6] 2.4 lb a.i./100 gal EC	3.6	NA	NS	NA			7		Application rate is provided as a dilution factor.
FRUITS & NUTS Non-bearing (not to bear fruit within 1 year) fruit trees in nurseries (includes: almonds, citrus, filbert, apple, cherry, nectarine, peach, pear, plum, prune).		✓		Foliar-Non-bearing nursery broadcast	High/low volume spay/ handheld sprayer/power sprayer	4.0 EC	4.0	NA	NS	NA	14	NS	7		For nectarines and peaches, the use is restricted to one application of no more than 3 lb a.i./A per cc. For apples, the max rate is 2 lb a.i./A per crop cycle and the use is restricted to 1 application (either canopy or trunk drench) per year.

Table A.5. Summary of Current Chlorpyrifos Usage															
Crop/Site	**Residential**	**Agricultural**	**Forestry**	**Timing; Application Type**	**Method/ Equipment**	**Maximum Single Application Rate by Formulation[1] (lb a.i./A)**	**Maximum Application Rate**		**Maximum Application Number**		**PHI (days)[3]**	**REI (hours)[3]**	**MRI (days)[3]**	**Geographic Restrictions**	**Comments**
							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
															Example label, 62719-254
		✓		Foliar-Non-bearing nursery trunk drench	drencher, high- and low-pressure sprayer	2.0 WDG	2.0	NA	NS	1	14		7		
				Total		**4.0**	**6.0**								Maximum Single Rates: 3.0 (nectarines and peaches) 2.0 (apples) Maximum Yearly Rates: 3.0 (nectarines and peaches) 2.0 (apples)
GINSENG (MEDCINAL)		✓		Preplant, post-emergence	Ground, soil broadcast	2.0 G	2.0	NA	1	NA	365	24	NA	Permitted in Michigan and Wisconsin	MI110006,WI110003) Minimum incorporation: 4 inches Application should be followed by rainfall or overhead watering. Valid until June 29, 2016.

Table A.5. Summary of Current Chlorpyrifos Usage															
Crop/Site	**Residential**	**Agricultural**	**Forestry**	**Timing; Application Type**	**Method/ Equipment**	**Maximum Single Application Rate by Formulation[1] (lb a.i./A)**	**Maximum Application Rate**		**Maximum Application Number**		**PHI (days)[3]**	**REI (hours)[3]**	**MRI (days)[3]**	**Geographic Restrictions**	**Comments**
							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
GOLF COURSE TURF				When needed, soil broadcast/ spot treatment	Ground, low pressure	1.0 EC	2.0	NA	2	NA		24	NS		
				Foliar, broadcast,	Ground boom, handgun, low pressure and backpack	1.0 EC, G, B	2.0	NA	2	NA		24	NS		Chemigation not allowed for the EC formulation.
					Tractor drawn spreader, push type spreader, belly grinder	1.0 G						[24] NS	7		
				Mound treatment	Granule applicator	1.0 G	2.0	NS	2	NS		NS	7		
				Total		**2.0**	**2.0**	**NA**	**2**	**NA**	**NS**		**NS**		
GRAPES		✓		Dormant/ Delayed Dormant (pre-bloom)	Ground boom, broadcast, drench high/low spray volume	1.0 WDG, EC	1.0	1	1	NA	35	24	NS	East of the continental divide only.	Do not use in conjunction with soil surface applications for grape borer control.
		✓				2.0 EC	2.0	1	1	NA	35			Permitted in Colorado, Idaho, and Washington	CO080008, ID090004, WA090002 Master label: 62719-591

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Crop/Site	**Residential**	**Agricultural**	**Forestry**	**Timing; Application Type**	**Method/ Equipment**	**Maximum Single Application Rate by Formulation[1] (lb a.i./A)**	**Maximum Application Rate**		**Maximum Application Number**		**PHI (days)[3]**	**REI (hours)[3]**	**MRI (days)[3]**	**Geographic Restrictions**	**Comments**
							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
		✓		Foliar	Ground/ broadcast, basal spray and drench (soil treatment)	2.25 EC	2.25	1	1	NA	35		NS	Permitted east of the continental divide.	
		✓				1.0 EC	3.0	3	3	NA	35		NS	California	CA080010
		✓		Postharvest, dormant/ delayed dormant	Ground boom, broadcast	2.0 EC	2.0	1	1	NA	NS		NS	California	CA080009
				Total		**2.25**	**2.25**	**1**			**35**	**24**	**NS**	Permitted east of the continental divide.	
						2.0	**5.0**	**4**			**NS**		**NS**	California	
GRASS FORAGE/ FODDER/HAY		✓		Foliar, broadcast	Aircraft, ground boom, chemigation	1.0 EC	3.0	NA	3	NA	NS	24		Permitted in Nevada, Oregon, Washington, and Idaho	NV080004, NV940002, OR090009, WA090010, ID090003
GREENHOUSE		✓		early evening, aerosol, fog or fumigation	Total release fogger	0.029 0.0066 lb a.i./1000 sq. ft PL	NS	NA	NS	NA	NS	NS	2		
HOUSEHOLD/ DOMESTIC DWELLINGS INDOOR PREMISES	✓			When needed	Bait station	0.0003 lb/bait station	NS	NA	NS	NA	NA	NS	NS		9688-67

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Crop/Site	**Residential**	**Agricultural**	**Forestry**	**Timing; Application Type**	**Method/ Equipment**	**Maximum Single Application Rate by Formulation[1] (lb a.i./A)**	**Maximum Application Rate**		**Maximum Application Number**		**PHI (days)[3]**	**REI (hours)[3]**	**MRI (days)[3]**	**Geographic Restrictions**	**Comments**
							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
HYBRID COTTONWOOD/ POPLAR PLANTATIONS		✓		Foliar, dormant, delayed dormant; broadcast	High volume (dilute) Low volume (concentrate)	1.9 EC	[2.0] NS	6.0	[1] NS	3		24	7	Washington	WA090004 Energy wood plantations may be harvested as often as every 2-3 years; pulpwood 5-10 years; and saw timber 15-20 years. (Arkansas production guide). In Washington the crop takes 2-8 years
LEGUME VEGETABLES		✓		Preplant, soil treatment	Ground boom	1.0 EC, WDG	1.0	NA	1	NA	NS	24	NA		No MRI because application only once a year
		✓		At planting, soil treatment	Ground boom	1.0 EC, WDG	1.0	NA	1	NA	NS		NA		
				Total		**1.0**	**1.0**	**NA**	**1**	**NA**	**NS**	**24**	**NS**		Assumed either a preplant or an at plant treatment.
MINT/ PEPPERMINT/ SPEARMINT		✓		Preplant soil incorporated	Aerial or ground/ broadcast	2.0 EC, WDG	[2.0] NS	2.0	[1] NS	1	90	24	NA	No use in Mississippi.	19713-599, 33658-26, 34704-857, 67760-28, 84229-25,

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Crop/Site	**Residential**	**Agricultural**	**Forestry**	**Timing; Application Type**	**Method/ Equipment**	**Maximum Single Application Rate by Formulation[1] (lb a.i./A)**	**Maximum Application Rate**		**Maximum Application Number**		**PHI (days)[3]**	**REI (hours)[3]**	**MRI (days)[3]**	**Geographic Restrictions**	**Comments**
							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
															84930-7, OR940027 MRI NA due to once per crop cycle application
		✓		Post-emergence, Postharvest, Foliar	Chemigation, ground/ airblast	2.0 EC	2.0	2.0	[1] NS	2	90		NS	No use in Mississippi.	Postharvest application retreatment not specified on some labels.
				Total		**2.0**	**4.0**	**4.0**	**2.0**	**3**	**90**	**24**	**NS**		Labels allow one growing season application including pre-plant and one post-harvest application per season.
MOSQUITO CONTROL; HOUSEHOLD/ DOMESTIC DWELLINGS OUTDOOR PREMISES; RECREATIONAL AREAS	✓			When needed; broadcast	Ultra-low volume air and ground	0.01 EC	0.26	NA	26	NS	NA	NS	24 h	In Florida: Do not apply by aircraft unless approved by the Florida Dept of Ag.	Aerial applications may be made at altitudes ranging from 75-300 ft (see labels for specifics).

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Crop/Site	**Residential**	**Agricultural**	**Forestry**	**Timing; Application Type**	**Method/ Equipment**	**Maximum Single Application Rate by Formulation[1] (lb a.i./A)**	**Maximum Application Rate**		**Maximum Application Number**		**PHI (days)[3]**	**REI (hours)[3]**	**MRI (days)[3]**	**Geographic Restrictions**	**Comments**
							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
															For use by federal, state, tribal or local government officials or by persons certified in the appropriate category or authorized by the state or tribal lead regulatory agency.
NECTARINE		✓		**dormant/ delayed dormant** broadcast	airblast, handgun	3.0 WDG, EC	3.0	NA	1	NA	NS	24/ 4d	10		83222-20 others at 2 lb a.i./a
					Aircraft	2.0 WDG, EC									Updated to reflect spray drift mitigation.
		✓		pre-plant, foliar; **trunk spray/drench or pre-plant dip**	Handgun, low pressure backpack, dip	2.5 (3.0/100 gal) WDG, EC	2.5	NA	1	NA	14		5		There is no application retreatment interval specified on some of the label. The application rate is provided as a dilution factor.

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Crop/Site	**Residential**	**Agricultural**	**Forestry**	**Timing; Application Type**	**Method/ Equipment**	**Maximum Single Application Rate by Formulation[1] (lb a.i./A)**	**Maximum Application Rate**		**Maximum Application Number**		**PHI (days)[3]**	**REI (hours)[3]**	**MRI (days)[3]**	**Geographic Restrictions**	**Comments**
							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
				Total		**3.0**	**5.5**	**NA**	**2**	**NA**					Some labels limit the amount a.i./A per year. Multiple types of applications can occur such as preplant, trunk drench and dormant, delayed dormant applications. Excludes nursery applications (See general "Fruits" listing)
NONAGRICULTURAL OUTDOOR BUILDINGS/STRUCTURES to and around outside surfaces of nonresidential buildings and structures. Permitted areas of use include				Outdoor general surface/ Band (may be better if called perimeter)	Ground sprayer/ band sprayer	1.0 EC	NS	NA	NS	NA	NA	NS	NS		

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							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
fences, pre-construction foundations, refuse dumps, outside of walls, and other areas where pests congregate or have been seen															
NURSERY-STOCK: : Ornamental nursery stock annuals, perennials and woody plants being grown in the field, in ball and burlap or in containers outdoor and in greenhouses				Dormant/ Delayed Dormant	high spray	3.0 EC	3.0	NA	1	NA		24	NS		
				Preplant	Ground boom, soil incorporated	4.0 EC, WP	NS	NA	NS	NA					
				foliar, soil directed	Tractor drawn spreader, push type spreader, belly grinder, gravity fed	1.1 G									

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Crop/Site	**Residential**	**Agricultural**	**Forestry**	**Timing; Application Type**	**Method/ Equipment**	**Maximum Single Application Rate by Formulation[1] (lb a.i./A)**	**Maximum Application Rate**		**Maximum Application Number**		**PHI (days)[3]**	**REI (hours)[3]**	**MRI (days)[3]**	**Geographic Restrictions**	**Comments**
							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
					backpack, spoon										
				Total		**4.0**	**CBD**		**3**						
ONIONS		✓		Post plant (seeding) Broadcast	Ground boom	1.0 EC	1.0	NS	2	NS	60	24	NS		
		✓		At plant, soil drench or basal spray	Ground boom	1.0 EC, WDG, G	1.0		1						2-inch incorporation
				Total		2.0	2.0		2		60	24	NS		
ORNAMENTAL AND/OR SHADE TREES, HERBACEOUS PLANTS		✓		Foliar broadcast	Ground boom, air blast, handgun, low- and high-pressure hand wands	2.0 EC, WP 1.0 G, B	2.0	NA	[2] NS	NA	NS	24	NS		Some labels include an MRI of 7 days.
		✓		Dormant /Delayed Dormant	Handgun, low pressure and backpack	3.0 EC	3.0	NA	1	NA	NS		7		Low volume spray permitted for concentrated solutions and lower rates.
ORNAMENTAL LAWNS AND TURF, SOD FARMS (TURF)		✓		When needed, broadcast, soil or spot treatment	ground boom (WP only), high pressure hand wand	3.76 EC, WP	7.52	NA	2	NA	NS	24	NS		
		✓		NS	Tractor drawn spreader, push type spreader, belly grinder	1.0 B	2.0	NA	2	NA	NS	24	NS		Bait is used for fire ant control.

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Crop/Site	**Residential**	**Agricultural**	**Forestry**	**Timing; Application Type**	**Method/ Equipment**	**Maximum Single Application Rate by Formulation[1] (lb a.i./A)**	**Maximum Application Rate**		**Maximum Application Number**		**PHI (days)[3]**	**REI (hours)[3]**	**MRI (days)[3]**	**Geographic Restrictions**	**Comments**
							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
ORNAMENTAL NON-FLOWERING PLANTS		✓		Foliar, broadcast, soil drench	Chemigation, ground boom, low and high pressure handwand, handgun, backpack sprayer, sprinkling can	0.007/gal ME	NS	NA	12	NA	NA	24	NS		Application rate provided as a dilution factor. Restricted use—occupational only
ORNAMENTAL WOODY SHRUBS AND VINES				Foliar broadcast	Ground boom, air blast, handgun, low- and high-pressure sprayer, backpack	2.0 EC, WDG 0.01 lb/gal EC	2.0 0.01 lb/gal	NA	[1] NS	NA	NS	24	NS		Several labels do not restrict the application rate in lb a.i./A. Examples include 16.5 lb/100 gal (228-625) and 1.0 lb/100 gal (829-280).
				Dormant/ delayed dormant		1.0 EC 0.005 lb/gal EC	1.0	NA	[1] NS	NA					
				Preharvest	Tractor drawn spreader, push type spreader, belly grinder	6.0 G	6.0	NA	[1] NS	NA					
				Preplant, potted, bailed-and	groundboom, handgun, low- and high-	1.0 EC	NS	1	NS	1					

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Crop/Site	**Residential**	**Agricultural**	**Forestry**	**Timing; Application Type**	**Method/ Equipment**	**Maximum Single Application Rate by Formulation[1] (lb a.i./A)**	**Maximum Application Rate**		**Maximum Application Number**		**PHI (days)[3]**	**REI (hours)[3]**	**MRI (days)[3]**	**Geographic Restrictions**	**Comments**
							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
				burlapped, containerized	pressure sprayer, backpack, drench										
				Pretransplant	groundboom	4.0 WP	[48.0] NS	4	12	4					
				Total		**6.0 G 4.0 WP**	**CBD**		**CBD**						
PEACH		✓		**dormant/ delayed dormant** broadcast	airblast	3.0 EC 2.0 WDG	3.0	NA	1	NA	10	24/ 4d	NS		83222-20 (all other labels restrict to 2 lb ai/a)
					aircraft,	2.0 EC 2.0 WDG							NS		Updated to reflect spray drift mitigation.
		✓		**Post-harvest** broadcast	airblast	2.5 (3.0/100 gal) EC	2.5	NA	1	NA	NA		NS	Permitted in Georgia and South Carolina	GA0400001, SC040001 SLN Expires:
					aircraft	2.0 (3.0/100 gal) EC	2.0								GA0400001, SC040001 SLN Expires: Updated to reflect spray drift mitigation
		✓		pre-plant, foliar;	handheld, backpack, drench/dip,	2.5 (3.0/100 gal) WDG	2.5	NA	1	NA	14	5	NS		Some labels do not specify minimum

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							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
				trunk spray/drench or pre-plant dip; ground	handgun, and low-pressure hand wand										retreatment interval.
						3.0	**5.5**	**NA**	**3**	**NA**	**NA**	**24**	**NS**		It is possible that multiple types of applications can occur such as soil, foliar and/or post-harvest and dormant/ delayed dormant applications. Excludes nursery applications (See general "Fruits" listing)
				Total		**3.0**	**8.0**	**NA**	**3**	**NA**	**NA**	**24**	**NS**	Permitted in Georgia and South Carolina	
PEANUT		✓		Preplant	Aerial or ground/ broadcast	2.0 EC, WDG	[4.0] NS	4.0	[2] NS	2	NA	24	10	Do not apply aerial in Mississippi	Assumes one crop cycle per year.
		✓		At plant, post plant		4.0 G	[4.0] NS	4.0	2	2	21	24	10		
		✓		At pegging		2.0 G EC, WDG	[4.0] NS	4.0	2	[2] NS	21	24	10		

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							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
				Total		**4.0 G 2.0 EC, WDG**	**4.0**	**4.0**	**2**	**2**	**10**	**24**	**10**		
PEAR		✓		**dormant/ delayed dormant** broadcast	aircraft, airblast	2.0 WDG, EC	2.0	NA	1	NA	NA	24	NA	Restricted use in California.	83222-20 allows 3.0 lb a.i./ A; however, this does not match the 2001 RED.
		✓		**Post-harvest** broadcast	aircraft, airblast	2.0 WDG, EC	2.0	NA	1	NA	NA	24	NS	Permitted in California, Oregon and Washington.	
				Total		**2.0 WDG, EC**	**4.0**	**NA**	**2**	**NA**	**NA**	**24**	**NS**		Multiple types of applications may occur in within a year in California, Oregon and Washington such as a post-harvest application and a dormant, delayed dormant. Excludes nursery applications

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Crop/Site	**Residential**	**Agricultural**	**Forestry**	**Timing; Application Type**	**Method/ Equipment**	**Maximum Single Application Rate by Formulation[1] (lb a.i./A)**	**Maximum Application Rate**		**Maximum Application Number**		**PHI (days)[3]**	**REI (hours)[3]**	**MRI (days)[3]**	**Geographic Restrictions**	**Comments**
							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
															(See general "Fruits" listing)
PEAS		✓		Preplant Seed treatment	Seed Treatment	0.30 0.000625 lb/lb seed WP 0.28 0.00058 lb/lb seed EC	NS	NS	NS	NS	NS	NS	NS		There is a range of potential application rates depending on the number of seeds per lb and the number of seeds planted per acre. Seeding information provide by BEAD.[2]
PECANS		✓		**dormant/ delayed dormant** broadcast	aircraft, airblast	2.0 EC, WDG	2.0	NA	1	NA	14		10		66222-19 and 66222-233
		✓		**foliar**; broadcast	airblast	4.3 EC, WDG	6.3	NA	3	NA	14	24	10		Some labels require a 28 d PHI
					aircraft	2.0 EC, WDG									Updated to reflect spray drift mitigation.
		✓		foliar; **orchard floors broadcast**	Ground boom, chemigation	4.3 EC, WDG	4.3	NA	2	NA	14		10		

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Crop/Site	**Residential**	**Agricultural**	**Forestry**	**Timing; Application Type**	**Method/ Equipment**	**Maximum Single Application Rate by Formulation[1] (lb a.i./A)**	**Maximum Application Rate**		**Maximum Application Number**		**PHI (days)[3]**	**REI (hours)[3]**	**MRI (days)[3]**	**Geographic Restrictions**	**Comments**
							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
				Total		**4.3**	**12.6**	**NA**	**6**	**NA**	**14**	**24**	**10**		Considers multiple type of applications (*e.g.*, dormant, foliar broadcast, and orchard floor) but excluding nursery For nursery applications (See general "Fruits" listing)
PEPPER		✓		Foliar	Ground broadcast	1.0 WDG	[8] NS	8.0	[8] NS	8	7	24	10	Permitted in Florida	FL040005; 1 crop cycle per year.
PINEAPPLE		✓		Post plant	Ground boom, broadcast	2.0 EC	6.0	6.0	3	NA	365	24	30	Permitted in Hawaii	HI090001 SNL Expires: March 29, 2014. Do not make applications beyond three months after planting.
PLUM/ PRUNE		✓		**dormant/ delayed dormant**; broadcast	Aircraft, airblast	2.0 EC, WDG	2.0	NA	1	NA	NA	24/ 4d	10		

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							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
		✓		foliar; **trunk spray/drench**	handheld, backpack, drench/dip, handgun, and low-pressure hand wand	2.5 3.0/100 gal WDG	2.5	NA	1	NA	NA		10		
				Total		**2.5**	**4.5**	NA	2	NA					Excludes nursery applications (See general "Fruits" listing)
POULTRY LITTER		✓		When needed, animal bedding/litter treatment.	Sprayer	0.07126 a.i./1000 sq ft 3.1 ME	NS	NA	NS	NA	NA		NS		53883-264, 84575-3
PUMPKIN		✓		Preplant Seed treatment	Seed treatment	0.3 0.00058 lb /lb seed WP	[0.3] NS	[1] NS	[1] NS	1	NS	NS	NS	California maximum single rate 0.000625 lb a.i./lb.	There is a range of potential application rates depending on the number of seeds per lb and the number of seeds planted per acre. Seeding information provide by BEAD.[4]

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							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
RADISH		✓		Foliar	Broadcast ground	1.0 EC	NS	1	NS	1	NS	24	NS	permitted in Oregon	OR090012 on radish grown for seed. Label valid until December 31, 2012. (per registrant SLN still valid)
		✓		Preplant	Soil incorporation ground	3.0 EC	12.0	3	4	1	NS	NS	10		
		✓		At plant/post-plant	In furrow drench/ treatment	3.0 EC 2.8 G	[15.0] NS	3	[5] NS	1	30, EC, 7, G	24	10		Only one granular application permitted.
				Total		**3.0**	**[22.0] NS**	**2**	**[9] NS**						Only one preplant or at plant application is assumed.
RIGHTS OF WAY, ROAD MEDIANS				When needed, soil broadcast	Granular or low-pressure wand	1.0 EC, G, Bait	[2.0] NS	NA	2	NA	NA	NS	7		Apply when needed
RUTABAGA		✓		Preplant	Chemigation, Groundboom	2.4 EC, WDG	[4.8] NS	2.4	[2] NS	1	30	24	10		
					Aerial	2.0 EC, WDG		2.0							Updated to reflect spray drift mitigation.

Table A.5. Summary of Current Chlorpyrifos Usage															
Crop/Site	**Residential**	**Agricultural**	**Forestry**	**Timing; Application Type**	**Method/ Equipment**	**Maximum Single Application Rate by Formulation[1] (lb a.i./A)**	**Maximum Application Rate**		**Maximum Application Number**		**PHI (days)[3]**	**REI (hours)[3]**	**MRI (days)[3]**	**Geographic Restrictions**	**Comments**
							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
		✓		At plant/post-plant	In furrow drench/ treatment	2.4 EC, G WDG	4.8	2.4	[2] NS	1	7	24	10	Disallowed in California and Arizona.	Two crop cycles per year
				Total		**2.4**	**[9.6] NS**	**4.8**	**[4] NS**	**2**		**24**	**10**		
SEWER MANHOLE COVERS AND WALLS				When needed	Low pressure	0.31 lb/manhole RTU	NS	NA	NS	NA	NA	NA	NS		3 pints product/ manhole
SEED ORCHARD TREES		✓		**foliar**; broadcast	Ground boom	1.0 EC	3.0	3.0	NS	NA	30	24	7		62719-575, 62719-615
		✓			High volume sprayer	2.5 0.01 a.i./tree 0.02 EC	2.5	NS	[1] NS	NA	30	24	7		Cone worm treatment (62719-575 and 62719-615) Treatment of 1000 trees per acre would results in a single application rate of 10 lb a.i./a. DAS: 1000 is a bit high, typically for orchards 312 trees per acre
		✓		foliar; **stump treatment**	backpack, drencher, low	0.3 EC	0.3	1.0	NS	NA	30	24	7		62719-575, 62719-615

Table A.5. Summary of Current Chlorpyrifos Usage															
Crop/Site	**Residential**	**Agricultural**	**Forestry**	**Timing; Application Type**	**Method/ Equipment**	**Maximum Single Application Rate by Formulation[1] (lb a.i./A)**	**Maximum Application Rate**		**Maximum Application Number**		**PHI (days)[3]**	**REI (hours)[3]**	**MRI (days)[3]**	**Geographic Restrictions**	**Comments**
							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
					pressure hand wand,										
				Total		**1.0**	**5.8**	**3**	**NS**	**NA**	**30**	**24**	**7**		The total number of applications assumed is either three foliar applications or two foliar applications with one stump treatment.
SORGHUM GRAIN		✓		Seed Treatment	Seed treatment	[0.0009] 0.01-0.0024 lb ai/ 100 lbs seed EC	0.01	0.01	[1] NS	1	NA	NS	NS		264-932
		✓		Preplant Soil Directed	Ground Spreader/T Band	1.5 G	1.5	1.5	[1] NS	1	60	24	10		
		✓		Foliar/Post emergent	Ground, Aerial, Chemigation	1.0 EC, WDG	1.5	[1.5] NS	[1] NS	3	30	24	10		PHI varies across labels
				Total		**3.3 G 1.0 EC, WDG**	**3.01**	**3.01**	**[3] CBD**	**3**	30	24	10		One crop cycle per year.
SOYBEAN		✓		foliar , post-emergence soil broadcast	broadcast ground, aerial, chemigation	1.0 EC, WDG	3.0	3.0	3	3	28	24	14		One crop cycle per year.

Table A.5. Summary of Current Chlorpyrifos Usage															
Crop/Site	**Residential**	**Agricultural**	**Forestry**	**Timing; Application Type**	**Method/ Equipment**	**Maximum Single Application Rate by Formulation[1] (lb a.i./A)**	**Maximum Application Rate**		**Maximum Application Number**		**PHI (days)[3]**	**REI (hours)[3]**	**MRI (days)[3]**	**Geographic Restrictions**	**Comments**
							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
		✓		At plant/post plant treatment; soil band	ground boom	2.2 G 1.0 EC	3.0	3.0	1 (G), 3 (EC)	1 (G), 3 (EC)	28	24	10		
				Total		**1.0 EC, WDG 2.2 G**	**3.0**	**3.0**	**3**	**3**					One crop cycle per year.
STRAW-BERRIES		✓		Pre-plant	Aerial or ground/ broadcast	2.0 EC	2.0	**NS**	1	NS	NA	24	10	No use in Mississippi	33658-26
		✓		Foliar	Aerial or ground/ broadcast, foliar spray	1.0 EC, WDG	2.0	**NS**	2	**NS**	21	24	10		Two applications (2 lb ai) for all products per cc.
		✓		Post-harvest	Ground directed spray	1.0 EC, WDG	2.0	**NS**	2	**NS**	21		14		
				Total		**2.0**	**4.0**		**3**						One preplant application and two foliar and/or postharvest application permitted per year.
SUNFLOWER		✓		At plant	Aerial/ground	2.0 G	3.0	3.0	[1] NS	1	42	24	10		Per registrant 1 cc per year

Table A.5. Summary of Current Chlorpyrifos Usage															
Crop/Site	**Residential**	**Agricultural**	**Forestry**	**Timing; Application Type**	**Method/ Equipment**	**Maximum Single Application Rate by Formulation[1] (lb a.i./A)**	**Maximum Application Rate**		**Maximum Application Number**		**PHI (days)[3]**	**REI (hours)[3]**	**MRI (days)[3]**	**Geographic Restrictions**	**Comments**
							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
		✓		Preplant		2.0 EC, WDG	3.0	3.0	[1] NS	1	42		10		2 inches min incorporation
		✓		Post emergent or foliar		1.5 EC, WDG	3.0	3.0	[2] NS	2	42		10		
				Total		**2.0**	**5.0**	**5.0**	**3**	**3**					Assumed either an at plant or preplant application followed with two foliar applications. One crop cycle per year
SWEET POTATO		✓		Preplant, soil broadcast	Aircraft, ground boom	2.1 G, EC, WDG	2.1	NS	1	1	125	24		LA090002, MS080007, NC090001 permits 60 PHI	
					Aircraft	2.0 G, EC, WDG									Updated to reflect spray drift mitigation.
TOBACCO		✓		Preplant	Aircraft, ground boom	2.0 EC, G, WDG	2.0	NS	1	1	7	24	NA		
TRITICALE		✓		Storage Commercial Slurry Seed Treatment	Seed treatment	0.003 0.0024 lb ai/ 100 lbs seed EC	[0.003] NS	[1] NS	[1] NS	[1] NS	NA	[10] NS	[10] NS		264-932 Seeding information provide by BEAD.[4] One crop cycle per year.

Table A.5. Summary of Current Chlorpyrifos Usage															
Crop/Site	**Residential**	**Agricultural**	**Forestry**	**Timing; Application Type**	**Method/ Equipment**	**Maximum Single Application Rate by Formulation[1] (lb a.i./A)**	**Maximum Application Rate**		**Maximum Application Number**		**PHI (days)[3]**	**REI (hours)[3]**	**MRI (days)[3]**	**Geographic Restrictions**	**Comments**
							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
TURNIP		✓		Preplant	soil incorporation/ ground boom, handgun	2.3 G, WDG	[4.6] NS	2.3	[2] NS	1	30	24	10		Minimum incorporation: 2 inches.
		✓		Post plant	Soil incorporation/ ground boom, handgun	2.3 G, WDGP	[4.6] NS	2.3	[2] NS	1	30	24	10		Minimum incorporation: 2 inches.
				Total		**2.3**	**4.6**	**2.3**	**2**	**1**	**30**	**24**	**10**		Assumed either a preplant or post plant application. Two crop cycles per year
UTILITIES For use in and around telecommunications, power, utilities and railroad systems equipment: Buried cables, cable television pedestals, cables, pad-mounted electric power transformers, telephone cables, underground				When needed, broadcast	Product container	190.5 G 0.44 lb ai./100 sq ft (see comments)	NS	NS	NS	NS	NS	NS	NS		Applications permitted as needed. Reg. Nos. 13283-14, 13283-17 Broadcast product onto the ground covering the area of the pad location, plus a two-foot perimeter around the outside of the pad location.

Table A.5. Summary of Current Chlorpyrifos Usage															
Crop/Site	**Residential**	**Agricultural**	**Forestry**	**Timing; Application Type**	**Method/ Equipment**	**Maximum Single Application Rate by Formulation[1] (lb a.i./A)**	**Maximum Application Rate**		**Maximum Application Number**		**PHI (days)[3]**	**REI (hours)[3]**	**MRI (days)[3]**	**Geographic Restrictions**	**Comments**
							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
vaults, telecommunications equipment, power and utilities equipment															
WALNUTS		✓		**dormant/ delayed dormant**; broadcast	Aircraft, airblast	2.0 EC, WDG	2.0	NA	1	NA	14		10		62719-301 (12 lb a.i./A)
		✓		**foliar**; broadcast	aircraft, airblast, chemigation	2.0 EC, WDG	4.0	NA	2	NA	14	24	10		Some labels do not specify retreatment interval.
		✓		foliar; **orchard floors broadcast**	Ground boom, chemigation	4.0 EC, WDG	4.0	NA	1	NA	14		10		
				Total		**4.0**	**10.0**		**4**						Excluding nursery applications; includes dormant, foliar broadcast, and orchard floor. For nursery applications (See general "Fruits" listing)

Table A.5. Summary of Current Chlorpyrifos Usage															
Crop/Site	**Residential**	**Agricultural**	**Forestry**	**Timing; Application Type**	**Method/ Equipment**	**Maximum Single Application Rate by Formulation[1] (lb a.i./A)**	**Maximum Application Rate**		**Maximum Application Number**		**PHI (days)[3]**	**REI (hours)[3]**	**MRI (days)[3]**	**Geographic Restrictions**	**Comments**
							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
WIDE AREA/ GENERAL OUTDOOR TREATMENT For ants and other misc. pests.	✓	✓		when needed, Broadcast	Ground sprayer	0.5084 lb ai/100 gal EC	[1.02] NS	NA	2	NA	NA	NS	NS		66222-19
				when needed, Drench	Drench	1	NS	NA	NS	NA	NA		NS		228-624
						[1] 8.2 lb a.i/100 gal EC	NS	NA	NS	NA	NA		NS		228-625
				Total		[1]	NS	NA	NS	NA	NA				
WHEAT		✓		Slurry Seed Treatment	Seed treatment	0.003 0.0024 lb ai/ 100 lbs seed EC	[0.006] NS	1	[2] NS	1	NA	NA	NA	Only for use in AZ, CA, CO, ID, KS, MN, MO, NE, NM, NV, ND, OK, OR, SD, TX, UT, WA and WY	Seeding information provide by BEAD.[4]
		✓		Foliar, soil treatment	Ground, broadcast	0.5 EC	[8.0] NS	4.0	[2] NS	1	14/ 28	24	14		PHI: 14 forage or hay, 28 grain or straw
		✓		Post-emergence foliar	Ground, Aerial, Chemigation	1.0 EC	[4.0] NS	2.0	[4] NS	2	14/ 28		NS		Label states 1.0 lb ai/A for cereal leaf beetles and then state max rate 0.5 lb ai/A in restriction). Some labels restrict no more than 2 applications per crop/season PHI 14 forage or hay, 28 grain or straw

Table A.5. Summary of Current Chlorpyrifos Usage															
Crop/Site	**Residential**	**Agricultural**	**Forestry**	**Timing; Application Type**	**Method/ Equipment**	**Maximum Single Application Rate by Formulation[1] (lb a.i./A)**	**Maximum Application Rate**		**Maximum Application Number**		**PHI (days)[3]**	**REI (hours)[3]**	**MRI (days)[3]**	**Geographic Restrictions**	**Comments**
							Per Year lb a.i./A	**Per CC[2] lb a.i./A**	**Per Year**	**Per CC[2]**					
				Total		**[1] 4.0 EC**	[12.006]	**[6.003] 5.0**	[8] NS	[4] 2					MO otherwise 2.0 plus seed treatment
WOOD PROTECTION TREATMENT TO BUILDINGS/ PRODUCTS OUTDOOR				When needed, Wood surface treatment	Low pressure handwand, backback sprayer, paintbrush	16.65 lb/10,000 sq ft 0.17 lb a.i./gal EC	NS	NA	NS	NA	NS	NS	NS		
						0.08 lb ai/gal EC, RTU EC, ME	NS	NA	NS	NA	NS	NS	NS		Apply 1 gal per 100 sq ft of wood

1. EC - emulsifiable concentrate; WDG – water dispersible granular in water soluble packet; WP – wettable power in water soluble packet; B – bait (granular), G – granular; ME – microencapsulated; RTU – ready to use.
2. Reported as per crop cycle or per season
3. PHI – Preharvest interval; REI – reentry interval; MRI – Minimum retreatment interval
4. Becker, J.; Ratnayake, S. Acres Planted per Day and Seeding Rates of Crops Grown in the United States, U.S. EPA OPP/BEAD, 2011; example calculations provided below:
   Beans: 0.00058 lb a.i./lb seed / 960 seeds/lb seed x 418,176 seeds/A [pgs. 19, 81 (beans, succulent)]
   Corn: 0.000625 lb a.i./lb seed / 1,800 seeds/lb seed x 59,739 seeds/A [pgs. 24, 81 (corn, sweet)]
   Cotton: 0.00116 lb a.i./lb seed / 4,500 seeds/lb seed x 85,00 seeds/A [pgs. 13, 81]
   Cucumber: 0.00058 lb a.i./lb seed / 12,000 seeds/lb seed x 80,418 seeds/A [pgs. 25, 81]
   Peas: 0.000625 lb a.i./lb seed / 1,361 seeds/lb seed x 653,400 seeds/A [pgs. 34, 82]
   Pumpkin: 0.00058 lb a.i./lb seed / 1,600 seeds/lb seed x 7,260 seeds/A [pgs. 37, 82]
   Sorghum: 0.001 lb a.i./lb seed / 11,000 seeds/lb seed x 100,000 seeds/A [pgs. 16, 39]
   Triticale: 0.003 lb a.i./100 lb seed / 109 lb seed/A [pg.16]
   Wheat: 0.003 lb a.i./100 lb seed /116 lb seed/A [pg. 16]
   [ ] indicate assumptions that are made when the information is not specified but can be inferred

Appendix 6: Review of Human Research

This risk assessment relies in part on data from studies in which adult human subjects were intentionally exposed to a pesticide or other chemical. These data, which include studies from PHED 1.1; the AHETF database; the Outdoor Residential Exposure Task Force (ORETF) database; the ARTF database; ExpoSAC Policy 14 (SOPs for Seed Treatment); the 2012 Residential SOPs: Lawns/Turf, Outdoor Fogging/Misting Systems; registrant-submitted exposure monitoring studies MRIDs 44180401, 44301301, 44793301, 44829601, 42974501, 43062701, 44748101, 44748102, 46722701, and 46722702; and published literature studies are (1) subject to ethics review pursuant to 40 CFR 26, (2) have received that review, and (3) are compliant with applicable ethics requirements. For certain studies, the ethics review may have included review by the Human Studies Review Board. Descriptions of data sources, as well as guidance on their use, can be found at the Agency.

Appendix 7: Residential Mosquito ULV Spreadsheets

See attached spreadsheets:

- Appendix 7_1_Adult Worst Case Aerial Mosquito ULV applications.xlsx
- Appendix 7_2_Adult Best Case Aerial Mosquito ULV applications.xlsx
- Appendix 7_3_Child Worst Case Aerial Mosquito ULV applications.xlsx
- Appendix 7_4_Child Best Case Aerial Mosquito ULV applications.xlsx
- Appendix 7_5_Adult Ground Mosquito ULV applications.xlsx
- Appendix 7_6_Child Ground Mosquito ULV applications.xlsx

Appendix 8: Residential Post-Application Golfing Spreadsheet

See attached spreadsheet:

- Appendix 8_Chlorpyrifos Residential Golfer Postapp.xlsx

Appendix 9: Spray Drift Spreadsheets

See attached spreadsheets:

- Appendix 9_1_Adult Drift with MS TTR Data _ 6 lb ai through 3.xlsx
- Appendix 9_2_Adult Drift with MS TTR Data _ 2 lb ai and below.xlsx
- Appendix 9_3_Child Drift with MS TTR Data _ 6 lb ai through 3.xlsx
- Appendix 9_4_Child Drift with MS TTR Data _ 2_3 lb ai through 1_0.xlsx

Appendix 10: Occupational Handler Spreadsheets

See attached spreadsheets:

- Appendix 10_1_Chlorpyrifos Occup Handler Risk Estimates.xlsx
- Appendix 10_2_Occ Seed Treatment.xlsx

Appendix 11: Occupational Post-Application Spreadsheets

See attached spreadsheet:

- Appendix 11_Occupational Postapp.xlsx

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OFFICE OF CHEMICAL SAFETY
AND POLLUTION PREVENTION

September 15, 2020

PC Code: 059101
DP Barcode: 456426

MEMORANDUM

SUBJECT: **Chlorpyrifos:** Draft Ecological Risk Assessment for Registration Review

FROM: Colleen M. Rossmeisl, DVM, Senior Biologist
Rochelle Bohaty, PhD, Senior Chemist
Environmental Risk Branch III
Environmental Fate and Effects Division (7507P)

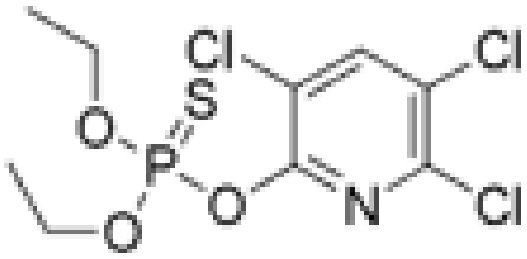
THRU: Dana Spatz, Branch Chief
Environmental Risk Branch III
Environmental Fate and Effects Division (7507P)

REVIEWED BY: Joe Milone, Ph.D., Biologist
Rosanna Louie-Juzwiak, Risk Assessment Process Leader
Environmental Risk Branch III
Environmental Fate and Effects Division (7507P)

TO: Patricia Biggio, Chemical Review Manager
Matthew Manupella, Acting Team Leader
Dana Friedman, Branch Chief
Risk Management and Implementation Branch 1
Pesticide Re-evaluation Division (7508P)

The Environmental Fate and Effects Division (EFED) has completed the streamlined draft ecological risk assessment in support of the Registration Review of the insecticide chlorpyrifos.

Draft Ecological Risk Assessment for the Registration Review of Chlorpyrifos



Chlorpyrifos

Chlorpyrifos; CAS No 2921-88-2
USEPA PC Code: 059101

Prepared by:
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United States Environmental Protection Agency

September 15, 2020

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1 Overview

Chlorpyrifos is an organophosphate used as an insecticide on a wide variety of terrestrial food and feed crops, terrestrial non-food crops, greenhouse food/non-food, and non-agricultural indoor and outdoor sites. Based on an Office of Pesticide Programs Information Network (OPPIN) query (conducted September 2020) there are currently 112 active product labels (76 Section 3s and 36 Special Local Needs), which include formulated products and technical grade chlorpyrifos. Chlorpyrifos can be applied in a liquid, granular, or encapsulated form or as a cattle ear tag or seed treatment. Aerial and ground application methods (including broadcast, soil incorporation, orchard airblast, and chemigation) are allowed.

Chlorpyrifos is currently registered on a variety of agricultural use sites, including: agricultural farm premises (such as, barns, empty chicken houses, dairy areas, calving pens), poultry litter, cattle (impregnated collars/ear tags), alfalfa, orchards [including, almonds, apple, cherries, citrus, figs, filberts, non-bearing fruit and nuts (nursery), grapes, nectarine, peach, pear, pecan, plum/prune, seed orchard trees, and walnut], asparagus, beans, beets (grown for seed), sugar beets, carrots (grown for seed), clover (grown for seed), cole crops, corn (all), cotton, cranberry, cucumber, ginseng (medicinal), grass (forage/fodder/hay), legumes, mint, nursery stock, peanut, peas, pepper, pineapple, pumpkin, radish, rutabaga, sod farms, onions, sorghum, soybean, strawberry, sunflower, sweet potato, tobacco, triticale, turnip, wheat, and tree plantations [including, Christmas trees, nursery plantations (conifer and deciduous trees), reforestation programs, conifers, and hybrid cottonwood/poplar].

Chlorpyrifos is also currently registered for use on a variety of non-agricultural use sites, including: commercial/institutional/industrial (indoor and outdoor – *e.g.*, warehouses, food processing plants, ship holds, railroad cars), golf course turf, greenhouse, households (indoor), mosquito control (outdoor), nonagricultural buildings (outdoor – *e.g.*, fences, construction foundations, dumps), ornamental plants, ornamental lawns, rights-of-way (including road medians), sewer manhole covers and walls, utilities (*e.g.*, power lines, railroad systems, telecommunication equipment), wide area general outdoor use (*e.g.*, for ants and other misc. pests), and wood protection treatment (for outdoor building products).

Registered labels for liquid formulations require 25-foot (ground boom and chemigation), 50-foot (orchard airblast), or 150-foot (aerial) no-spray buffer zones adjacent to waterbodies.

Several assessments for chlorpyrifos have been completed in recent years, including the Biological Evaluation for Endangered Species in 2017 (USEPA, 2017; hereafter referred to as biological evaluation), the 2016 Drinking Water Assessment (USEPA, 2016; hereafter referred to as 2016 DWA) and the concurrently completed 2020 Draft Drinking Water Assessment (USEPA, 2020; hereafter referred to as 2020 DWA). This streamlined DRA draws on available data and analysis from these assessments, particularly the biological evaluation, which includes extensive characterization of chlorpyrifos fate and toxicity data. The purpose of this DRA is to describe the

ecological risks posed by the current uses of chlorpyrifos in the context of FIFRA, by providing a range of screening level risk quotients (RQs).

2 Risk Conclusions Summary

Potential risks of concern were identified for mammals, birds, fish and terrestrial/freshwater invertebrates based on RQs. Citrus and tart cherries are associated with some of the highest RQs, but RQs exceed the level of concern (LOC) for all uses assessed for all taxa.

- Mammals
    - Acute RQs range up to 10, with half of the uses assessed resulting in RQs above 5
    - Chronic RQs range up to 625 (reproduction) and 1900 (growth), with 50% of uses resulting in RQs over 147 and 450, respectively
    - Chronic endpoints are based on reduced body weight and 30% loss of pups in litter
- Birds
    - Acute RQs range up to 380, with half of the uses assessed resulting in RQs above 95
    - Chronic RQs range up to 58, with 50% of uses resulting in RQs over 14
- Fish
    - Maximum acute and chronic RQs of 160 and 135, respectively
    - Half of all uses resulted in acute and chronic RQs above 32 and 20, respectively

- Terrestrial and aquatic invertebrates
    - Maximum acute RQs are 4300 and 4900, respectively, with 50% of all uses having RQs over 820 and 880, respectively.
    - Chronic aquatic RQs range up to 8600 with over 50% of uses assessed resulting in RQs above 1540.
    - No tier I chronic bee data available

In addition to LOC exceedances, ecological incidents have been reported for all taxa, and include notable incidents (*e.g.,* significant fish kills, large number of bird deaths, bee kills). Although no RQs exceeded the LOC for plants, there were also reported incidents involving plants.

3 Environmental Fate and Exposure Summary

3.1 Environmental Fate Properties

Chlorpyrifos will initially enter the environment via direct application (*e.g.*, liquid spray and granular) to use sites (*e.g.*, soil, foliage, seed treatments, urban surfaces). It may move off-site via spray drift, volatilization (primarily following foliar applications), and runoff (generally by soil erosion rather than dissolution in runoff water). Major routes of chlorpyrifos transformation in

the environment include alkaline hydrolysis, photolysis in air, and soil and aquatic metabolism (both aerobic and anaerobic). Chlorpyrifos is known to form chlorpyrifos-oxon, 3,5,6-trichloro-2-pyridinol (TCP), and 3,5,6-trichloro-2-methoxypyridine (TMP). The impact of chlorpyrifos-oxon, TCP and TMP were considered qualitatively in the biological evaluation, largely based on uncertainty regarding their formation in the environment. This assessment focuses primarily on anticipated ecological risks from parent chlorpyrifos. Further discussion on the consideration of residues of concern and the fate of chlorpyrifos is found in the biological evaluation, the 2016 DWA and the 2020 DWA.

3.2 Environmental Exposure Modeling and Results

3.2.1 Use Rates Modeled and Input Parameters

In general, current single maximum chlorpyrifos application rates do not exceed 4 lb a.i./A nationwide; however, single application rates greater than 4 lb a.i./A are currently permitted for some specific use patterns. Aerial applications are not permitted at rates higher than 2.0 lb a.i./ except for treatment of Asian citrus psyllid (citrus use).

For the purpose of this streamlined assessment, modeling for both the terrestrial and aquatic environment were based on an evaluation of uses assessed both in the biological evaluation and the 2016 and 2020 DWAs. Although all chlorpyrifos uses were not modeled for this assessment, the uses evaluated provide a comprehensive evaluation (or cover the range) of the pertinent rates and types of applications, thereby providing coverage of the anticipated RQs and ecological risks associated with chlorpyrifos uses as labeled and any agreed upon changes to these labels from the registrants. While the current labels may not reflect all the agreed upon changes, the registrants have agreed (in the form of a commitment letter) to update the chlorpyrifos labels to be reflective of these changes (see biological evaluation for further information). **Table 3-1** and **Table 3-2** summarize the uses, and application rates and methods, evaluated for this assessment.

For terrestrial modeling, application rates were modeled that were representative of the use rates for groups of uses or crops (i.e., by use data layer, as defined in the biological evaluation) as provided in the biological evaluation. **Table 1** shows the use groups modeled and the application rates, number of applications and the retreatment interval used to represent that group based on maximum label rates.

Table 3-1. Use data layer (UDL) groups, application rates and methods evaluated for terrestrial exposure (all modeled as foliar spray)

Use Data Layer (UDL) grouping	Maximum single application rate (lb a.i./A)	Number of applications	Retreatment interval (days)
Corn	1.5	2	10
Cotton	2.2	1	NA
Orchards and Vineyards	6	1	NA
Other Crops	3.76	2	3

Other Grains	1	1	NA
Other Row Crops	2	2	30
Pasture	1	4	10
Soybeans	1	3	14
Vegetables and Ground Fruit	3	3	30
Wheat	1	2	7
Developed	1	26	7
Managed Forests	1	6	7
Nurseries	4	1	NA
Open Space Developed	1	3	7
Right of Way	1	2	7
Christmas Trees	1	6	7
Golf courses	1	2	7
Wide Area Use	1	26	7

For aquatic exposure estimates, the modeling focused on those crops that provide a comprehensive national coverage of EECs. These crops still generally covered the same groups included in terrestrial modeling but focus on crops within these groups. **Table 3-2** provides a high-level summary of the aquatic exposure modeling. Additional details including scenarios and application dates and the batch input utilized in modeling are provided in **Appendix A**.

Table 3-2. Summary of use site, UDL groups, application rates and methods evaluated for aquatic exposure[1]

Use Site	UDL Grouping	Maximum single application rate[1]	Maximum number of applications[1]
corn	Corn	1.61	5
alfalfa	Pasture/hay/forage	1	4
almonds	Orchards and Vineyards	4	5
apples	Orchards and Vineyards	2	2
asparagus	Vegetables and ground fruit	1	3
beets	Other row crops	1.88	1
carrots	Vegetables and ground fruit	0.94	1
cauliflower	Vegetables and ground fruit	2.25	4
Christmas trees	Christmas Trees	1	4
citrus	Orchards and Vineyards	6	5
clover	Other crops	1.9	1
cole crops	Vegetables and ground fruit	2	6
cotton	Cotton	2.23	2

figs	Orchards and Vineyards	1	1
filbert	Orchards and Vineyards	2	4
ginseng	Vegetables and ground fruit	2	1
golf courses	Golf courses	1	2
grapes	Orchards and Vineyards	2.25	1
grapes3	Orchards and Vineyards	1	4
legumes	Vegetables and ground fruit	1	1
mint	Vegetables and ground fruit	2	2
nectarine	Orchards and Vineyards	3	2
nursery	Nurseries	4	1
onion	Vegetables and ground fruit	1	2
peach	Orchards and Vineyards	3	3
peanuts	Other row crops	2	2
pear	Orchards and Vineyards	2	2
pecans	Orchards and Vineyards	4.3	4
peppers	Vegetables and ground fruit	1	8
plums	Orchards and Vineyards	2	2
radishes	Vegetables and ground fruit	3	4
rutabaga	Vegetables and ground fruit	3	5
sorghum	Other grains	1	4
soybeans	Soybeans	2.23	2
strawberry	Vegetables and ground fruit	1	2
sugar beets	Other row crops	1	3
sunflower	Other row crops	2	3
sweet cherries	Orchards and Vineyards	2.5	2
sweet potatoes	Vegetables and ground fruit	2	1
tart cherries	Orchards and Vineyards	2	5
tobacco	Other row crops	2	1
turnips	Vegetables and ground fruit	2.3	2
walnuts	Orchards and Vineyards	4	4
wheat	Wheat	1	3

[1] Some applications modeled included variable rates for multiple applications. Rate listed in table is maximum application rate used in modeling. See **Appendix A** for more details on aquatic modeling runs, including application dates modeled.

Summaries of the environmental fate input parameters used in the PWC modeling of chlorpyrifos are presented in **Table 3-3** below.

Table 3-3. Input parameters used for aquatic modeling

Parameter (units)	Value	Source	Comments
Organic-carbon Normalized Soil-water Partitioning Coefficient (K_{OC} (L/kg-$_{OC}$))	6040	Acc. # 260794	The mean K_{oc} value (K_{oc} values = 7300, 5860 and 4960 mL/g_{OC}) is used for modeling.
Water Column Metabolism Half-life or Aerobic Aquatic Metabolism Half-life (days) 25 ˚C	91.2	MRID 44083401	Only one half-life value is available, so this value (30.4 days) is multiplied by 3 to get 91.2 days. This half-life value was not corrected for hydrolysis.
Benthic Metabolism Half-life or Anaerobic Aquatic Metabolism Half-life (days), 25^{o}C	202.7	MRID 00025619	The 90th percentile confidence bound on the mean chlorpyrifos half-life value determined following the NAFTA kinetics guidance is 87.6 + [(3.078 x 52.9)/√2)] = 202.7 days.
Aqueous Photolysis Half-life at pH 7 (days) and 40° Latitude, 25 °C	29.6	MRID 41747206	
Hydrolysis Half-life (days)	0	MRIDs 00155577 (Acc. # 260794) and 40840901	Since the aerobic aquatic metabolism half-life value was not corrected for hydrolysis, it is possible that hydrolysis would be double counted in the model simulation. Therefore, hydrolysis is set to 0 (stable) here as it is already accounted for in the aerobic aquatic metabolism study and input parameter.
Soil Half-life or Aerobic Soil Metabolism Half-life (days), 25 °C	170.6	Acc. # 241547 and MRID 42144911	Half-life values of 19, 36.7, 31.1, 33.4, 156, 297, 193, and 185 days are obtained from empirical data following the NAFTA kinetics guidance. The 90th percentile confidence bound on the mean chlorpyrifos half-life value is 118.9 + [(1.415 x 103.3)/√8)] = 170.6 days.
Molecular Weight (g/mol)	350.57	product chemistry	
Vapor Pressure (Torr) at 25 °C	1.87 x 10^{-5}	product chemistry BC 2062713	
Solubility in Water at 25 °C (mg/L)	1.4	MRID 41829006	The water solubility of chlorpyrifos is reported to be between 0.5-2.0 mg/L for temperatures between 20 – 25 °C. Based on data submitted to EPA, 1.4 mg/L was used in modeling.
Foliar Half-life (days)	0	Default value	
Application Efficiency	0.99 (ground; air-blast) 0.95 (aerial)	Default Values	
Application Drift	0.009 (ground) 0.008 (air blast) 0.039 (air)	AgDRIFT modeling based on label restrictions	Labels contain aquatic buffer distances of 25, 50 and 150 ft for ground, airblast and aerial applications.

Drift fractions used in this assessment for liquid formulation are presented in **Table 3-4.** Spray drift estimates consider the currently labeled buffer restrictions [25 ft. (ground), 50 ft. (air-

blast), and 150 ft. (aerial)] for aquatic water bodies included on all agricultural chlorpyrifos labels. No spray drift is assumed for granular applications.

Table 3-4. Chlorpyrifos Spray Drift Estimates for Liquid Formulations Used in PWC

Spray Drift Fraction (unitless) Application Method and Buffer		
Ground	**Air-blast**	**Aerial**
25 ft	**50 ft**	**150 ft**
0.008	0.009	0.039

3.2.2 Exposure modeling results

Various models are used to calculate aquatic and terrestrial EECs. The specific models used in this assessment included PWC version 1.52, T-REX version 1.5.2, TerrPlant version 1.2.2 and BeeREX version 1.0[1].

EECs on terrestrial food items range from 15 to 1440 mg/kg-diet based on upper bound Kenaga values and 7 to 510 mg/kg-diet based on mean Kenaga values. Results for specific uses and taxa are found in **Appendix B**.

Aquatic exposure EECs range from 0.72 to 59 ug/L for 1-day EECs, 0.37 to 39 for 21-day EECs and 0.30 to 34 for 60-day EECs. The maximum EECs were associated with applications modeled on tart cherries. EECs are summarized below in **Table 3-5** and detailed results for uses modeled are provided in **Appendix B.**

Table 3-5. Ranges of aquatic EECs for modeled uses.

	1-day EECs	21-days EECs	60-day EECs
Minimum values	0.72	0.37	0.30
Maximum values	59	39	34
Maximum EEC Crop	Tart cherries	Tart cherries	Tart cherries
50% of all uses modeled exceed an EEC of...	12	7.1	5.5

4 Ecological Effects Summary

4.1 Ecological Effects Endpoints

Chlorpyrifos is an insecticide that acts by inhibiting cholinesterase activity, thereby preventing the natural breakdown of various cholines and ultimately causing the neuromuscular system to seize. This may lead to a series of various effects, which may culminate in death. The effects of chlorpyrifos have been studied extensively in many taxa, particularly in fish and aquatic and

[1] https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/models-pesticide-risk-assessment

terrestrial invertebrates. Studies include acute and chronic laboratory studies with either technical or formulated chlorpyrifos and include both registrant-submitted and open literature studies. A detailed description of the toxicity data available for chlorpyrifos is detailed in the biological evaluation.

One study that was not reviewed for the 2017 biological evaluation was an acute larval honeybee study. A registrant study (MRID 49960301) was submitted on the effects of chlorpyrifos to honeybee larvae after acute exposure. This study resulted in an LD_{50} of 0.0165 µg a.i./larva. This represented the most sensitive endpoint available for effects to honeybee larvae and was used as the endpoint for risk estimation in this DRA.

Table 4-1 includes a summary of the toxicological endpoints used for risk estimation in this assessment. These endpoints were extracted from ***Appendix 3.6*** *Chlorpyrifos Input Parameters for Weight of Evidence Matrices* in the biological evaluation. For all studies other than the acute honeybee larval study discussed above, additional study information can be found in the biological evaluation. Other endpoints and the large toxicological dataset available for chlorpyrifos is extensively discussed in the biological evaluation; only those endpoints used in this assessment are listed below. Where a NOAEC was not defined, a LOAEC was used as a surrogate in the analysis, but listed RQs could be higher than those reported.

Table 4-1. Toxicity endpoints used for risk estimation.

Study Type	Test Species	Toxicity Value	MRID or ECOTOX No.
Birds			
Acute Oral	Ring-Necked Pheasant *(Phasianus colchicus)* Body weight = 1133.5 g	LD_{50} = 7.95 mg a.i./kg-bw	ECOTOX No. 35499
Sub-acute dietary	Mallard Duck (*Anas platyrhynchos*)	LC_{50} = 203 mg a.i./kg-diet	MRID 40854702
Chronic	Mallard Duck (*Anas platyrhynchos*)	NOAEC = 25 LOAEC = 125 mg/kg-diet based on 83% reduction in eggs laid	MRID 0046952
Mammals			
Acute Oral	House Mouse (*Mus musculus*) Body weight = 26 g	LD_{50} = 60 mg a.i./kg-bw	ECOTOX No. 93364, Cometa *et al.* 2007
Acute Oral Dietary	Norway rat *(Rattus Norvegicus)*	LC_{50} = 1330 mg a.i./kg-diet	MRID 44585409
Chronic (growth)	Norway rat *(Rattus Norvegicus)*	NOAEL = 0.33 LOAEL = 6.99 mg a.i./kg-bw/day based on 4-5% decreased body weight	MRID 42172802
Chronic (reproduction)	Norway rat *(Rattus Norvegicu)s*	NOAEL = 1 LOAEL = 5 mg a.i./kg-bw/day based on 30% loss of pups	ECOTOX No. 82431

Study Type	Test Species	Toxicity Value	MRID or ECOTOX No.
Terrestrial Invertebrates			
Acute contact (adult)	Honey bee (*Apis mellifera L.*)	LD_{50} = 0.059 µg a.i./bee	MRID 05001991
Acute oral (adult)	Honey bee (*Apis mellifera L.*)	No data	No data
Chronic oral (adult)	Honey bee (*Apis mellifera L.*)	No data	No data
Acute oral (larval)	Honey bee (*Apis mellifera L.*)	LD_{50} = 0.0165 µg a.i./larvae	MRID 49960301
Chronic oral (larval)	Honey bee (*Apis mellifera L.*)	No data	No data
Terrestrial and Wetland Plants			
Seedling Emergence	Various species	Dicots (Lettuce): IC_{25} = 2.03 lb a.i./acre; Monocots (No effects seen): IC_{25} >5.79 lb a.i./acre	MIRD 49307202
Vegetative Vigor	Various species	Dicots (No effects seen): IC_{25} >5.7 lb a.i./acre Monocots (No effects seen): IC_{25} >5.7 lb a.i./acre	MRID 48602604 MRID 49307201
Freshwater Fish			
Acute	Bluegill *(Lepomis macrochirus*)	LC_{50} = 1.7 ug a.i./L	ECOTOX No. 6797
Chronic	Fathead minnow *(Lepomis macrochirus*)	NOAEC <0.251 ug a.i./L LOAEC= 0.251 ug a.i./L based on 52% reduction in fecundity	MRID 48615505
Estuarine/Marine Fish			
Acute	Tidewater Silverside (*Menidia peninsulae*)	LC_{50} = 0.37 ug a.i./L	E11868
Chronic	Atlantic Silverside (*Menidia menidia*)	NOAEC <0.28 ug a.i./L LOAEC= 0.48 ug a.i./L based on 32% reduction in bodyweight	Goodman et al 1985; MRID 154718
Freshwater Invertebrates			
Acute	Scud (Hyalella azteca)	LC_{50} = 0.0138 ug a.i./L	MRID 44345601
Chronic	Water flea (*Daphnia magna*)	NOAEC <0. 0.005 ug a.i./L LOAEC= 0.005 ug a.i./L based on ↓offspring per female (~20%)	Zalizniak et al, 2006 (E107384)

Study Type	Test Species	Toxicity Value	MRID or ECOTOX No.
Estuarine/Marine Invertebrates			
Acute	Mysid (*Americamysis bahia*)	LC_{50} = 0.035 ug a.i./L	15639 MRID 40228401
Chronic	Mysid (*Americamysis bahia*)	NOAEC <0.0046 ug a.i./L LOAEC= 0.0046 ug a.i./L based on ↓progeny at all concentrations	MRID 42664901
Aquatic Plants			
Vascular	*Pistia stratiotes* and *Lemna minor*	NOAEC =500 ug a.i./L LOAEC= 1000 ug a.i./L based on Relative growth rate (no EC_{50} available)	E155150
Non-vascular	Marine species (*Isochrysis galband*)	IC_{50} = 140 ug a.i./L IC_{10}= 37 ug a.i./L based on decreased photosynthesis	MRID 40228401

4.2 Incident Data

An extensive analysis of reported incidents was provided in the biological evaluation on chlorpyrifos, broken down into analysis by individual taxa. Some notable highlights from the assessment include:

- Chlorpyrifos has been reported as the 'probable' or 'highly probable' causative agent for 110 adverse aquatic incidents (e.g., fish kills).
- For birds, 64 incidents have been associated with a certainty index of 'possible', 'probable' or 'highly probable'
- 43 terrestrial plant incident reports with a certainty index of 'possible', 'probable' or 'highly probable'. Most of the terrestrial plant incident reports involve damage to the crop treated, but some were associated with spray drift.
- 36 terrestrial invertebrate incident reports (all for bees) in the EIIS with a certainty index of 'possible', 'probable' or 'highly probable'. All of the terrestrial invertebrate incident reports involve honeybees, with bees being exposed via spray drift or by foraging on treated plants.

An updated incident report was generated on August 14, 2020 from the Incident Data System (IDS) for the time period from January 1, 2015 (approximate date when last incident report was generated for the biological evaluation) to present. In IDS, there were 20 unique incidents reported associated with wildlife, plants or other nontarget organism. All of these incidents, except for one where the organism impacted was not specified, were associated with bee kills. In addition to these incident reports, there have also been 2 aggregate incidents reported to

the agency, one involving 'Other Non-Target' (ONT) organisms, which are generally presumed to be bees, and one involving non-specified wildlife. Only limited information is available on aggregated incidents.

5 Risk Characterization and RQ Summary Table

Based on the analysis described above, RQs for all taxa except plants exceeded the LOC for both acute and chronic risks. Terrestrial animal RQs range as high as 390 for acute effects and 1900 for chronic effects. Chronic risks in animals were generally based on significant reproductive effects in terrestrial and aquatic environments (*e.g.*, 52% reduction in fecundity, 30% loss of pups). Terrestrial invertebrate acute RQs range as high as 4900. For aquatic animals and invertebrates, RQs range up to 4300 for acute effects and 8600 for chronic effects. RQs were not exceeded for terrestrial or aquatic plants. **Table 5-1** below describes the range of RQs and for chronic RQs, the effects associated with each RQ. These RQs are consistent with previous assessments, including the Reregistration Eligibility Decisions (RED), and are consistent with the known toxicity of chlorpyrifos as an OP, having general toxicity against numerous taxa.

As described above, numerous incidents have also been reported for chlorpyrifos, Chlorpyrifos has been reported with incidents related to various wildlife, including fish and birds, sometimes with a high certainty level that chlorpyrifos was the associated causative agent. Incidents were additionally reported involving plants. The recent incident updated incident report conducted for this assessment generally reported incidents associated with honeybees.

For terrestrial invertebrates, a complete set of Tier I data is not available for chlorpyrifos.

Table 5-1. Summary of Risk Quotients for Taxonomic Groups from Current Uses of Chlorpyrifos

Taxa	Range of Acute RQs[1]	50% of all uses have an RQ greater than...	Range of Chronic RQs[1]	50% of all uses have an RQ greater than...	Chronic endpoint based on
Birds	0.07 to **380**	**93**	0.60 to **58**	**14**	83% reduction in number of eggs laid
Mammals (Chronic RQs for both growth and reproduction endpoints provided)	0.01 to **10**	**5**	**2.01** to **1900**	**450**	4-5% decrease in body weight
			0.66 to **625**	**148**	30% loss of pups in litter
Terrestrial invertebrates[2]	**820** to **4900**	**820**	No data	No data	No data

Terrestrial Plants	<0.01 to 0.33	0.05	NA	NA	NA
Fish	0.42 to **160**	**33**	**1.1** to **135**	**52**	52% reduction in fecundity
Aquatic Invertebrates	**6.5** to **4300**	**880**	**46** to **8600**	**1540**	20% decrease in offspring per female
Aquatic Plants	0.01 to 0.42	0.09	NA	NA	NA

Level of Concern (LOC) Definitions:
Terrestrial Animals: Acute=0.5; Chronic=1.0; Terrestrial invertebrates=0.4
Aquatic Animals: Acute=0.5; Chronic=1.0
Plants: 1.0
Bold indicates RQs exceed the LOC
[1] RQs reflect exposure estimates for chlorpyrifos and maximum application rates allowed on labels. Minimum value in range of EECs for terrestrial animals represents minimum application rate and minimum dietary item EEC
[2] RQs for terrestrial invertebrates are applicable to honey bees, which are also a surrogate for other species of bees. Risks to other terrestrial invertebrates (*e.g.*, earthworms, beneficial arthropods) are only characterized when toxicity data are available.

6 REFERENCES

USEPA, 2016. *Chlorpyrifos Refined Drinking Water Assessment for Registration Review*. Office of Pesticide Programs. U.S. Environmental Agency, April 14, 2016. DP 432921.

USEPA, 2017. *Chlorpyrifos Biological Evaluation for Endangered Species*. Office of Pesticide Programs. U.S. Environmental Agency, January 2017.

USEPA, 2020. *Updated Chlorpyrifos Refined Drinking Water Assessment for Registration Review*. Office of Pesticide Programs. U.S. Environmental Agency, September 15, 2020. DP 459269.

7 APPENDICES

Appendix A Aquatic modeling parameters

Appendix A Chlorpyrifos aquatic (SEE ATTACHED)

Use	Scenario	Maximum Application Rate (lb/A)	Number of applications[1]	Application method
alfalfa	TXalfalfaOP	1.00	4	aerial
almonds	CAalmond_WirrigSTD	4.00	5	ground
apples	PAappleSTD_V2	2.00	2	ground
apples	NCappleSTD	1.50	2	ground
apples	ORappleSTD	2.00	1	ground
asparagus	MIAsparagusSTD	1.00	3	aerial
beets	ORsnbeansSTD	1.88	1	ground
carrot	ORsnbeansSTD	0.94	1	aerial
cauliflower	MImelonStd	2.25	4	ground
cauliflower	CAColeCropRLF_V2	2.25	4	ground
christmas_trees	ORXmasTreeSTD	1.00	4	ground
christmas_trees	NCappleSTD	1.00	4	ground
christmas_trees	PAappleSTD_V2	1.00	4	ground
tartcherries	MICherriesSTD	2.00	5	ground
citrus	FLcitrusSTD	4.00	5	ground
citrus	CAcitrus_WirrigSTD	6.00	5	ground
clover	CAalfalfa_WirrigOP	1.90	1	ground
colecrop	FLcabbageSTD	1.00	6	aerial
colecrop	CAColeCropRLF_V2	2.00	6	ground
corn	KSCornStd	1.61	5	ground
cotton	NCcottonSTD	2.23	2	granular
figs	CAalmond_WirrigSTD	1.00	1	ground
filbert	ORfilbertsSTD	2.00	4	aerial
ginseng	MImelonStd	2.00	1	granular
golfcourse	PAturfSTD	1.00	2	ground
golfcourse	FLturfSTD	1.00	2	ground
golfcourse	CATurfRLF	1.00	2	ground
grapes	NYGrapesSTD	2.25	1	ground
grapes3	CAgrapes_WirrigSTD	1.00	4	ground
legume	MSsoybeanSTD	1.00	1	aerial

mint	ORmintSTD	2.00	2	ground
nectarine	PAappleSTD_V2	3.00	2	ground
nectarine	CAalmond_WirrigSTD	3.00	2	ground
nursery2	FLnurserySTD_V2	4.00	1	ground
nursery2	CAnurserySTD_V2	4.00	1	ground
onion	GAOnion_WirrigSTD	1.00	1	ground
onion	IDNpotato_WirrigSTD	1.00	2	ground
peach	GAPeachesSTD	2.50	3	ground
peach	PAappleSTD_V2	3.00	2	ground
peach	ORfilbertsSTD	3.00	2	ground
peanut	NCpeanutSTD	2.00	2	aerial
pear	ORfilbertsSTD	2.00	2	ground
pear	CAalmond_WirrigSTD	2.00	2	ground
pecan	GAPecansSTD	4.30	4	ground
pepper	FLpeppersSTD	1.00	8	ground
sorghum	KSsorghumSTD	1.00	4	aerial
strawberry	CAStrawberry-noplasticRLF_V2	1.00	2	aerial
strawberry	FLstrawberry_WirrigSTD	1.00	2	aerial
sugarbeet	MNsugarbeetSTD	1.00	3	aerial
Sunflower	NDwheatSTD	2.00	3	aerial
wheat	NDwheatSTD	0.00	3	granular
soybean	MSsoybeanSTD	2.23	2	granular
sweetcherries	PAappleSTD_V2	2.50	2	ground
sweetcherries	ORfilbertsSTD	2.50	2	ground
sweetpotato	NCSweetPotatoSTD	2.00	1	aerial
tobacco	NCtobaccoSTD	2.00	1	aerial
walnut	CAalmond_WirrigSTD	4.00	4	ground
plum	CAalmond_WirrigSTD	2.00	2	aerial
turnip	NCSweetPotatoSTD	2.30	2	ground
rutabaga	CAColeCropRLF_V2	3.00	5	granular
radish	CAColeCropRLF_V2	3.00	4	granular

Appendix B Details of aquatic and terrestrial output, summary tables for EECs and RQs

Aquatic results

Appendix B Aquatic exposure concentrat

(SEE ATTACHED)

Terrestrial results

Appendix B Terrestrial output ta

(SEE ATTACHED)