XII. VINYL-ASBESTOS FLOOR TILE

A. Product Description

Vinyl-asbestos floor tiles are manufactured from polyvinyl chloride polymers or copolymers and are usually produced in squares 12 inches by 12 inches. They are commonly sold in thicknesses of 1/16, 3/32, and 1/8 of an inch.

The exact composition of vinyl-asbestos floor tile varies by manufacturer. Typical ranges for the percentage of each constituent are:

- asbestos : 5-25 percent,
- binder : 15-20 percent,
- limestone : 53-73 percent,
- plasticizer: 5 percent,
- stabilizer : 1-2 percent, and
- pigment : 0.5-5 percent.

Although each company has its own specific process for manufacturing vinyl-asbestos floor tile, the basic steps are very similar. Raw asbestos fiber, pigment, and filler are mixed dry to form a cohesive mass to which liquid constituents are added if required. Although the mixture is exothermic (it generates heat during mixing), it may need to be heated further in order to reach a temperature of at least 300°F at which point it is fed into a two-roll mil where it is pressed into a slab or desired thickness. The slab is then passed through calenders, machines with rollers, where it acquires a uniform finished thickness (Krusell and Cogley 1982). Embossing, pigmenting, and other surface decoration is done while the material is still soft. The tile is then cooled using one of three processes: immersion in water, spraying with water, or placing in a refrigeration unit. In order to minimize shrinkage after cutting, the tile is allowed to air cool before it is cut into squares and waxed (Krusell and Cogley 1982).

Vinyl-asbestos floor tile can be used in commercial, residential, and institutional buildings. It is often used in heavy traffic areas such as supermarkets, department stores, commercial plants, kitchens, and "pivot points" -- entry ways and areas around elevators. The tile is also suitable for radiant-heated floors as long as temperatures do not exceed 100°F. The tile may be installed on concrete, prepared wood floors, or old tile floors (Floor Covering Weekly 1980).

B. Producers and Importers of Vinyl-Asbestos Floor Tile

There were six primary processors of this asbestos product in 1981: Amtico Division of American Biltrite, Armstrong World Industries, Azrock Industries, Congoleum Corp., Kentile Floors, Inc., and Tarkett, Inc. (TSCA 1982a). There were no secondary processors of vinyl-asbestos floor tile, and a survey of importers failed to identify any importers of vinyl-asbestos floor tile (TSCA 1982b, ICF 1984). All six primary processors have stopped using asbestos since that time. Tarkett, Inc. and Azrock Industries were the first companies to eliminate the use of asbestos in vinyl floor tiles. Armstrong World Industries had eliminated asbestos by the end of 1983, and Congoleum Corp. had eliminated it in 1984. Amtico Division of American Biltrite phased out asbestos in 1985, and Kentile Floors, Inc. phased out the use of asbestos in 1986. Because none of the other respondents to our survey indicated that they had begun production of vinyl-asbestos floor tile or were aware of any other producers or importers of vinyl-asbestos floor tile, we have concluded that there are currently no domestic producers or consumers of this product (ICF 1986).

C. Trends

1981 production of vinyl-asbestos floor tile was 58,352,864 square yards. In 1985, only one company was still processing asbestos in order to make floor tile and its production was 18,300,000 square yards. This represents a decline of almost 70 percent. In addition, Kentile Floors phased out asbestos use in 1986 and current production of vinyl-asbestos floor tiles is 0.

D. Substitutes

The use of asbestos in the production of vinyl composition floor tile conferred a number of advantages to consumers in its end use as well as to producers in its manufacturing process. Asbestos fiber imparted the following properties in its use in floor tile: abrasion and indentation resistance, dimensional stability, durability, flexibility, and resistance to moisture, heat, oil, grease, acids, and alkalis. The heat resistance and dimensional stability of asbestos are important in the manufacturing process. The ability to withstand high temperature prevents possible cracking. Dimensional stability prevents shrinkage or expansion during production and helps manufacturers meet their tolerance limits.

The major substitute for vinyl-asbestos floor tile is asbestos-free vinyl composition tile. Manufacturers have reformulated their mixtures using a combination of synthetic fibers, fillers, binders, resins, and glass. The binders and fillers include limestone, clay, and talc. The fiber substitutes include fiberglass, polyester, Pulpex(R), Santoweb WB(R), and Microfibers(R). The substitutes for asbestos in vinyl floor tiles and their characteristics are summarized in Table 1.

Fiberglass floor tile is produced by many manufacturers and has many of the same properties as asbestos fiber. It is used in floor tile primarily for its dimensional stability under wet conditions. Since fiberglass does not absorb moisture, the tile is prevented from shrinking. In addition, fiberglass is heat resistant and can withstand temperatures as high as 800°F without softening (Krusell and Cogley 1982).

Polyester fiber is produced by many manufacturers. When it is used in combination with other binders and fillers, it is able to achieve many of the

Table 1. Substitutes for Asbestos in Vinyl Floor Tile

Product	Manufacturer	Advantages	Disadvantages	References
Asbestos	None	Heat resistance during manufacture. Indentation resistance. Flexibility. Abrasion resistance. Moisture resistance. Chemical resistance. Fungal resistance. Dimensional stability.	Environmental and occupational health problems.	Krusell and Cogley (1982) ICF (1986)
Pulpex(R) (Polyolefin Pulp)	Hercules, Inc. Wilmington, DE	Dimensional stability. Moisture resistance. Rot resistance.	Low tensile strength. Low heat resistance.	Hercules (1986)
Santoweb WB(R) (Hardwood Fiber)	Monsanto Corp. St. Louis, MO	Impact resistance. Heat resistance.	Absorbs water when large amounts are used.	Monsanto (1986)
Microfibers(R) (Polyester and Cellulose Fibers)	Microfibers, Inc. Pawtucket, RI	Dimensional stability. Thickening properties.		Microfibers (1986)
Fiberglass	Many	Dimensional stability Moisture resistance. Rot resistance.	Lower strength. More brittle.	Krusell and Cogley (1982)
Polyester	Many	Dimensional stability. Moisture resistance.	Less flexible. Subject to bacterial attack.	Krusell and Cogley (1982)

characteristics of asbestos. The major drawbacks are that the tiles are less flexible and that the tiles are subject to bacterial attack (Krusell and Cogley 1982).

Pulpex(R) is a fibrillated polyolefin pulp made by Hercules, Inc. It also has many of the same characteristics as asbestos when used in combination with other fillers and binders, but it cannot be used at extremely high temperatures. Pulpex(R) has been commercially available in the U.S. since 1981. Although its primary use in the U.S. has been in flooring felt, it has been used in vinyl tile as an asbestos substitute in Europe (Hercules 1986).

Santoweb WB(R) is a hardwood fiber and has been on the market for 10 years. It is produced by Monsanto Corporation. Its major strengths are its high impact resistance and its high heat resistance. It can withstand temperatures of at least 300°F during calendaring. In addition, it is less brittle than fiberglass and more cost-effective than chopped polyester. The Santoweb WB(R) composition of floor tile is ideally 1.5 percent and the upper limit is 2.5 percent beyond which the floor tile will absorb too much water (Monsanto 1986).

Microfibers(R) are reinforcing fibers which consist of a combination of polyester, cotton, nylon, and cellulose fibers. Microfibers(R) are made by the Microfibers Corporation. Their primary advantages are their dimensional stability as well as their ability to serve as a thickener (Microfibers 1986).

Several non-asbestos blends use larger amounts of resins, binders, and fillers in place of asbestos. One producer of asbestos-free vinyl composition tile uses increased amounts of limestone and resin. These new vinyl composition tiles appear to share many of the qualities of vinyl-asbestos floor tile, but they have three drawbacks. They do not wear as well, they have reduced dimensional stability, and they are more expensive to produce (ICF 1986).

In addition to the new vinyl composition tiles being produced, substitutes for vinyl-asbestos floor tile include solid vinyl tile, rubber tile, ceramic tile, linoleum, wood, and carpet. However, these floor coverings lack many of the qualities of vinyl-asbestos floor tile. For example, solid vinyl is not as abrasion resistant as vinyl-asbestos tile and has a low resistance to solvent-based cleaning materials. Rubber tile is also susceptible to deterioration from certain cleaning compounds, is not grease resistant, and is more difficult to maintain. Carpet is less durable in most uses, and it is more difficult to keep clean. In addition to these drawbacks, all these substitutes are more expensive than vinyl-asbestos floor tile.

On the whole, vinyl composition tiles are the best substitute for vinyl-asbestos tiles in terms of prices and performance. Distributors claim that consumers of vinyl composition tile are almost never concerned about whether or not asbestos fibers are used. They believe that the most important considerations in choosing vinyl tile are color, style, and price and that there have been no difficulties in switching from vinyl-asbestos floor tile to vinyl composition tile (John Ligon, Inc. 1986, H&M Tile & Linoleum Co. 1986).

E. Summary

Asbestos fiber was used in the production of vinyl floor tiles because it imparted the following characteristics to the tile: abrasion and indentation resistance, dimensional stability, flexibility, and resistance to moisture, heat, oil, grease, acids, and alkalis. However, producers have been able to generate these characteristics by reformulating their mixtures using a combination of synthetic fibers, fillers, binders, resin, and glass. (A more complete description is not possible because floor tile producers consider these formulations to be proprietary.) This reformulation appears to have been successful because there are currently no domestic processors of vinyl-asbestos floor tile.

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XIII. ASBESTOS DIAPHRAGMS

Asbestos Diaphragms are employed in the chlor-alkali industry for the production of chlorine and other primary products such as caustic soda. There are presently three types of electrolytic cells in commercial use: asbestos diaphragm cells, mercury cells, and membrane cells (Kirk-Othmer 1985). All electrolytic cells operate on the same principle -- an electric current decomposes a solution of brine into (1) chlorine, liberated at the anode (positive electrode) and (2) caustic soda and hydrogen, liberated at the cathode (negative electrode). The ratio of chlorine to caustic soda produced during the process is 1:1.1 by weight (Chemical Week 1982). Most of the chlorine produced in the United States is made using electrolytic cells (Kirk-Othmer 1985).

Asbestos diaphragm and mercury cells account for over 90 percent of domestic chlorine production; electrolytic cells using asbestos diaphragms accounted for 76.7 percent of the chlorine production capacity as of January 1, 1986, while mercury cell technology accounted for 16.5 percent (Chlorine Institute 1986b). In the past few years, a new technology, known as membrane cell technology, has been developed to replace diaphragm cells in the chlorine production process. As reported by the Chlorine Institute, membrane cell technology accounted for 2.4 percent of the total chlorine production capacity as of January 1, 1986 (Chlorine Institute 1986b).

In Sections A, B, and C of this paper, each of the cell technologies is discussed individually; Section D compares some salient characteristics of the three technologies, while Section E discusses market trends for the chorine production industry.

A. Asbestos Diaphragm Technology

In this chlor-alkali production process, an asbestos diaphragm is used to physically separate chlorine produced at the anode from caustic soda and hydrogen produced at the cathode; the diaphragm thus, acts as a mechanical barrier between the two chambers (Kirk-Othmer 1985).

Diaphragm cells are especially appropriate where salt (the raw material for chlorine production) is present at the plant site in underground formation. The salt can be solution-mined[1] with water, treated, and sent to the chlorine cells for decomposition into chlorine and caustic soda (Chlorine Institute 1986a). The diaphragm material is critical to the proper operation of a diaphragm cell and some of the properties that are necessary for proper cell operation are as follows (Chlorine Institute 1986a):

- sufficient mechanical strength;
- high chemical resistance to acids and alkalies;
- optimum electrical energy efficiency;
- easy to deposit on the cathode with uniform thickness and without voids;
- appropriate physical structure to permit percolation of depleted brine with minimum back-migration; and
- acceptable service life.

Asbestos is uniquely qualified as a diaphragm material, exhibiting the most favorable combination of these properties (Chlorine Institute 1986a). This has resulted in widespread use of asbestos made diaphragms throughout the chlorine production industry.

Asbestos diaphragms are prepared at the chlorine plant site itself and are not available as pre-manufactured products ready for use. In the diaphragm forming process, a slurry of asbestos in water is drawn through a screen or perforated plate by vacuum techniques. Asbestos fibers are deposited on the screen, or plate, forming a paper-like mat approximately an eighth of an inch

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[1] Water is pumped into the salt mine, a salt solution is then pumped out.

thick (Coats 1983). This asbestos-coated screen is used as the cathode in electrolytic cells. In the past twenty years, many advances have been made in the design of asbestos diaphragms and in the design of the cell itself. These have included the introduction of dimensionally stable metal anodes[2] as a replacement for graphite anodes and the development of the modified asbestos (resin bound) diaphragms which consist of chrysotile and polymeric powders of fibers stabilized at high temperatures before use (Chlorine Institute 1986a). Today, the majority of U.S. diaphragm cells utilize modified asbestos diaphragms and have metal anodes; they consume 2,300 KWH of power per ton of chlorine produced (Chlorine Institute 1986a, Chemical Week 1982).

The surface area of the diaphragm is quite large, ranging from approximately 200 to 1,000 square feet for a cell with a volume of 64 to 275 cu ft (Coats 1983). Each diaphragm may use 60 to 200 pounds of asbestos fiber and have a service life of three months to over one year (three months for plants where graphite anodes are still in use; 6 to 15 months for plants using resin bound asbestos diaphragms) (Chlorine Institute 1986b). Using modified asbestos diaphragm technology, production of 1000 tons of chlorine and co-products requires about 250 pounds or 0.125 ton of asbestos (Chlorine Institute 1986b). The only major disadvantage of using asbestos diaphragm cells is the weak concentration of the caustic soda produced by the cell (usually about 10 percent by weight) because of the permeability of the cell to both brine and water (Chemical Week 1981). This necessitates further processing for concentrating the caustic to the industry standard, typically 50 percent, using multiple-effect evaporators and large amounts of steam. Removing the excess salt involves crystallization and, possibly, ammonia extraction, both of which add to the cost of production (Chemical Week 1982).

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[2] Dimensionally stable anodes consist of a coating of ruthenium dioxide and titanium applied to an expanded titanium metal base (Kirk-Othmer 1983).

1. Producers of Asbestos Diaphragms

Asbestos diaphragms are not marketed; the chlorine producers purchase asbestos fiber and manufacture and install the diaphragm themselves. Table 1 provides a list of chlorine manufacturers (SRI 1984, Verbanic 1985). In 1985, 28 manufacturers were operating 57 chlorine plants in 26 states throughout the U.S. with an estimated total annual capacity of 13.2 million tons (Chlorine Institute 1986b), a reduction from previous years when annual capacity had reached almost 15 million tons (Verbanic 1985). The largest of these chlorine producers was Dow Chemical, with a combined annual capacity of 3,750,000 tons, approximately 28.5 percent of the total U.S. chlor-alkali capacity followed by PPG Industries and Diamond Shamrock, each accounting for about 10 percent of the chlorine production capacity (Verbanic 1985). Chlorine production and asbestos fiber consumption information for the period 1983-1985 is presented in Table 2. Based on this information, about 975 metric tons of asbestos fibers were estimated to have been consumed by the chlorine industry in the production of approximately 10 million tons of chlorine during 1985. According to a separate estimate given by the Chlorine Institute, 900 metric tons of asbestos had been consumed during this period.

2. Substitutes for Asbestos Diaphragms

No other substance has been found to be suitable for replacing asbestos diaphragms in electrolytic cells. This has resulted in the development of alternative cell technologies that require either the building of new chlorine plants or the retrofitting of existing plants. Among the new technologies, the most significant one that is steadily gaining acceptance in the U.S. is the membrane cell technology (Chemical Business 1985).

Table 1. Producers of Chlorine

Company[a]	Plant	Remarks
AMAX Inc. AMAX Specialty Metals Corp, Subsidiary Magnesium Division	Rowley, Utah	
Brunswick Pulp and Paper Company Brunswick Chemical Company, Division	Brunswick, GA	
Champion International Corporation Wood Chemicals and Associated Products Division	Caston, NC	
Diamond Shamrock Corporation Diamond Shamrock Chemicals Company	Battleground, TX	
Chlor-Alkali Division	Deer Park, TX	
	Delaware City, DE	
	La Porte, TX	
	Mobile, AL	
	Muscle Shoals, AL	146,000 tons/annum mercury-cell plant switching to membrane cells of the company's own design.[c]
Dow Chemical U.S.A.	Oyster Creek, TX	Combined capacity is 4,100,000. 2,000 tons/day on standby.[b]
	Pittsburg, CA	
	Plaquemine, LA	
	Freeport, TX	456,250 tons/annum of chlorine capacity has been shutdown -- about 10% of Dow's chlorine capacity on the Gulf Coast.[e]
E.I. duPont de Nemours & Co., Inc. Chemicals and Pigment Department	Niagara Falls, NY	
Petrochemicals Department Freon Products Division	Corpus Christi, TX	
FMC Corp., Industrial Chemical Group	South Charleston, WV	To close end of 1985.[b]
Formosa Plastics Corporation, U.S.A.	Baton Rouge, LA	
Fort Howard Paper Company	Green Bay, WI	
	Muskogee, OK	Membrane cell technology.
General Electric Company Plastics Business Operations	Mount Vernon, IN	
Georgia-Pacific Company Chemical Division	Bellingham, WA	
Georgia-Gulf Corporation	Plaquemine, LA	

Table 1 (Continued)

Company[a]	Plant	Remarks
The B.F. Goodrich Company	Clavert City, KY	Plant for sale.[b]
Convent Chemical Corporation, Subsidiary	Convent, LA	
Kaiser Aluminum and Chemical Corporation	Gramercy, LA	
Kaiser Industrial Chemicals Division		
LCP Chemicals and Plastics, Inc.	Acme, NC	
LCP Chemicals Divisions	Ashtabula, OH	
	Brunswick, GA	
	Linden, NJ	
	Syracuse, NY	
	Orrington, ME	
	Moundsville, WV	
Mobay Chemical Corporation	Baytown, Texas	
Inorganic Chemicals Division		
Monsanto Company	Sauget, IL	
Monsanto Industrial Chemicals Company		
Niacor	Niagara Falls, NY	Due to begin production in 1987. 50/50 joint venture between Olin and DuPont; will use membrane cell technology.[b]
Occidental Petroleum Corporation		
Occidental Chemical Corporation, Subsidiary		
Hooker Industrial and Specialty Chemicals	Niagara Falls, NY	
	Taft, LA	Membrane cell unit of 146,000 tons on stream in 1986.[b]
	Tacoma, WA	Includes membrane cell units.[c]
Olin Corporation	August, GA	
Olins Chemicals Group	Charleston, TN	
	Niagara Falls, NY	
Oregon Metallurgical Corporation	Albany, OR	
Pennwalt Corporation		
Chemicals Group		
Inorganic Chemicals Division	Portland, OR	
	Tacoma, WA	Membrane cell technology.[b]
	Wyandotte, MI	
PPG Industries	Lake Charles, LA	
	Natrium, WV	

Table 1 (Continued)

Company[a]	Plant	Remarks
RMI Company	Ashtabula, OH	
Stauffer Chemical Company		
Chlor-Alkali Products Division	Henderson, NV	
	Le Moyne, AL	
	St. Gabriel, LA	
Titanium Metals Corporation of America		
TIMET Division	Henderson, NV	
Vertac Chemical Corporation	Vicksburg, MS	
Vulcan Materials Company		
Vulcan Chemicals, Division	Port Edward, WI Geismar, LA	Approximately 75% of caustic/chlorine is produced via the asbestos diaphragm cell process.[d]
	Wichita, KS	
	Denver City, TX	Includes 73,000 tons of membrane technology.[b]
Weyerhaeuser	Longview, WA	

Sources:

[a] SRI 1984.

[b] Verbanic C. 1985.

[c] Chemical Engineering 1976. Cell employs modified Nafion perfluorosulfonic-acid membranes which separate the anode and cathode halves in the same manner as conventional asbestos diaphragms.

[d] Vulcan Chemicals 1986.

[e] Chemical Week 1986c.

Table 2. Chlorine Production/Asbestos Fiber Consumption

(1) Year	(2) Annual Capacity (millions of tons)[b]	(3) Utilization Rate (on average)[b]	(4) Production (millions of tons)[b] (2 x 3)	(5) Percentage of Production Using Asbestos A Diaphragms	(6) Consumption of Asbestos Fiber (tons)
1981	14.8	72%	10.7	75.0	1,004
1985	13.2	77%	10.2	76.7	977

Sources:

[a] Chlorine Institute 1986b.

[b] Chemical Week 1985 (February 1).

[c] Coats V. 1983.

B. Membrane Cells

Although diaphragms and membranes each serve a similar function of physically separating the two electrodes in an electrolytic cell, the mechanisms by which they operate are entirely different. In the diaphragm cell, brine flows through the asbestos diaphragm at a carefully controlled rate such that no back flow of hydroxyl ions occurs. In the membrane cell, a cation exchange membrane is used instead of a diaphragm, utilizing solid salt as opposed to brine. The cation exchange membrane permits the passage of sodium ions into the cathode compartment, but rejects the passage of chloride ions. Chlorine is formed on the anode side; hydrogen and caustic soda are formed on the cathode side. Because the membrane is very thin, some chloride or hydroxyl ion transfer occurs; however, pure water may be added to the cathode compartment to maintain a constant sodium hydroxide concentration (Kirk-Othmer 1985). As a result, membrane cells can produce caustic soda of high concentration (30-35 percent) with a low salt content (0.02-0.2 percent).

The most prominent advantages offered by the membrane cell technology are the reduced energy consumption, improved product quality, less frequent cell maintenance, and increased flexibility in plant operation (Chemical Marketing Reporter 1983). Worldwide, there are 70 plants that have opted for membrane technology, more than half of them being in Japan (Chemical Week 1986a). Outside Japan, the membrane process has been installed in 5 plants in the United States, 7 in Europe, 4 in Latin America, and 20 in other parts of the world (Chemical Week 1986a). Membrane cell technology is offered by firms such as Diamond Shamrock and Hooker Chemical, Japan's Asahi Chemical, Asahi Glass, and Tokuyama Soda, and Italy's Oronzio de Nora (Chemical Week 1981). Dow Chemical may now be added to this list. In July, 1986, Dow joined Italy's Oronzio de Nora in a new 50-50 joint venture to license technology and equipment. They will operate globally under the name, Oronzio de Nora

Technologies (Chemical Week 1986a).

The first large-scale membrane cell installation in the U.S. came on stream in late 1983 at a 73,000 ton/year facility of Vulcan Chemicals Division at Wichita, Kansas (Verbanic 1985). Other membrane facilities are presently being created either through retrofits of existing asbestos diaphragm cells to accept an ion-exchange membrane or through conversions (cell replacement) which require replacement of the diaphragm cells with membrane electrolyzers. Both retrofits and conversions require additions and modifications to existing ancillary equipment. Conversions have been occurring in the U.S. for several years but no commercial retrofits have been attempted in the U.S. to date.

It has been found that retrofits are not only costly but do not achieve the energy savings that total cell replacement (conversion) provides. Moreover, in some cases retrofitting is not even an option due to either the incompatibility of the available salt source and the available membrane materials, or the complexity of the diaphragm cell geometry. The cost of conversion varies widely, depending on cell size and type. An April 1986 Chlorine Institute survey of diaphragm cell producer members projected the membrane replacement cost of the current total chlorine production capacity of the industry to be $2.1 billion (1986 dollars) -- or about $75,600 per daily ton (Chlorine Institute 1986b).

Table 3 provides a list of manufacturers employing the membrane cell technology. Those facilities presently on stream have chlorine production capability from 12 to 400 tons/day each, for a combined capacity of less than 900 tons/day or approximately 328,000 tons per annum -- less than 2.5 percent of the total industry capacity (Chlorine Institute 1986b). By 1987 another 366,000 tons are expected to be added (i.e. Occidental, Niacor), creating a

Table 3. Chlorine Producers Using Membrane Cell Technology

Company	Plant Location	Annual Capacity (metric tons/ year)	Year Due on Stream
Fort Howard Paper Company[a]	Muskogee, OK	N/A[c]	N/A
P&G Paper Products Co.[a]	Green Bay, WI	N/A	N/A
Vulcan Chemicals Division[a]	Wichita, KS	73,000	1983
Pennwalt Corporation[a]	Tacoma, WA	91,000	1985
Occidental Chemical Corp.[a]	Taft, LA	146,000	1986
Niacor[b]	Niagara Falls, NY	220,000	1987

Source: [a] Chemical Week 1986a.
[b] Verbanic 1985.
[c] N.A. -- Not Available.

projected total annual capacity of approximately 542,000 tons/year employing membrane technology.

The cost of the high performance membrane materials which are being used in the newer cell installations are estimated to be in the order of 60 to 75 dollars per square foot of surface area (Coats 1983). Some cells may use membranes with an area of less than 10 square feet, while others may use membranes of over 50 square feet. Associated costs, such as installation and regasketing, are not well known due to the limited number of plants presently operating with the membrane cell technology (Chlorine Institute 1986b). However, the labor required to make a membrane for retrofit purposes is substantially greater than that required to prepare an asbestos diaphragm. In addition, the cost of making shaped membranes, necessary for optimal power efficiency for retrofit purposes, adds significantly to the cost (PPG Industries 1986).

Although the service life of a membrane cell is generally estimated at about 2 years (Chlorine Institute 1986b), it is possible to routinely achieve a three-year membrane life (Chemical Week 1986a). At typical operating conditions, about 85 tons of chlorine would be produced per square meter of membrane during a 2 year membrane life (Chlorine Institute 1986b).

C. Mercury Cells

Mercury cell technology involves a chemical process to separate the chlorine from the caustic soda and hydrogen as opposed to the physical processes of the diaphragm and membrane cells. The mercury cell process involves two subcells: (1) the brine (electrolyzer) subcell, and (2) the denuder or soda (decomposer) subcell.

The cathode in the mercury cell is a thin layer of mercury which is in contact with the brine. Closely spaced above the cathode is the anode. The anode is a suspended, horizontal assembly of blocks of graphite or dimensionally stable (titanium-base) anodes (Kirk-Othmer 1983). Purified, saturated brine containing approximately 25.5 percent by weight sodium chloride is decomposed as it passes between the cathode and anode in the primary brine cell. Chlorine gas is liberated at the anode and is then discharged to the purification process while sodium metal is liberated at the cathode. A low concentration amalgam, containing 0.25-0.5 percent by weight of sodium, is formed in the mercury cell (Kirk-Othmer 1985).

A second reaction is carried out in a separate device, the denuder subcell, where the dilute amalgam is fed and then reacted with water. The dilute amalgam is converted directly into 50 or 73 percent caustic that contains very little salt. A significant amount of electricity is involved in this reaction (Kirk-Othmer 1985).

Mercury cells must operate with solid salt in order to maintain a water balance. Unique to the operation of mercury cells is the total salt resaturation which occurs after the brine has passed through the primary brine subcell. At this point, a portion (or in some cases, all) of the depleted brine is dechlorinated, resaturated with solid salt, and returned to the cell-brine feed (Kirk-Othmer 1983).

Many of the mercury cells presently in operation have been in service for at least 20 years. During that period, some cell modifications have been made including the substitution of metal anodes for graphite anodes. Due to the wide difference in cell design, chlorine produced per mercury cell could vary from 1 ton/day to 7 or 8 tons/day. In addition, energy consumption varies. Total energy consumption using the mercury cell process could be less than that for using the diaphragm cell production process; while, in many cases, the disparity between technologies could be little or none (Chlorine Institute 1986b).

Mercury cells once accounted for a major part of the world's chlor-alkali capacity. However, in recent years, this technology has been steadily replaced by the asbestos diaphragm cell due primarily to the environmental and industrial hygiene concerns associated with mercury. The first major industrialized country to complete the process switchover was Japan, having eliminated the use of mercury cells in chlor-alkali production in 1986 (Chemical Week 1986b). In the United States, only 16.5 percent of chlorine is produced using mercury cell technology. No new mercury cell construction has occurred in the United States since 1970, and none is likely to in the future (Chlorine Institute 1986b).

D. Comparison of the Three Cells' Characteristics

The three cell technologies (asbestos diaphragm, membrane and mercury) each have distinct price, performance, and market characteristics as indicated in Table 4.

1. Cost of Cell Technology

Diaphragm cell technology is the most used technology for chlorine production in the United States, accounting for 76.7 percent of U.S.installed chlorine production capacity (Chlorine Institute 1986b). There are many different sizes and designs of asbestos diaphragm cells presently used in the industry. Hence, the costs of an asbestos diaphragm varies considerably, ranging from $250 to $2,000. Actual asbestos cost may represent only 10 to 20 percent of the total diaphragm replacement cost (Chlorine Institute 1986b). Other costs associated with the diaphragm include the cost of resin binders and the labor involved for removal and reinstallation of the cell (Chlorine Institute 1986b).

The membrane cell, which accounts for 2.4 percent of the present U.S. chlorine capacity, have estimated costs in the area of $60 to $75 per square foot (Chlorine Institute 1986b). Cells may use membranes with an area of less than 10 square feet, while others may use membranes of over 50 square feet.

Table 4. Comparison of Electrolytic Cell Technologies

	Asbestos Diaphragm	Membrane Cell	Mercury Cell
Price			
o Purchase Cost[j]	\$250-\$2,000[a]	\$600-\$3,750[b]	Not Available
o Other[j]	Other costs include cost of resin binders; labor removal and reinstallation of cell[a]	Associated costs of installation, regasketing, etc. not well known	Not Available
Performance			
o Service Life[j]	3 months to 15 months	2 years	20 years or more[d]
o Energy consumption[k] (KWH/metric ton of chlorinated produced)	2,800-3,000 (average) 2,300 (Best Available Technology)[c]	2,100-2,300[c]	2,900 (average)
o Purity of caustic soda[g] produced (alkali)	10-15% caustic, 1.0-1.2% salt content	30-35% caustic, 0.02-0.2% salt content	50% caustic with low salt content
Market Share[j]	76.7%	2.4%	16.5%

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[a] The cost of asbestos for a diaphragm could range from \$50-\$250; actual asbestos cost may account for only 10-20 percent of the total diaphragm replacement cost (Chlorine Institute 1986b). The surface area of the diaphragm ranges from approximately 200 to 1,000 sq ft for a cell with a volume of 64 to 275 cu ft (Coats 1983).

[b] Some cells use membranes with an area of less than 10 square feet, while others use membranes of over 50 square feet.

[c] 20-30 percent less energy than mercury cell or asbestos diaphragm technology.

[d] During this 20 year period some cell modifications have been made (i.e., substitution of metal anodes for graphite anodes).

[e] N/A = Not Available.

[f] Rizzo 1983 (August).

[g] Chemical Week 1981 (May 27).

[h] Chemical Week 1982 (November 17).

[i] Chemical Week 1984 (February 1).

[j] Chlorine Institute 1986b.

[k] Verbanic 1985.

Hence, the purchase cost of materials for membrane cells may range from $600 to $3,750. Since only a few U.S. plants are operating with membrane cells, the associated costs of installation, regasketing, etc. are not well known (Chlorine Institute 1986b). However, the labor costs involved in making a membrane for retrofitting purposes is significantly more expensive than that required for preparing an asbestos diaphragm.

The mercury cell accounts for 16.5 percent of the U.S. chlorine production capacity; however, it is steadily being replaced by both the membrane cell and the asbestos diaphragm cell technologies. Price information for the mercury cell is not available.

2. Useful Service Life

The life of a membrane cell is about two years, while an asbestos diaphragm is expected to last from three to 15 months. The modified (resin bound) asbestos diaphragm, which is most often employed in chlorine plants, lasts 6 to 15 months (Chlorine Institute 1986b).

Most of the mercury cells in operation today have been in service for 20 years or more, although during this period some cell modifications have been made such as the replacement of metal anodes for graphite anodes (Chlorine Institute 1986b).

3. Energy Consumption

In comparing the three cell technologies in terms of energy consumption, the membrane cell is generally the lowest consumer at 2,100 to 2,300 KWH per metric ton of chlorine produced (Verbanic 1985). In some instances total energy consumption via the mercury cell route may be less than that for the diaphragm cell, but typically, the disparity is marginal. On average, both technologies consume 2,800 to 3,000 KWH per metric ton of chlorine (Verbanic 1985).

4. Purity of Product

Lastly, a primary advantage the membrane cell has over the asbestos diaphragm is the quality of caustic soda produced. Membrane cells produce a stronger caustic solution, 30 to 35 percent, compared to the diaphragm's 10 to 15 percent (Chemical Week 1981). The caustic soda product produced via the mercury cell is more pure than that produced via the asbestos diaphragm cell.

E. Market Trends for the Chlorine Industry

Slow growth and overcapacity have characterized the industry since the early 1970s (Verbanic 1985). During these years of increasing environmental awareness, chlorine growth slowed to only 2 to 3 percent per year (Verbanic 1985). With the imposition of new regulations on several end-use markets (e.g., chlorinated pesticides and solvents, chlorofluorocarbons as aerosol propellants, etc.), demand for chlorine was reduced by several million tons by mid-1970 (Verbanic 1985). However, this drastic reduction in demand was not immediately recognized by producers, and installation of additional capacity continued throughout the 1970s. Consequently, operating rates in the chlor-alkali industry have been low since 1974, remaining below the 80 percent level except for 1979, when the high of 84 percent was achieved (Verbanic 1985). Operating rates have been improving for the industry as the economy has recovered from the 1982 recession (Verbanic 1985). Estimates for 1985 capacity utilization rates have been as high as 84 percent, while most estimates have remained in the area of 75-80 percent (Verbanic 1985). One source forecasts the 1986 average operating rate to be 87 percent, a definite gain over the 1985 average (Chemical Week 1985). The recent improvement stems from both a reduction in annual production capacity of more than 1 million tons and the departure by several well-known producers from the chlor-alkali industry (Verbanic 1985). Since 1980, some 23 chlor-alkali production facilities have been completely or partially closed, involving about 2,740,000 tons of annual production capacity (Chlorine Institute 1986a).

The chlor-alkali business is now a slow-growing, mature business with a long-term growth trend of 1.5 percent (Verbanic 1985). However, general gains may be expected in the 1986 chlor-alkali market, stemming from a 2 to 3 percent boost in industrial and chemical demand and a relative 8 percent decline in the trade-weighted value of the dollar, increasing the demand for chlorine products overseas (Chemical Week 1985).

As a result of slow-growth in demand, few, if any, new chlor-alkali plants are expected to open in the U.S. Rather than building new plants, existing firms are switching over from asbestos diaphragm and mercury cells to membrane cell technology because of the many advantages the membrane technology offers. The future of membrane cell technology in the chlor-alkali industry seems certain; it's not a question of whether U.S. producers will switch to membranes, but when and where (Chemical Week 1984).

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XIV. ASBESTOS-CEMENT PIPE AND FITTINGS

A. Product Description

This 1988 report on asbestos-cement pipe has been updated from the 1986 report to account for the increased acceptance of polyvinyl chloride (PVC) pipe over the past two years. Sussex Plastics Engineering was hired to conduct a survey of the present status of standards for plastic pipe products suitable to replacing asbestos-cement pipe in potable water and sewer applications. This survey was intended to update the information of the Malcolm Pirnie (1983) report because plastic pipe standards have been extended to larger diameters and new products have been developed since 1986 (Sussex Plastics Engineering 1988a).

Asbestos-cement pipe is made of a mixture of Portland cement (42 to 53 percent by weight), asbestos fibers (15 to 25 percent by weight), and silica (34 to 40 percent by weight). These materials are combined with water and processed into a pliable mass that is wound around a steel cylinder and then compressed and cut into 10 or 13-foot lengths. The product then goes through a curing process, known as autoclaving, that involves immersion in water or pressurized steam to enhance corrosion resistance to high sulfate soils and waters. Cured pipes then undergo a finishing process that includes machining the ends and, optionally, lining the pipe with gilsonite coatings, asphalt-based coatings, or other coatings to protect the pipe from acidic or corrosive fluids (ICF 1985).

According to the Bureau of Mines, approximately 18 percent of the total asbestos fiber consumed in the U.S., or 30,871, tons was used in the production of asbestos-cement pipe in 1985 (Bureau of Mines 1986a, Bureau of Mines 1986b). Applications for asbestos-cement pipe may be divided into pressure pipe (water mains) and non-pressure pipe (sewer line) applications. The pressure pipe applications include conveyance of potable water, force main sewers, industrial process lines, and industrial fire protection systems (Association of Asbestos Cement Pipe Producers 1986b). Non-pressure pipe applications include use in storm drain pipes and sewer pipes, although these uses constitute only a small portion of present asbestos-cement pipe production. Asbestos-cement pipe is especially widespread throughout the Southeast, Mountain, and Pacific regions (Association of Asbestos Cement Pipe Producers 1986b).

Approximately 22 million linear feet, or 4,167 miles, of asbestos-cement pipe are installed annually in the U.S. (Association of Asbestos Cement Pipe Producers 1986a). As of 1986 it is roughly estimated that 400,000 miles of asbestos-cement pipe have been installed in the U.S., over 325,000 miles of which is asbestos-cement water pipe (Association of Asbestos Cement Pipe Producers 1986b; American Waterworks Association 1986). A small but unknown amount of asbestos-cement pipe is also used as conduits for electrical and telephone cables and for laterals from street mains to consumers (Krusell and Cogley 1982).

Asbestos-cement pipe comes in a variety of diameters, formulations, and weights designed for different applications. In the past, diameters ranged from 4 inches through 42 inches, however, current production of asbestos-cement pipe larger than 24 inches in diameter was not reported by any domestic manufacturer (Certain-Teed 1986c, JM Manufacturing 1986a, Capco 1986a, Capco 1986b). Standard lengths are 10 and 13 feet. Among the many factors that are important in selecting pipe for pressure (water mains) and non-pressure applications (sewer mains) the major ones are:

- Fluid conveyed;
- Flow capacity;
- Depth of cover/external loads;
- Soil characteristics;
- Flexibility;
- Bedding requirements; and
- Connections.

Other factors used in selecting pipe include cost, availability, useful life, and the experience of the engineer, contractor, or utility director (Malcolm Pirnie 1983).[1]

For the purpose of this discussion, the enormously complex asbestos-cement pipe market has been divided into 10 submarkets which are shown in Table 1. (These asbestos-cement submarkets were originally derived by Malcolm Pirnie (1983). Table 1 also shows, in addition to the 10 submarkets, the 1981 relative market share of each asbestos-cement pipe submarket by linear foot of asbestos-cement pipe (see Attachment, Item 1).[2]

In 1981, according to Table 1, by linear feet, approximately 83 percent of the asbestos-cement pipe produced was used in pressure applications and 17 percent was used in non-pressure applications. The relative market shares by weight of pressure and non-pressure asbestos-cement pipe shipments from 1980 to 1985 are presented in Table 2. Pressure pipe has taken a larger share of the asbestos-cement pipe shipments since 1980, comprising 89 percent of all asbestos-cement pipe shipments by 1985.

B. Producers and Importers of Asbestos-Cement Pipe

The number of plants producing asbestos-cement pipe was reduced from 9 to 5 between 1981 and 1983. All of those five are still operating today (ICF 1985, ICF 1986). Plants were closed or dismantled in response to several

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[1] For a more detailed description of the significance of each factor and how asbestos-cement pipe's performance relates to it, refer to Malcolm Pirnie (1983).

[2] 1981 data is used because this is the most recent year for which production of asbestos-cement pipe in each of the 10 submarkets chosen by Malcolm Pirnie (1983) are available. Note that in 1981 there were 5 additional submarkets of pipe >24" in diameter, one for each of the two operating pressure classes and one for each of the three depth of cover classes. Since asbestos-cement pipe is no longer produced over 24" in diameter these 5 submarkets have been deleted. Thus, the markets shares shown in Table 1 are derived only for asbestos-cement pipe 24" in diameter based upon 1981 production in each of the 10 submarkets (see Attachment, Item 1 and Malcolm Pirnie 1983).

Table 1. Asbestos-Cement Pipe Submarkets in the United States

Asbestos-Cement Pipe Application	Specifications	Share of Asbestos-Cement Pipe Market (by linear feet) Consumed in 1981
Pressure Flow Water Pipe	0-150 psi, 4"-12" diameter	59.52
Pressure Flow Water Pipe	>150 psi, 4"-12" diameter	5.33
Pressure Flow Water Pipe	0-150 psi, 12"-24" diameter	16.39
Pressure Flow Water Pipe	>150 psi, 12"-24" diameter	1.72
Total Pressure	82.96	
Non-Pressure Gravity Sewers	0'-8' deep, 4"-12" diameter	7.04
Non-Pressure Gravity Sewers	0'-8' deep, 12"-24" diameter	6.86
Non-Pressure Gravity Sewers	8'-16' deep, 4"-12" diameter	1.35
Non-Pressure Gravity Sewers	8'-16' deep, 12"-24" diameter	1.47
Non-Pressure Gravity Sewers	>16' deep, 4"-12" diameter	0.15
Non-Pressure Gravity Sewers	>16' deep, 12"-24" diameter	0.17
Total Non-Pressure	17.04	
Total Pressure and Non-Pressure		100.00

See Attachment, Item 1 for sources and calculations.

Table 2. Market Share of Domestic Asbestos-Cement Shipments by Weight

Year	Pressure Flow Water Pipe (percent)	Non-Pressure Flow Gravity Sewers (percent)
1980	73	27
1981	76	24
1982	85	15
1983	86	14
1984	89	11
1985	89	11

Source: Association of Asbestos Cement Pipe Producers 1986a.

factors. Among these were competition from substitute pipe (especially polyvinyl chloride), the drop in sewer system construction since EPA grant cutbacks in 1978, and the drop in housing starts in prior years (U.S. Industrial Outlook 1983). Table 3 lists these remaining domestic producers of asbestos-cement pipe. The locations of the remaining producers confirm the fact that the asbestos-cement pipe market is primarily in the southwestern part of the nation.

All companies which produce asbestos-cement pipe also produce PVC pipe (Association of Asbestos Cement Pipe Producers 1986a). There appears to be a greater demand for pressure pipe as is shown by Certain-Teed's Riverside, CA plant which produces only pressure pipe and is currently operating at 95 percent of capacity, while Certain-Teed's Hillsboro, TX plant, which produces both pressure and non-pressure asbestos-cement pipe, is operating at only 60 percent of capacity (Industrial Minerals 1986). No importers of asbestos-cement pipe were identified, although according to the U.S. Bureau of the Census a very small amount (relative to domestic production) of pipe was imported in 1985 (see Trends) (U.S. Dep. Com. 1986).

C. Trends

Domestic asbestos-cement pipe shipments from 1980 through 1985 are presented in Table 4. As Table 4 indicates domestic asbestos-cement pipe shipments have decreased by about 42 percent since 1980, with a 78 percent decline in non-pressure pipe shipments and a smaller decline (28 percent) in pressure pipe shipments (see Attachment, Item 2). Table 5 presents 1985 production of asbestos-cement pipe and asbestos consumption. There were 216,903 tons (15,062,708 feet) of asbestos-cement pipe, valued at about $110 million, produced in 1985 (ICF 1986, Association of Asbestos Cement Pipe Producers 1986b, see Attachment, Item 10).

Table 3. Producers of Asbestos-Cement Pipe

Company	Plant	Product Lines Asbestos-Cement	PVC
Capco Inc.	Van Buren, AR	X	X
Certain-Teed Corp.	Riverside, CA Hillsboro, TX	X	X
JM Manufacturing Corp.	Stockton, CA	X	X
	Denison, TX	X	X

Table 4. Domestic asbestos-cement Pipe Shipments[a]

Year	Total Shipments (tons)	Pressure Pipe Shipments (tons)	Non-Pressure Pipe Shipments (tons)
1980	417,816	302,928	114,888
1981	346,678	265,147	81,531
1982	286,555	242,453	44,102
1983	288,671	248,863	39,808
1984	296,450	262,527	33,923
1985	243,873	218,191	25,682
Totals	1,880,043	1,540,109	339,934

[a] Association of Asbestos Cement Pipe Producers 1986a.

Table 5. 1985 Production of Asbestos-Cement Pipe

	Tons of Asbestos Consumed	Production (tons)
Total[a]	32,690.8	216,903

[a] One company refused to provide production and fiber consumption data for their asbestos-cement pipe plant (ICF 1986). Their production and fiber consumption have been estimated using a method described in Appendix A of this RIA.

Source: ICF 1986.

Imports of asbestos-cement pipe are insignificant. In 1984 they were about 4,191 tons, or equal to 1.4 percent, by weight, of domestic shipments and in 1985 they dropped to about 2,790 tons, or 1.1 percent, by weight, of domestic shipments (U.S. Dep. Comm. 1986).

The growth of the pipe industry, including asbestos-cement pipe, will be largely determined by trends in the sewer and waterworks construction industry. The value of sewer system construction, which accounts for 11 percent of the asbestos-cement pipe market in 1985, increased by about 5 percent in 1985 and is expected to increase further in 1986. In the longer term, sewer system construction may decline slightly due to less federal spending and the projected eventual leveling of housing starts at a relatively high level (U.S. Industrial Outlook 1986). Waterworks construction, accounting for about 89 percent of asbestos-cement pipe use, increased sharply in 1984 and 1985, recovering from a slump in the early 1980's. The increased level of housing starts and the record amounts of municipal bonds issued for waterworks systems were two important factors responsible for this change (U.S. Industrial Outlook 1986). For the longer term outlook, waterworks construction is predicted to be one of the fastest growing segments of public construction. Growth will come from two sources: the high level of housing starts, and the need to replace old waterworks in cities (engineers recommend that this should be done every 50 years) (U.S. Industrial Outlook 1986). The new demand in asbestos-cement pipe's largest market could have a positive impact on the demand for asbestos-cement pipe, although detailed forecasts are not available.

Potential growth in asbestos-cement pipe demand will be limited by the availability of satisfactory substitutes (discussed below). In some instances, notably PVC pipe, costs are approaching those of asbestos-cement pipe, especially large diameter pipes (ICF 1985).

D. Substitutes

As Table 1 indicates, there are many submarkets within the asbestos-cement pipe market. In reality, this exhibit provides only a broad aggregate of pipe submarkets because every site has unique characteristics in which price and performance tradeoffs among different types of pipe must be made.

For all 10 submarkets of asbestos-cement pipe, Malcolm Pirnie (1983) found two main substitutes: polyvinyl chloride (PVC) and ductile iron pipe. The major factors Malcolm Pirnie (1983) considered in determining substitutes in the non-pressure submarkets were pipe diameter, depth of cover, and soil characteristics and for pressure submarkets the major factors were pipe diameter, operating pressure, fluid characteristics and soil characteristics (Malcolm Pirnie 1983). (For a more in-depth discussion of how these substitutes were determined see Malcolm Pirnie 1983.)

The following paragraphs describe the two substitutes and discuss two other products that have already replaced asbestos-cement in the over 24 inch diameter submarkets. It should be noted that the substitutes discussed here are the ones most likely to replace asbestos-cement pipe because of their price and performance characteristics, but are not the only ones available (Malcom Pirnie 1983).

1. Polyvinyl Chloride Pipe (PVC)

PVC pipe is produced by more than 13 U.S. companies including the three producers of asbestos-cement pipe (ICF 1985). The advantages of PVC pipe include the following:

- Lightweight;
- Long laying lengths; and
- Ease of installation (Malcolm Pirnie 1983).

Industry representatives report that PVC can be joined to existing asbestos-cement pipe when repairs in water or sewer mains are required (ICF 1985). Disadvantages of PVC include:

- Subject to attack by certain organic chemicals.
- Subject to excessive deflection when improperly installed.
- Limited range of diameters are available.
- Subject to surface changes caused by long term ultra-violet exposure (Malcolm Pirnie 1983).

In addition it cannot withstand high temperatures as well as asbestos-cement pipe or some other substitutes (ICF 1985).

PVC is the most important substitute for asbestos-cement pipe because it could fill much of the asbestos-cement pipe market if asbestos were banned (American Concrete Pressure Pipe Association 1986, Industrial Minerals 1986), especially in the following applications (Malcolm Pirnie 1983):[3]

- pressure pipe, 0-150 psi, 4"-12" diameter
- pressure pipe, 0-150 psi, 12"-24" diameter
- non-pressure, 0'-16' deep, 4"-24" diameter

Thus PVC is the most probable substitute for the "small" end of the asbestos-cement pressure pipe market (small diameter pipe under low pressure), and for all diameter pipes (at relative shallow depths) in the non-pressure market. PVC has largely taken over the sewer market (Industrial Minerals 1986, Sussex Plastics Engineering 1988a and b, JM Manufacturing 1988).

2. Ductile Iron (DI) Pipe

Ductile iron pipe is manufactured by at least six companies, including the Jim Walter Corporation (the parent company of U.S. Pipe and Foundry), American Cast Iron Pipe Company, McWane Cast Iron Pipe Company, Pacific Cast

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[3] In the 1986 report, ductile iron was the pipe chosen to replace asbestos-cement in the pressure pipe, 0-150 psi, 12"-24" diameter category. Based on the updated Sussex Plastics Engineering (1988) survey of PVC pipe standards and availability, PVC is the most likely substitute for asbestos is this submarket (Sussex Plastics Engineering 1988a and b and ICF estimate).

In 1988, PVC has also taken over the 4"-12" non-pressure (sewer/gravity) pipe market and might therefore also take away the >16' deep, 4"-12" diameter market from the other major substitute, ductile iron (JM Manufacturing 1988). However, because this submarket represents only 0.15 percent of the entire asbestos-cement pipe market, it was considered insignificant and has been left as a ductile iron submarket in this analysis.

Iron Company, the Clow Company, and Atlantic States Cast Iron Company. Clow, Atlantic States, and Pacific States are all owned by McWane Cast Iron Pipe Company. U.S. Pipe and Foundry and American Cast Iron Pipe Company are the largest producers (Ductile Iron Pipe Research Association 1986b).

Ductile iron is produced by adding magnesium to molten iron and then casting the materials centrifugally to control pipe thickness. The pipe is lined with cement mortar and often encased in plastic to prevent internal and external corrosion. The pipe is usually cut into 18 or 20 foot lengths.

The major advantages of ductile iron pipe include:

- Long laying lengths;
- Not brittle;
- High internal pressure and load bearing capacity; and
- High beam and impact strength (Malcolm Pirnie 1983).

Ductile iron is very strong, can handle stress from water hammer and highway traffic, and is more flexible and less brittle than cement-based pipes. Major disadvantages of ductile iron are:

- Subject to corrosion where acids are present;
- Subject to chemical attack in corrosive soils; and
- High weight (Malcolm Pirnie 1983).

However, DI is usually lined and sometimes encased to prevent corrosion and rusting.

Ductile iron pipe is a direct competitor with asbestos-cement pipe in several submarkets, most importantly in parts of the pressure pipe (water main) submarket. In this study, DI has been chosen as the probable substitute for asbestos-cement pipe in the following submarkets (Malcolm Pirnie 1983):

- pressure pipe, >150 psi, 4"-24" diameter
- non-pressure pipe, >16' deep, 4"-24" diameter

Table 6 shows the costs of asbestos-cement pipe and its two major substitutes, PVC and ductile iron.[4] F.O.B. plant prices are based on weighted averages of several companies' prices (see Attachment, Items 4-7). Installation costs were derived from Means Guide to Building Construction Costs (1986) (see Attachment, Item 8). In 1986, industry representatives reported that the price of PVC had come down as the market for it had grown and possibly because of falling oil and natural gas prices (Industrial Minerals 1986). Since 1986, the price of PVC pipe has increased approximately 50 percent due to a temporary shortage of resin, which is one of the primary ingredients in the manufacture of PVC pipe. When the supply of resin increases, the price of PVC pipe should decline (see Attachment, Items 5a-b) (JM Manufacturing 1988, Sussex Plastics Engineering 1988a). DI is overall the most expensive substitute.

The following concrete substitutes have already replaced asbestos-cement pipe in the over 24 inch diameter submarkets; asbestos-cement pipe is no longer made in diameters greater than 24 inches.

a. Prestressed Concrete Pipe (PCP)

Prestressed concrete pipe is the most probable substitute for asbestos-cement pipe in large water mains (greater than 24" diameter). PCP is all pressure pipe. It ranges from 16 to 252 inches in diameter. It is less expensive, less brittle, and comes in longer lengths, 20 feet or longer, than asbestos-cement pipe (American Concrete Pressure Pipe Association 1986).

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[4] There is some uncertainty about the comparative installation costs of asbestos-cement and DI pipes. Estimates given by industry representatives indicated that ductile iron is sometimes more expensive to install than asbestos-cement pipe because its flexibility demands some compacting of the soil around the pipe. Yet engineers also say that DI is easier to install because it is less brittle and comes in longer lengths, normally 18 feet sections as opposed to asbestos-cement which is 10 and 13 feet (Ductile Iron Pipe Research Association 1986a).

Table 6. Cost of Asbestos-Cement Pipe and Substitutes

	Asbestos-Cement Pipe	PVC Pipe	Ductile Iron Pipe	References
FOB Plant Cost[a] ($/foot) 1986b,	6.74	6.84	10.01 McWane 1986, U.S. Pipe 1986, Atlantic Cast Iron Pipe 1986.	Certain-Teed 1986, JM Manufacturing
Installation Cost[b] ($/foot)	2.20	4.24	5.86	Means 1985.
Total Cost ($/foot)	8.94	11.08	15.87	
Operating Life[c] (years)	50	50	50	ICF 1985.
Present Value[d] ($/foot)	8.94	11.08	15.87	

[a] See Attachment, Items 4-7 for calculations.

[b] Derived from Means 1985. See Attachment, Item 8 for calculations.

[c] Operating life estimates for pipe vary from 35 to 1,000,000 years. Operating life depends on many factors, including the appropriateness of the pipe for a specific site and application. The 50 years estimated here is a reasonable estimate for the useful life of pipe (ICF 1985).

[d] Present values equal total cost because operating life is the same for asbestos-cement pipe and its substitutes.

PCP is made of sand, gravel, and cement cast into various thicknesses and lengths. Steel wire under tension is wound around the outside of the pipe core before a mortar coating is applied. The wire adds to the pipe's ability to withstand the forces of water flowing through it under pressure. Another type of concrete pipe which is very similar to PCP is pretensioned concrete pipe. It is made the same way as PCP except that a rod, as opposed to a wire, is wrapped around the pipe before the last mortar coat. This rod enables one to use less steel for the interior cylinder than for PCP (U.S. Concrete Pipe 1986). PCP and other types of concrete pipe are produced by many manufacturers who can use readily-available local materials and produce customized shapes and lengths to meet local specifications.

b. <u>Reinforced Concrete Pipe (RCP)</u>

Reinforced concrete pipe and other pipes have already substituted for asbestos-cement pipe in storm drains and sewer lines which require diameters greater than 24 inches.

RCP is made of sand, gravel, and cement reinforced with steel bars and/or welded wire mesh (ICF 1985). It differs from PCP and pretensioned concrete pipe in that RCP has steel bars or a wire cage for a core instead of a steel cylinder and it does not have a wire or rod wrapped around it before the final mortar coat. The lack of a steel cylinder core makes it more permeable than the previously mentioned concrete pipes. Therefore it is used for nuisance runoff, sewer and storm drain pipe (U.S. Concrete Pipe 1986). At large diameters, it was less expensive than asbestos-cement pipe. The price factor explains why over 60 percent of U.S. sewer lines of greater than 24" diameter are made of reinforced concrete. The second most important material used in this submarket (greater than 24" diameter) is vitrified clay pipe, which accounts for 15 percent of the in-place pipe. In 1981, asbestos-cement pipe occupied fifth place in this market, accounting for 0.5 percent of it (Krusell and Cogley 1982).

Reinforced concrete pipe is produced by many manufacturers in the United States, in contrast to asbestos-cement pipe, which is produced at only a few plants. The disappearance of asbestos-cement pipe from the market has had no noticeable impact on the submarkets in which reinforced concrete pipe already dominated.

If asbestos-cement pipe were not available, based on the 1981 submarket shares, it is estimated that by weight of asbestos-cement pipe, 91.16 percent would shift to PVC and 8.84 percent to ductile iron (see Attachment, Item 9). By linear foot, 92.63 of the previous purchasers of asbestos-cement pipe would purchase PVC and 7.37 percent would use ductile iron (see Attachment, Item 1). Table 7 presents the data for the asbestos regulatory cost model and summarizes the findings of this analysis. Data inputs for the Asbestos Regulatory Cost Model are presented in units of linear feet because prices of asbestos-cement pipe and its substitutes are only available in cost per linear foot.

E. Summary

There are two types of asbestos-cement pipe; pressure pipe which comprises 89 percent of the asbestos-cement pipe market and non-pressure pipe which comprises about 11 percent of the market (Association of Asbestos Cement Pipe Producers 1986a). Pressure pipe applications include conveyance of potable water, force main sewers, industrial process lines, and industrial fire-protection systems. Non-pressure pipe applications include use in storm drains and sewers (Association of Asbestos Cement Pipe Producers 1986b).

Three companies, with a total of five plants, are still producing asbestos-cement pipe. In 1981, there had been nine plants operating (ICF 1985, ICF 1986). From 1980 through 1985 domestic pipe shipments have declined

Table 7. Data Inputs for Asbestos Regulatory Cost Model[a]

Product	Output (ft.)	Product Asbestos Coefficient	Consumption Production Ratio	Price ($/ft.)	Useful Life	Equivalent Price ($/ft.)	Market Share	Reference
Asbestos-Cement Pipe	15,062,708	0.0022	1.0128	8.94	50 years	8.94	N/A	See Attachment
PVC Pipe	N/A	N/A	N/A	11.08	50 years	11.08	92.63%	See Attachment
Ductile Iron Pipe	N/A	N/A	N/A	15.87	50 years	15.87	7.37%	See Attachment

N/A: Not Applicable.

[a] See Attachment, Items 1, 3-8, and 10-12 for explanation.

42 percent, with a 78 percent decline in non-pressure pipe shipments and a 28 percent decline in pressure pipe shipments (Association of Asbestos Cement Pipe Producers 1986a). Imports in 1985, about 1 percent of domestic shipments, were insignificant (U.S. Dep. Com. 1986). The two major substitutes are PVC and ductile iron pipe. If asbestos were no longer available it is estimated (by linear foot) that PVC would take 92.63 and ductile iron 7.37 of the asbestos-cement pipe market. PVC costs slightly more than asbestos-cement pipe and ductile iron costs almost twice as much as asbestos-cement pipe.

ATTACHMENT

(1) Calculations to derive each submarket's share, by linear feet, of the entire asbestos-cement pipe market.

In order to determine the market share by linear feet of each of the ten asbestos-cement pipe submarkets shown in Table 1, it is necessary to convert the amount of tons of asbestos-cement pipe produced in each submarket into linear feet of asbestos-cement pipe. First the average weight per foot of asbestos-cement pipe is calculated for each submarket. This weight per foot for each submarket is then multiplied by the tons of asbestos-cement pipe produced in 1981 in each submarket, giving linear feet produced in each submarket (As stated in the text, 1981 production data is the most recent available that is broken down into the ten submarkets). The calculations are shown in the following subsections a and b.

(a) Calculation of the weight per foot of asbestos-cement pipe in each submarket.

For the 0-150 pressure pipe submarkets an average was taken of Class 100 and 150 pipe. For the 0-8 feet depth non-pressure pipe submarkets Class 2400 pipe was used. For the 8-16 feet depth an average of Class 2400 and 3300 were used. For the >150 psi pressure pipe submarkets, an average was taken of Class 150 and 200 pipe and for >16 feet depth submarkets Class 3300 was used.

Submarkets taken by PVC as determined by Malcolm Pirnie (1983), Sussex Plastics Engineering (1988a), and ICF estimate.

0-150 psi, 4"-12" diameter

	Class 100 (lb/ft)	Class 150 (lb/ft)
4"	7.2	7.9
6"	10.6	11.9
8"	16.0	18.3
10"	23.5	30.0
12"	30.6	39.1

Average for this submarket is 19.51 lb/ft.

0-150 psi, 12"-24" diameter

	Class 100 (lb/ft)	Class 150 (lb/ft)
12"	30.6	39.1
14"	36.3	51.8
16"	46.6	65.9
18"	63.8	91.3
20"	77.0	111.0
24"	109.0	160.0

Average for this submarket is 73.53 lb/ft.

0-8' deep, 4"-12" diameter

	Class 2400 (lb/ft)
4"	5.3
6"	9.1
8"	12.8
10"	17.5
12"	23.3

Average for this submarket is 13.61 lb/ft.

0-8' deep, 12"-24" diameter

	Class 2400 (lb/ft)
12"	23.3
14"	27.1
15"	30.0
16"	33.2
18"	43.2
20"	48.9
21"	54.1
24"	66.1

Average for this submarket is 40.74 lb/ft.

8-16' deep, 4"-12" diameter

	Class 2400 (lb/ft)	Class 3300 (lb/ft)
4"	5.3	6.6
6"	9.1	10.7
8"	12.8	14.9
10"	17.5	20.2
12"	23.3	27.1

Average for this submarket is 14.75 lb/ft.

8-16' deep, 12"-24" diameter

	Class 2400 (lb/ft)	Class 3300 (lb/ft)
12"	23.3	27.1
14"	27.1	31.2
15"	30.0	34.8
16"	33.2	37.7
18"	43.2	48.2
20"	48.9	54.9
21"	54.1	62.3
24"	66.1	73.9

Average for this submarket is 43.50 lb/ft.

Submarkets taken by Ductile Iron (DI) as determined by Malcolm Pirnie (1983), Sussex Plastics Engineering (1988a) and ICF estimate.

>150 psi, 4"-12" diameter

	Class 100 (lb/ft)	Class 150 (lb/ft)
4"	7.9	9.2
6"	11.9	15.6
8"	18.3	23.1
10"	30.0	35.4
12"	39.1	48.9

Average for this submarket is 23.94 lb/ft.

>150 psi, 12"-24"

	Class 150 (lb/ft)	Class 200 (lb/ft)
12"	39.1	48.9
14"	51.8	61.8
16"	65.9	79.9
18"	91.3	--
20"	111.0	--
24"	160.0	--

Average for this submarket is 78.86 lb/ft.[5]

>16' deep, 4"-12" diameter

	Class 3300 (lb/ft)
4"	6.6
6"	10.7
8"	14.9
10"	20.2
12"	27.1

Average for this submarket is 15.90 lb/ft.

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[5] Weights were not found for all sizes, so this is an average of only the weights shown. The reader may note that later, for calculating ductile iron prices, averages were taken across rows for pipe of the same class, however, because the pipes in the above case are of different classes we did not feel this method was appropriate.

>16' deep, 12"-24" diameter.

	Class 3300 (lb/ft)	
12"	27.1	
14"	31.2	
15"	34.8	
16"	37.7	Average for this submarket is 46.26 lb/ft.
18"	48.2	
20"	54.9	
21"	62.3	
24"	73.9	

Source: Certain-Teed 1986c.

(b) Calculations to convert ton production for each submarket into each submarket's share by linear feet of the entire asbestos-cement pipe market.

	Tons Produced in 1981 for 24" Diameter	Multiplication Factors to Convert to Linear Feet	Linear Feet of Pipe Per Submarket	Submarket Share
		PVC Submarkets		
0-150 psi, 4"-12"[a]	108,843	x 2,000 lb/ton x 1 ft/19.51 =	11,157,662.737	59.52%
0-150 psi, 12"-24"[a]	112,957	x 2,000 lb/ton x 1 ft/73.53 =	3,072,405.821	16.39%
0-8' deep, 4"-12"	8,977	x 2,000 lb/ton x 1 ft/13.61 =	1,319,177.076	7.04%
0-8' deep, 12-24"	26,182	x 2,000 lb/ton x 1 ft/40.74 =	1,285,321.551	6.86%
8-16' deep, 4"-12"	1,870	x 2,000 lb/ton x 1 ft/14.75 =	253,559.322	1.35%
8-16' deep, 12"-24"	5,984	x 2,000 lb/ton x 1 ft/43.50 =	275,126.437	1.47%
				92.63%

	Tons Produced in 1981 for 24" Diameter	Multiplication Factors to Convert to Linear Feet	Linear Feet of Pipe Per Submarket	Submarket Share
		DI Submarkets		
>150 psi, 4"-12"[a]	11,969	x 2,000 lb/ton x 1 ft/23.94 =	999,916.458	5.33%
>150 psi, 12"-24"[a]	12,717	x 2,000 lb/ton x 1 ft/78.86 =	322,520.923	1.72%
>16′ deep, 4"-12"	224	x 2,000 lb/ton x 1 ft/15.90 =	28,176.101	0.15%
>16′ deep, 12-24"	748	x 2,000 lb/ton x 1 ft/46.26 =	32,338.954	0.17%
				7.37%
		Total	18,746,205.379	100.00%

Total market shares held by pressure and non-pressure pipe.

Pressure Pipe : 82.96%
Non-Pressure Pipe: 17.04%

Total market shares of the asbestos-cement replacement market that will be taken by PVC and Ductile Iron Pipe.

PVC Pipe : 92.63%
Ductile Iron Pipe: 7.37%

[a] These are pressure pipe submarkets.

The source for the 1981 tonnage is ICF 1985. The weight per ton came from Attachment, Item 1a.

(2) Calculation of the decline of asbestos-cement shipments, in tons, since 1980, based on Table 4.

All Pipe

(1980-1985)/1980 x 100 = (417,816-243,873)/417,816 x 100 = 42%

Pressure Pipe

(1980-1985)/1980 x 100 = (302,928-218,191)/302,928 x 100 = 28%

Non-pressure Pipe

(1980-1985)/1980 x 100 = (114,888-25,682)/114,888 x 100 = 78%

Source: Association of Asbestos Cement Pipe Producers 1986a.

(3) <u>Prices for asbestos-cement pressure and non-pressure pipe in each submarket</u>

For the 0-150 pressure pipe submarkets an average was taken of Class 100 and 150 pipe.

For the 0-8 feet depth non-pressure pipe submarkets Class 2400 pipe was used.

For the 8-16 feet depth non-pressure pipe submarkets an average of Class 2400 and 3300 were used.

For the >150 psi pressure pipe submarkets an average was taken of Class 150 and 200 pipe (when prices for Class 200 are not available on average of Class 150 is taken), and for >16 feet depth submarkets Class 3300 was used.

Submarkets taken by PVC as determined by Malcolm Pirnie (1983), Sussex Plastics Engineering (1988a) and ICF estimate.

<u>0-150 psi, 4"-12" diameter</u>

	Class 100 ($/ft)	Class 150 ($/ft)
4"	2.05	2.16
6"	2.66	3.01
8"	3.95	4.46
10"	4.96	6.51
12"	6.53	8.30

Average for this submarket is $4.46/ft.

<u>0-150 psi, 12"-24" diameter</u>

	Class 100 ($/ft)	Class 150 ($/ft)
12"	6.53	8.30
14"	7.92	10.11
16"	10.14	12.49
18"	15.31	18.31
20"	17.53	22.27
24"	25.15	31.05

Average for this submarket is $15.43/ft.

0-8' deep, 4"-12" diameter

	Class 2400 ($/ft)
4"	1.15
6"	1.65
8"	2.40
10"	4.00
12"	5.15

Average for this submarket is $2.87/ft.

0-8' deep, 12"-24" diameter

	Class 2400 ($/ft)
12"	5.15
14"	6.21
15"	8.40
16"	8.83
18"	11.38
20"	14.11
21"	14.36
24"	20.67

Average for this submarket is $11.14/ft.

8-16' deep, 4"-12" diameter

	Class 2400 ($/ft)	Class 3300 ($/ft)
4"	1.15	1.31
6"	1.65	1.88
8"	2.40	2.57
10"	4.00	4.39
12"	5.15	5.73

Average for this submarket is $3.02/ft.

8-16' deep, 12"-24" diameter

	Class 2400 ($/ft)	Class 3300 ($/ft)
12"	5.15	5.73
14"	6.21	7.85
15"	8.40	9.07
16"	8.83	9.61
18"	11.38	12.38
20"	14.11	15.39
21"	14.36	15.80
24"	20.67	20.96

Average for this submarket is $11.62/ft.

Submarkets taken by Ductile Iron (DI) as determined by Malcolm Pirnie (1983), Sussex Plastics Engineering (1988a) and ICF estimate.

≥150 psi, 4"-12" diameter

	Class 150 ($/ft)	Class 200 ($/ft)
4"	2.16	2.36
6"	3.01	3.41
8"	4.46	4.78
10"	6.51	7.50
12"	8.30	9.77

Average for this submarket is $5.23/ft.

≥150 psi, 12"-24" diameter

	Class 150 ($/ft)
12"	8.30
14"	10.11
16"	12.49
18"	18.31
20"	22.27
24"	31.05

Average for this submarket is $17.09/ft

≥16' deep, 4"-12" diameter

	Class 3300 ($/ft)
4"	1.31
6"	1.88
8"	2.57
10"	4.39
12"	5.73

Average for this submarket is $3.18/ft.

≥16' deep, 12"-24" diameter.

	Class 3300 ($/ft)
12"	5.73
14"	7.85
15"	9.07
16"	9.61
18"	12.38
20"	15.39
21"	15.80
24"	20.96

Average for this submarket is $12.10/ft.

Source: Certain-Teed 1986c.

(4) Weighted average calculation of F.O.B. plant price for A/C pipe

Submarket	Submarket's Share of Overall PVC Market (by Linear Foot)	x	Price/Foot	=	Submarket's Weighted Price Per Foot
0-150 psi, 4"-12" diameter	0.5952	x	$ 4.46	=	$2.65
0-150 psi, 12"-24" diameter	0.1639	x	$15.43	=	$2.53
0-8' deep, 4"-12" diameter	0.0704	x	$ 2.87	=	$0.20
0-8' deep, 12"-24" diameter	0.0686	x	$11.14	=	$0.76
8-16' deep, 4"-12" diameter	0.0135	x	$ 3.02	=	$0.04
8-16' deep, 12"-24" diameter	0.0147	x	$11.62	=	$0.17
>=50 psi, 4"-12" diameter	0.0533	x	$ 5.23	=	$0.28
>=150 psi, 12"-14" diameter	0.0172	x	$17.09	=	$0.29
>+16' deep, 4"-12" diameter	0.0015	x	$ 3.18	=	$0.00
>+16' deep, 12"-14" diameter	0.0017	x	$12.10	=	$0.02
		Total Weighted Price			$6.94

However, according to Certain-Teed (1986), these prices are 3 percent above plant F.O.B. cost.

Therefore, the actual price is: $6.94/1.03 = $6.74

Source: Certain-Teed 1986, ICF 1985.

(5a) Calculations of PVC Pipe prices for PVC Submarkets

(Source: JM Manufacturing 1986b)

0-150 psi, 4"-12" diameter

	Class 150 ($/ft)	
4"	1.20	
6"	2.20	
8"	3.80	Average for this submarket is $4.19/ft.
10"	5.75	
12"	8.00	

0-150 psi, 4"-12" diameter

See Items 5b and c. Average for this submarket is $17.19.

	Sewer Pipe ($/ft)	
4"	0.45	
6"	1.00	
8"	1.85	Average for this submarket is $2.06/ft.
10"	2.90	
12"	4.10	

0-8' deep, 12"-24" diameter

	Sewer Pipe ($/ft)	
12"	4.10	
15"	5.90	
18"	9.85	Average for this submarket is $10.29/ft.
21"	13.72	
24"	17.87	

8-16' deep, 4"-12" diameter

	Sewer Pipe ($/ft)	
4"	0.45	
6"	1.00	
8"	1.85	Average for this submarket is $2.06/ft.
10"	2.90	
12"	4.10	

8-16' deep, 12"-24" diameter

	Sewer Pipe ($/ft)
12"	4.10
15"	5.90
18"	9.85
21"	13.72
24"	17.87

Average for this submarket is $10.29/ft.

(5b) Calculation of 1988 PVC Pipe Prices for Updated PVC Submarkets

0-150 psi, 4"-12" diameter, Water or Pressure Pipe

	Extrusion (DR 18)	JM Manufacturing (DR 18)	Row Average
4"	$ 1.85	$ 2.00	$ 1.93
6"	$ 3.50	$ 3.60	$ 3.55
8"	$ 5.90	$ 6.20	$ 6.05
10"	$ 8.90	$ 9.20	$ 9.05
12"	$12.60	$13.00	$12.80

Average price for this submarket is: $6.68

0-150 psi, 12"-24" diameter, Water or Pressure Pipe
(New PVC submarket, formerly a Ductile Iron submarket)

	Extrusion* (DR 18, 25)	JM Manufacturing* (DR 18, 25)	Row Average
12"	$12.60	$13.00	$12.80
14"	$12.50	$12.50	$12.50
16"	$16.00	$15.80	$15.90
18"	$22.10	$19.80	$20.95
20"	$27.50	$24.40	$25.95
24"	$39.50	$33.75	$36.63

Average price for this submarket is: $26.04

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* In diameters of 14"-24", DR 25 is the type of pressure pipe usually used. DR 18, which is more expensive and stronger than DR 25, is the type of PVC pipe usually used for diameters of ≤12" (JM Manufacturing 1988).

0-8' deep, 4"-12" diameter, Sewer or Gravity Pipe

	Extrusion	JM Manufacturing	Certain-Teed	Row Average
4"	$ 0.75	$ 0.75	$ 0.75	$ 0.75
6"	$ 1.60	$ 1.60	$ 1.50	$ 1.57
8"	$ 2.80	$ 2.90	$ 2.75	$ 2.82
10"	$ 4.50	$ 4.50	$ 4.30	$ 4.43
12"	$ 6.20	$ 6.40	$ 6.05	$ 6.22

Average price for this submarket is: $3.16

0-8' deep, 12"-24" diameter, Sewer or Gravity Pipe

	Extrusion	JM Manufacturing	Certain-Teed	Row Average
12"	$ 6.20	$ 6.40	$ 6.05	$ 6.22
15"	$ 9.20	$ 9.50	$ 9.25	$ 9.32
18"	$14.50	$15.10	$14.50	$14.70
21"	$21.00	$21.00	$19.75	$20.58
24"	$27.00	$27.45	$25.50	$26.65

Average price for this submarket is: $15.01

8-16' deep, 4"-12" diameter, Sewer or Gravity Pipe

	Extrusion	JM Manufacturing	Certain-Teed	Row Average
4"	$ 0.75	$ 0.75	$ 0.75	$ 0.75
6"	$ 1.60	$ 1.60	$ 1.50	$ 1.57
8"	$ 2.80	$ 2.90	$ 2.75	$ 2.82
10"	$ 4.50	$ 4.50	$ 4.30	$ 4.43
12"	$ 6.20	$ 6.40	$ 6.05	$ 6.22

Average price for this submarket is: $3.16

8-16' deep, 12"-24" diameter, Sewer or Gravity Pipe

	Extrusion	JM Manufacturing	Certain-Teed	Row Average
12"	$ 6.20	$ 6.40	$ 6.05	$ 6.22
15"	$ 9.20	$ 9.50	$ 9.25	$ 9.32
18"	$14.50	$15.10	$14.50	$14.70
21"	$21.00	$21.00	$19.75	$20.58
24"	$27.00	$27.45	$25.50	$26.65

Average price for this submarket is: $15.01

(Sources: Extrusion 1988, JM Manufacturing 1988, and Certain-Teed 1988.)

(5c) Calculation of 1986 price of the new PVC submarket (0-150 psi, 12"-24")

The 1988 price of PVC is approximately 51 percent higher than the 1986 price due to a temporary nationwide shortage of resin, one of the primary ingredients in the manufacture of PVC pipe. Because of this temporary increase in price, the 1986 prices of PVC probably are more reflective of the long range price of PVC than are the 1988 prices. In order to determine what the 1986 price of the new PVC submarket (0-150 psi, 12"-24" diameter) would be, an average percent increase in price for all the 1986 submarkets of PVC pipe was calculated and this percent was then subtracted from the 1988 price of the new PVC submarket. These calculations are shown below.

Average Increase from 1986 PVC Prices to 1988 Prices
Taken from 5a and 5b Above

	1986 Price	1988 Price	Percent Increase
0-150 psi, 4"-12" diameter	$ 4.19	$ 6.68	59.31
0-8' deep, 4"-12" diameter	$ 2.06	$ 3.16	53.24
0-8' deep, 12"-24" diameter	$10.29	$15.01	45.87
8-16' deep, 4"-12" diameter	$ 2.06	$ 3.16	53.24
8-16' deep, 12"-24" diameter	$10.29	$15.01	45.87
Average Percent Price Increase			51.50

The price for the new PVC category is a 1988 price and thus reflects the temporary increase due to the resin shortage in the U.S. Deducting this percent increase of 51.50 percent from the 1988 price, we can derive a 1986 price for this new category.

$26.04/1.5150 = $17.19

(6) Calculations of Ductile Iron Pipe Prices ($/ft) for Ductile Iron Submarkets

All prices are for Class 50 pipe, except for the last Ductile Iron submarket. Each average submarket price is derived from the average price for each diameter within the submarket.

≥ 150 psi, 4"-12" diameter

	McWane	U.S. Pipe	Atlantic	Class 50 Average
4"	-	-	4.33	4.33
6"	-	-	4.78	4.78
8"	6.03	6.28	6.58	6.30
10"	-	-	8.70	8.70
12"	10.70	10.61	11.13	10.81

Average for this submarket is $6.98/ft.

≥150 psi, 12"-24" diameter

12"	10.70	10.61	11.13	10.81
14"	-	-	14.45	14.45
16"	15.68	16.28	16.93	16.30
18"	-	-	19.58	19.58
20"	-	-	22.39	22.39
24"	26.06	27.06	28.25	27.12

Average for this submarket is $18.44/ft.

>= 16' deep, 4"-12" diameter

4"	-	-	4.33	4.33
6"	-	-	4.78	4.78
8"	6.03	6.28	6.58	6.30
10"	-	-	8.70	8.70
12"	10.70	10.61	11.13	10.81

Average for this submarket is $6.98/ft.

	Class	U.S. Pipe	Atlantic	Class 50 Average
12"	50	10.61	11.13	10.87
14"	52	-	16.67	16.67
16"	52	18.70	19.46	19.08
18"	54	-	25.19	25.19
20"	54	-	28.56	28.56
24"	54	34.21	35.62	34.92

Average for this submarket is $22.55/ft.

Sources: McWane 1986; U.S. Pipe 1986; Atlantic Cast Iron Pipe 1986.

(7) Determination of average prices for PVC and Ductile Iron

Since PVC is 92.63 percent of the substitute market, we must determine a weighted market price.

PVC

Submarket	Submarket's Share of Overall PVC Market (by linear foot)	x	Price/Foot	=	Submarket's Weighted Price ($/ft.)
0-150 psi, 4"-12" diameter	59.52/92.63	x	$ 4.19	=	$2.69
0-150 psi, 12"-24" diameter	16.39/92.63	x	$17.19	=	$3.04
0-8' deep, 4"-12" diameter	7.04/92.63	x	$ 2.06	=	$0.16
0-8' deep, 12"-24" diameter	6.86/92.63	x	$10.29	=	$0.76
8'-16' deep, 4"-12" diameter	1.35/92.63	x	$ 2.06	=	$0.03
8'-16' deep, 12"-24" diameter	1.47/92.63	x	$10.29	=	$0.16
			Total Weighted PVC Price:		$6.84

Since Ductile Iron is 7.37 percent of the substitute market, we must determine a weighted market price.

Ductile Iron (DI)

Submarket	Submarket's Share of Overall DI Market (by linear foot)	x	Price/Foot	=	Submarket's Weighted Price ($/ft.)
≥150 psi, 4"-12" diameter	5.33/7.37	x	$ 6.98	=	$ 5.05
≥150 psi, 12"-24" diameter	1.72/7.37	x	$18.44	=	$ 4.30
≥16' deep, 4"-12" diameter	0.15/7.37	x	$ 6.98	=	$ 0.14
≥16' deep, 12"-24" diameter	0.17/7.37	x	$22.55	=	$ 0.52
			Total Weighted DI Price:		$10.01

(8) Calculations for Installation Costs ($/foot)

Costs are derived using an average of Means 1985 prices for 4"-12" diameter water distribution pipe. Piping excavation and backfill are excluded.

	A/C Pressure (150 psi)	PVC Pressure (Class 150, SDR 18)	DI, Class 250 Water Pipe		
			Mechanical Joint		
				4"	$3.50
				6"	$4.00
				8"	$6.30
4"	$1.68	$2.52		10"	$7.55
6"	$1.74	$2.80		12"	$9.40
8"	$2.34	$4.24			
10"	$2.51	$4.85	Tyson Joint		
12"	$2.71	$6.80		4"	$3.19
				6"	$3.65
				8"	$5.75
				10"	$6.80
				12"	$8.50
Average Total:	$2.20	$4.24	Average Total for Tyson and Mechanical:		$5.86

Source: Means 1985.

(9) Determination of Submarket Share by Weight Based on 1981 Production[a]

Submarket	1981 Tons Produced <=24" Diameter	1981 Market Share by Weight (percent)
PVC		
0-150 psi, 4"-12" diameter	108,843	37.47
0-150 psi, 12"-24" diameter	112,957	38.89
0-8' deep, 4"-12" diameter	8,977	3.09
0-8' deep, 12"-24" diameter	26,182	9.01
8-16' deep, 4"-12" diameter	1,870	0.64
8-16' deep, 12"-24" diameter	5,894	2.06
	264,813	91.16
Ductile Iron (DI)		
>=150 psi, 4"-12" diameter	11,969	4.12
>=150 psi, 12"-24" diameter	12,717	4.38
>=16' deep, 4"-12" diameter	224	0.08
>=16' deep, 12"-24" diameter	748	0.26
	25,658	8.84
Total 1981 Production	290,471	100.00

[a] See text for explanation of why 1981 production data is used.

Source: ICF 1985.

(10) Calculations for conversion of 1985 asbestos-cement pipe production from tons to feet.

216,903 tons of asbestos-cement pipe were produced in 1985 (ICF 1986). According to the Association of Asbestos Cement Pipe Producers (1986a), approximately 16,899,000 feet, or 243,873 tons, of asbestos-cement pressure pipe were shipped in the U.S. in 1985. Dividing tons by feet gives 0.0144 tons/feet of asbestos-cement pressure pipe.[6]

216,903 tons/(0.0144 tons/feet) = 15,062,708 feet of asbestos-cement pipe produced in 1985.

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[6] Even though this ratio is derived for pressure pipe, because pressure pipe is about 90 percent of all asbestos-cement pipe shipments, we apply it to our ton figure above, which includes both pressure and non-pressure asbestos-cement pipe. Comparable figures of the length of non-pressure pipe tonnage were not available.

(11) Calculations for product asbestos coefficient for asbestos regulatory cost model.

In 1985, 32,690.7 tons of asbestos were consumed in the production of asbestos-cement pipe (ICF 1986).

32,690.7 tons of asbestos/15,062,708 feet of asbestos-cement pipe
= 0.0022 tons/feet.

(12) Calculations for consumption production ratio for asbestos regulatory cost model.

In 1985, 2790.4065 tons of asbestos-cement pipe were imported into the U.S. (U.S. Dep. Comm 1986). This ton figure is converted to linear feet using the 0.0144 tons/linear foot figure derived previously.

2790.4065 tons/(0.0144 tons/feet)
= 193,778 feet of asbestos-cement pipe were imported in 1985.

The consumption production ratio is:

(domestic production + imports)/(domestic production)
= (15,062,708 + 193,778)/15,062,708
= 1.0129.

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