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ASBESTOS

A Chapter from Mineral Facts and Problems, 1985 Edition

UNITED STATES DEPARTMENT OF THE INTERIOR

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UNITED STATES DEPARTMENT OF THE INTERIOR

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BUREAU OF MINES

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As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

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ASBESTOS

By Robert A. Clifton[1]

The United States is probably still second only to the U.S.S.R. in the consumption of asbestos, although data to confirm it are lacking. The construction industry worldwide now uses the majority of asbestos fibers in such products as asbestos cement pipe and sheet, roofing products, flooring products, paints, and caulking, and should remain the largest user. U.S. mines produced 70,000 tons,[2] 33% of domestic consumption, which was 217,000 tons in 1983. Canada supplies about 94% of asbestos imports into the United States. The Republic of South Africa is second. The Republic of South Africa supplies all the U.S. demand for crocidolite and amosite, and the majority of imports from that country are these fibers.

World asbestos production declined by 14% from 1979 to 1982. The market losses were almost totally in mature market economy countries and were keyed to the recession and environmental problems. The market growth in the developing countries eased the decline somewhat.

The U.S.S.R. is the world's largest producer of asbestos. The level of activity in exploration, evaluation, and development of new ore bodies in Canada signals that it will probably continue as the leading world exporter.

U.S. demand in 1983 was just 33% of the 1976 record high. It showed, in 1984, the first increase since 1978. The quest for substitutes remains strong, but the substitute materials proposed generally fail to compete with asbestos when measured by quality and/or economic yardsticks. Viable substitutes are desirable for both health and economic reasons.

The health hazards associated with asbestos are still undergoing close scrutiny by Federal and local governments, unions, industry organizations, and environmentalists. The many areas of controversy give promise of prolonged dispute. Efforts to regulate conditions to minimize the hazard are given as a reason for the closure of two asbestos mines in the United States.

Table 1.—World asbestos production, 1983, and capacity, 1983, 1984, and 1990

(Thousand metric tons)

	Production	Capacity		
	1983	1983[e]	1984[e]	1990[1]
Chrysotile:				
North America:				
Canada	829	1,510	1,500	1,500
Mexico	—	—	—	50
United States	70	100	100	50
Total	899	1,610	1,600	1,600
South America:				
Brazil	135	200	200	200
Colombia	7	7	10	25
Total	142	207	210	225
Europe:				
Greece	93	100	100	100
Italy	120	150	150	190
U.S.S.R.	2,250	2,600	2,600	3,000
Yugoslavia	10	20	20	50
Other	1	7	7	7
Total	2,474	2,877	2,877	3,347
Africa:				
South Africa, Republic of	93	120	120	150
Swaziland	31	50	50	0
Zimbabwe	190	250	250	250
Other	1	1	1	1
Total	315	421	421	401
Asia:				
China	110	300	300	400
Cyprus	18	35	35	35
India	25	32	35	40
Japan	4	4	4	4
Korea, Republic of	15	15	15	20
Taiwan	3	4	4	5
Turkey	4	15	15	25
Total	179	385	408	528
Oceania:				
Australia	20	70	70	100
World chrysotile total	4,029	5,570	5,586	6,202
Crocidolite:				
South Africa, Republic of	87	210	210	230
Amosite:				
South Africa, Republic of	41	110	100	130

[e]Estimated.
[1]Forecast.

INDUSTRY STRUCTURE

Background

Canada, with major activity in the Province of Quebec, leads the market economy countries in both total quantity produced and the size of individual mines and mills. The U.S.S.R. is the leading world asbestos producer. The Republic of South Africa, Zimbabwe, China, Brazil, Italy, and the United States mine substantial tonnages and, in combination with Canada and the U.S.S.R., produce over 94% of the world's supply. Chrysotile is the variety most in demand by over 95% of the world's consumers, and most of the data in this report relate to chrysotile.

Total world production in 1983 was 4.2 million tons of all grades and varieties. Canada's share was 20%; the U.S.S.R. produced 54%; the Republic of South Africa and Zimbabwe, 5% each; China, Brazil, and Italy, 3% each; and Greece and the United States, 2% each. U.S. production was 70,000 tons, valued at $28 million. These data on world production do not credit U.S.S.R. production with the lower grades that are not used as fibers.

Geographic Distribution

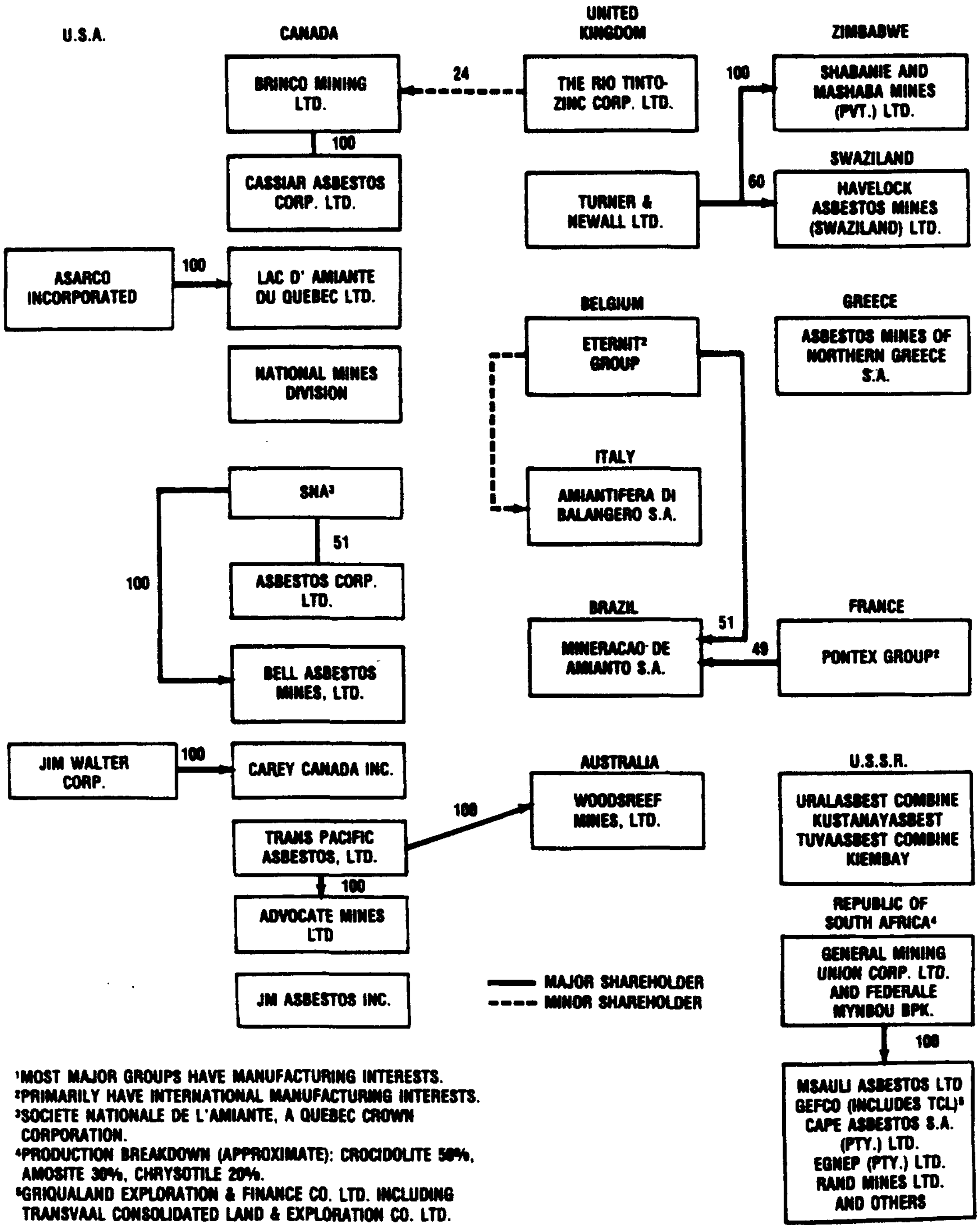
Only three mines in the United States continue to produce asbestos. Each of the three, two in California and another in Vermont, produce chrysotile.

An area roughly 120 kilometers[3] long and 8 to 10 kilometers wide, beginning 130 kilometers east of Montreal, Canada, and continuing eastward, contains the world's second largest mine and mill and, in toto, the largest concentration of known deposits in the world. Mergers and closings have reduced the number of operating companies to five in this "Eastern Townships" region, stretching from Danville to East Broughton, Quebec.

[1]Physical scientist, Section of Nonmetallic Minerals
[2]All tonnages reported are metric tons unless otherwise specified

[3]One mile = 1.6093 kilometers, 1 kilometer = 0.6213 mile

MAJOR INTERNATIONAL ASBESTOS MINING GROUPS[1]



[1]MOST MAJOR GROUPS HAVE MANUFACTURING INTERESTS.
[2]PRIMARILY HAVE INTERNATIONAL MANUFACTURING INTERESTS.
[3]SOCIETE NATIONALE DE L'AMIANTE, A QUEBEC CROWN CORPORATION.
[4]PRODUCTION BREAKDOWN (APPROXIMATE): CROCIDOLITE 50%, AMOSITE 30%, CHRYSOTILE 20%.
[5]GRIQUALAND EXPLORATION & FINANCE CO. LTD. INCLUDING TRANSVAAL CONSOLIDATED LAND & EXPLORATION CO. LTD.

Figure 1.—Major asbestos mining groups.

U.S. and British interests in the area have declined sharply. The Province of Quebec's Société Nationale de l'Amiante (SNA) takeover of the Asbestos Corp. in 1981 and purchase of Bell Asbestos Ltd. in 1980 led the way. Then, in 1983, the Manville Corp. sold its Jeffrey Mine and mill to a Canadian consortium. The Jim Walter Corp.'s Carey Canadian Mines Ltd. and the ASARCO Corporation's Lac d'Amiante du Quebec Ltd. are the only U.S.-owned asbestos mines operating in Quebec. Cassiar Asbestos Corp. Ltd. in British Columbia is now totally owned by British and Canadian interests.

The large integrated international corporation is no longer typical of the asbestos industry, as the Manville Corp. sold both its asbestos producing and manufacturing units and Cape Asbestos Ltd. sold its mines. Turner and Newell Ltd. now produces asbestos only in Zimbabwe and Swaziland and, along with the Eternite Group, are the only multinational corporations in the industry that both mine asbestos and manufacture asbestos products.

Definitions and Grades

The American Society for Testing and Materials (ASTM) has a new publication, much of which is devoted to asbestos definitions (*6*).[4] The compromise definition, which should be useful to both the environmental and minerals communities, is given below as well as excerpts from mineralogical definitions found in that paper.

Asbestos is a term applied to six naturally occurring minerals exploited commercially for their desirable physical properties, which are in part derived from their asbestiform habit. The six minerals are the serpentine mineral chrysotile and the amphibole minerals grunerite asbestos (also referred to as amosite), riebeckite asbestos (also referred to as crocidolite), anthophyllite asbestos, tremolite asbestos, and actinolite asbestos. (These minerals are defined in the sections that follow.) Individual mineral particles, however processed and regardless of their mineral name, are not demonstrated to be asbestos if the length-to-width ratio is less than 20:1.

Serpentine Asbestos

Chrysotile, the only commercial asbestos mineral belonging to the serpentine group, has an ideal chemical composition of $Mg_3Si_2O_5(OH)_4$. Moderate amounts of aluminum may substitute for silicon and moderate amounts of iron may substitute for magnesium. Certain end-use applications are sensitive to the iron content. Small amounts of manganous oxide (MnO), calcium oxide (CaO), potassium oxide (K_2O), and sodium oxide (Na_2O) are also reported in the chemical analyses.

The crystal structure of chrysotile asbestos consists of double layers, each consisting of a layer of linked SiO_4 tetrahedra coordinated to a second layer of linked $MgO_2(OH)_4$ octahedra through a sharing of oxygen atoms; the composite double layer rolls up, like a window shade, to form long hollow tubes. The diameters of the individual tubes are on the order of 25 nanometers, and the length-to-diameter ratio can vary from 20:1 to well over 10,000:1.

Chrysotile is characterized by a combination of (1) a distinctive shape, (2) a chemical composition close to $Mg_3Si_2O_5(OH)_4$, and (3) characteristic X-ray and electron diffraction patterns.

Amphibole Asbestos

Five of the six commercial asbestos minerals belong to the amphibole mineral group. These, with their ideal chemical formulas, are grunerite asbestos, $Fe_7Si_8O_{22}(OH)_2$ (usually but improperly referred to by the name amosite); riebeckite asbestos, $Na_2Fe_3^{2+}Fe_2^{3+}Si_8O_{22}(OH)_2$ (usually referred to by the varietal name crocidolite); anthophyllite asbestos, $Mg_7Si_8O_{22}(OH)_2$; tremolite asbestos, $Ca_2Mg_5Si_8O_{22}(OH)_2$; and actinolite asbestos, $Ca_2(Mg,Fe^{2+})_5Si_8O_{22}(OH)_2$. A considerable amount of substitution of other elements for Fe^{2+}, Fe^{3+}, silicon, sodium, calcium, and magnesium can take place in these minerals.

The crystal structure of the amphibole minerals, including the asbestiform varieties, are composed of strips or ribbons of linked polyhedra, which join together to form the three-dimensional crystal. The individual strips are composed of three elements: these are two double chains of linked $(Si,Al)O_4$ tetrahedra and a strip of linked MgO_6, FeO_6, or AlO_6 octahedra. The three-dimensional arrangements of these strips ("I-beams") are orthoamphibole (anthophyllite asbestos) and clinoamphibole (tremolite, actinolite, grunerite, and riebeckite asbestos).

Amphibole asbestos minerals are characterized by a combination of (1) a distinctive crystal habit with length-to-width ratios often of 20:1 or greater, (2) the typical chemical composition for that mineral, and (3) characteristic X-ray powder diffraction patterns or electron diffraction patterns.

Tremolite asbestos was included in spite of no longer being an item of commerce because of the continuing controversy over the health effects of tremolite in talc.

[4]Italicized numbers in parentheses refer to items in the list of references at the end of this chapter

Table 2.—Chemical composition of asbestos, weight percent

Component	Serpentine asbestos, chrysotile		Amphibole asbestos			
	King Beaver Mine, Quebec, Canada	Shabani Mines, Zimbabwe	Riebeckite asbestos (crocidolite), from Pomfret, Cape Province, Republic of South Africa	Grunerite asbestos (amosite), from Penge, Transvaal Province, Republic of South Africa	Anthophyllite asbestos, from Paakkila, Finland	Tremolite asbestos, from Pakistan
SiO	38.75	39.70	52.00	49.70	57.20	55.10
Al_2O_3	3.09	3 17	Nil	.40	Nil	1.14
Fe_2O_3	1.59	.27	16.05	.03	.13	32
FeO	2.03	.70	17 65	39.70	10 12	2.00
MnO	08	.26	Trace	.22	Nil	10
MgO	39.78	40.30	4.28	6.44	29.21	25.65
CaO	.89	1.08	1.20	1.04	1.02	11.45
K_2O	18	.05	.06	.63	Nil	.29
Na_2O	10	.04	6.21	.09	Nil	14
H_2O+	12.22	12.17	2.43	1.83	2.18	3.52
H_2O-	.60	.64	.26	.09	.28	.16
CO_2	48	2.13	.09	.09	—	.06
Total	99.79	100.51	100.23	100.26	100.14	99.93

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Chrysotile, the principal variety of commerce, is graded and grouped according to fiber length. Most of the groups are divided into several subgroups to comprise the commercial specifications. One producer alone has offered its customers 420 grades of fiber in 1,320 different forms (*5*). The methods of classification used in the principal producing countries are discussed in detail in a Bureau of Mines publication (*2*).

RESERVES-RESOURCES

U.S. and World

The definitions of reserves and reserve base are published in the U.S. Geological Survey Circular 831,"Principles of a Resource/Reserve Classification for Minerals," which is reprinted in the introduction of "Mineral Facts and Problems, 1985 Edition."

Recent economic pressures of remaining competitive while meeting environmental regulations are increasing production costs and thereby causing reserve estimates to decrease. The possible million tons of asbestos fiber reserves at the Copperopolis, CA, deposit are, under present environmental regulations, economic. The future of the millions of tons of short fibers available in the Coalinga, CA, area is doubtful, because of low demand and high environmental costs.

The world reserve situation and its implications for the future remain unclear. The plans of the U.S.S.R. to bring more asbestos mines into production indicate huge resources, but it is questionable whether they are all reserves using market economy yardsticks. Also questionable is whether the economy and demand for asbestos would raise prices to the level that certain large Canadian and Alaskan resources would become economically attractive. Present trends in world demand indicate that those resources presently called "reserves" will be adequate to meet that demand through the year 2000.

Geology

Most chrysotile asbestos deposits, including those of Vermont, Alaska, and California in the United States as well as of Canada, Zimbabwe, Swaziland, the Republic of South Africa, and the U.S.S.R., consist of irregular cross-fiber veins (closely packed fibers set at a right angle to the faces of the rock fractures) or slip-fiber zones (shear planes in rock, filled with fiber matted together parallel to the seam) in massive serpentine. Such deposits commonly extend to unexplored depths. Amosite and crocidolite of the Republic of South Africa occur in banded ironstones that are so folded and contorted that the veins are very irregular.

Table 3.—World asbestos reserves and reserve base
(Million metric tons)

	Reserves	Reserve base
North America:		
United States	4	8
Other	40	47
Total	44	55
South America	4	5
Europe	50	65
Africa	7	10
Asia	6	13
Oceania	1	1
World total[1]	110	150

[1]Does not add to totals shown because of independent rounding.

TECHNOLOGY

Exploration and Development

Exploration and development are apparently decreasing throughout the world because of the decreasing demand for asbestos fiber and plenty of production capacity to meet that demand. The asbestos showings in the Eagle Quadrant of Alaska have been extensively explored and tested, but no decision on production has yet been made. Canadian development has practically ceased, and only the U.S.S.R. has active development plans.

Mining

In Vermont and in the Copperopolis district in California, the fiber-bearing rock is removed from an open pit. In the Coalinga district of California, the highly sheared ore is simply "plowed" and allowed to air-dry, and the coarse fraction is then screened out from the mill feed. The Canadian mines generally are open pits. The chrysotile of Zimbabwe, the Republic of South Africa, and Swaziland is obtained from underground mines. Amosite is obtained chiefly from large underground workings, and blue asbestos (crocidolite) is taken from small open pits and shallow mines. The Soviet deposits are worked both in open pits and underground. Cyprus has large open pit workings.

Processing

Asbestos dry milling is a complex operation involving primarily the separation of fiber from rock and classification of fiber by length. There has been little change in the basic methods described in a previous Bureau of Mines publication (*3*).

Special milling techniques have been developed for the matted short-fiber chrysotile of the Coalinga district of California, including grinding and wet-milling.

In Copperopolis, CA, Vermont, and Canada, the mills are large and complex. The fiber is classified in many grades, such as spinning, cement stock, and paper stock.

In many mills, asbestos fiber is packed under pressure in five-ply paper and/or woven vinyl bags. Each pressure-packed bag contains 100 pounds of asbestos and occupies about 2 cubic feet. With this pressure-packing, the asbestos measures 45 cubic feet per short ton.

British patent application WD 83/04190A, in 1983, describes a two-stage Australian wet process. In the first stage, crushed chrysotile ore slurried with water is comminuted by crushing or grinding to release asbestos fibers and open the fiber bundles; the fibers are then concentrated by screw classifier and spiral concentrator. In the second stage, the concentrated fibers are cleaned by low-pressure hydrocyclones and then separated into well-opened and poorly opened fibers by high-pressure hydrocycloning. Poorly opened fibers are mechanically milled and recycled. The well-opened concentrates are dewatered by high-pressure filtration. The patent application claims that the process concentrate yields are at least equal to those obtained by the conventional dry process. It is also claimed that the process is suitable for reclaiming fibers from dry process tailings and capable of treating the low-grade ores that the dry process cannot handle.

Products for Trade and Industry

The environmental problems of asbestos continue to depress its entry into new markets. New product inventors and designers as well as old product redesigners apparently no longer think of asbestos as a desirable, available, and economic raw material.

Current Research and Applications

The vast majority of current research concerning asbestos is divided into two totally separate areas: health and substitutes. They are linked because the perceived bad health effects feed the drive for safer substitutes. Each are discussed later in this chapter.

USES

Asbestos is used only after processing to release the fibers from the rock matrix and from each other. The processed chrysotile fibers are grouped by fiber length as follows:

Groups 1, 2, and 3.—These groups are composed of the longest fibers; the major end-use products include fireproof textiles, clothing, and theater curtains; also different types of packings, woven brake linings, clutch facings, electrical insulation materials, and high-pressure and marine insulation.

Group 4.—Its major use is in asbestos cement pipe, which is used mainly in transporting water, such as in municipal waterworks, irrigation, and conservation projects.

Group 5.—This group is used in asbestos cement sheets, low-pressure asbestos cement pipes, and molded products. It is also used in some paper products such as pipe insulation, wrappings, and other products, including brake linings and gaskets.

Group 6.—The main consumption for this group is in asbestos cement products, gaskets, brake linings, vinyl sheet backings, and millboard.

Group 7.—The group is used in molded brake linings and clutch facings, as a filler in vinyl and asphalt floor tile, and in asphalt compounds, joint and insulation cements, roof coatings, plastics, and caulking compounds.

Amosite is used for felted insulation in blanket form for high-temperature service up to 480 °C. A loosely compacted form is applied as a covering for marine turbines, jet engines, and similar applications. Amosite is also used as a constituent of lightweight, fire-resistant marine partition board. Long-fiber crocidolite ("blue asbestos") is woven into fabrics for locomotive-boiler lagging and for acid-resistant packings and gaskets. The principal use of the shorter crocidolite fibers is in asbestos cement pipe.

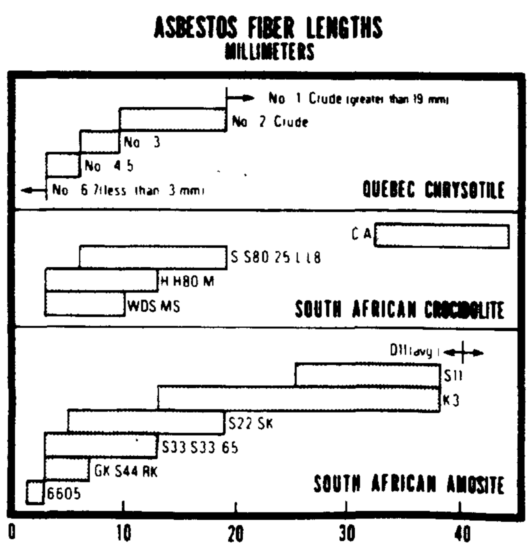

Figure 2 —Asbestos fiber lengths

World end-use patterns are not discernible from available data, and the use of U.S. patterns to project usage in the rest of the world cannot be justified. In the 1970's, 70% of the world's asbestos was reportedly connected with products used in the construction industry. This is expected to continue into the 1980's and can be used for planning purposes.

Domestic asbestos-product plants are located principally in the eastern, southern, and west coast areas.

Asbestos is adaptable to more than 2,000 uses. Because of its high tensile strength and high temperature resistance, it is used in rockets and missiles. In an unclassified Government stockpile report to the Congress in 1980, the Federal Emergency Management Agency (FEMA) describes the use of asbestos in the production of weapons subsystems including the Army Tow, Lance, Pershing, and the Navy Trident. The Department of Defense remains vitally interested in the status of asbestos availability because of critical needs for this raw material.

SUPPLY-DEMAND RELATIONSHIPS

Components of Supply

During the entire history of the asbestos industry in the United States, domestic sources have been able to meet only a small percentage of U.S. requirements. Vermont and the Copperopolis district of California have been the only consistent U.S. sources of Quebec-type asbestos. Both are predominantly producers of short fiber, but the Vermont asbestos mines can produce about 500 tons per year of spinning-length fiber. Most of it is applied to nonspinning uses.

Canada furnished about 94% of the asbestos tonnage imported by the United States during the past decade, but only a small portion was spinning-grade fibers. The comparatively small quantities of chrysotile received from Africa, particularly those from Zimbabwe, are mmore important than would appear on a tonnage basis because they consist largely of special kinds and qualities unobtainable elsewhere. Under emergency conditions, imports of spinning fibers are of primary importance. The longer fibers of chrysotile suitable for spinning represent a small fraction of the total world production. Shortages of spinning-grade fibers have occurred previously, but no longer seem to be chronic except for certain special grades.

U.S. imports of amosite, available only from the Republic of South Africa, averaged about 2,200 tons per year from 1973 to 1983. However, 1983 imports were only 9% of those in 1973. Amosite remains a strategic and critical material with a Government stockpile goal.

Imports of crocidolite, also available only from the Republic of South Africa, averaged about 10,000 tons per year from 1973 to 1983. Imports in 1983 were the lowest since 1973 and were only 37% of those in 1978. Economic recession and environmental fears were contributing factors.

U.S. and World Production

In 1973, U.S. production of asbestos fiber was at an alltime high; however, production had declined by 50% by 1983. Canadian production of asbestos, all chrysotile, also peaked in 1973, at 1.6 million metric tons and had also decreased by roughly 50% by 1983. The Asbestos Hill Mine in Northern Quebec was closed in 1983 because of the depressed market. The early 1980's have been characterized as a buyer's market with most producers having such high inventories that periodic miner layoffs have been necessary.

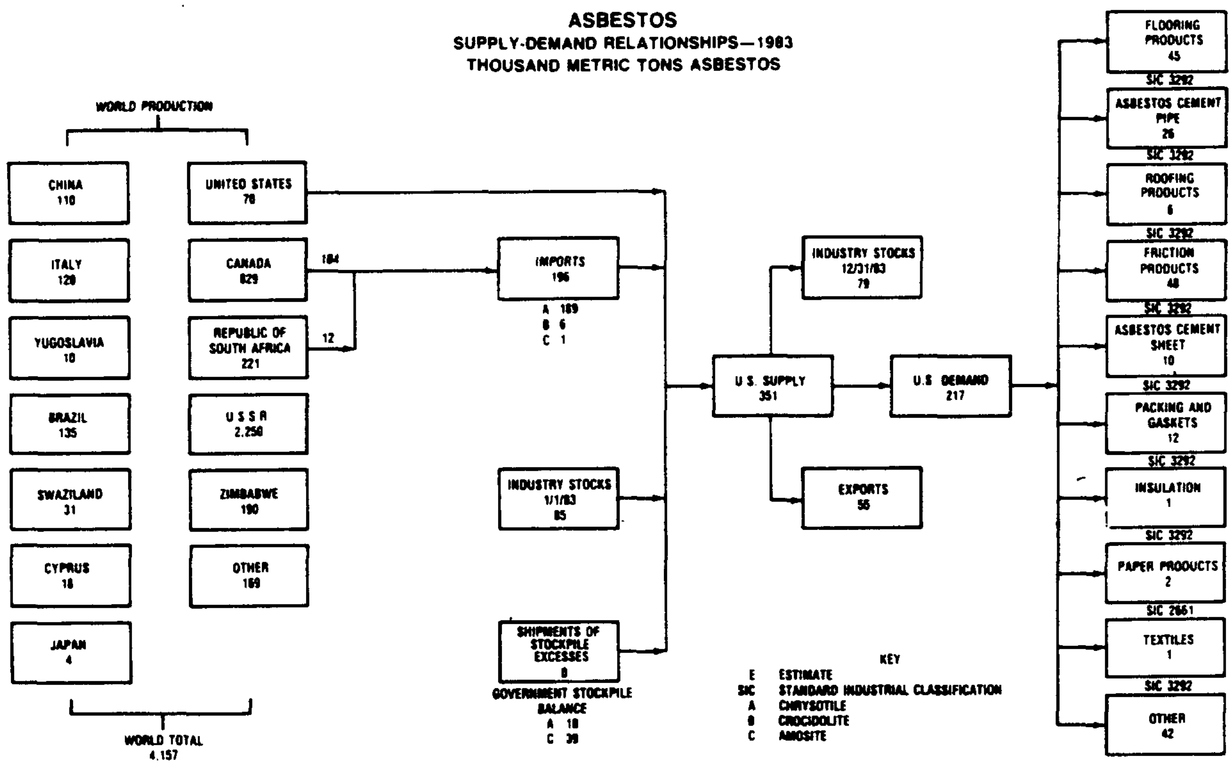

Figure 3.—Supply-demand relationships for asbestos, 1983.

Table 4.—Asbestos supply-demand relationships, 1973–83

(Thousand metric tons)

	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
					WORLD PRODUCTION						
United States	136	99	89	105	92	93	93	80	76	64	70
Rest of world	4,050	4,058	4,050	4,662	4,701	4,600	4,813	4,619	4,261	4,016	4,087
Total	4,186	4,157	4,139	4,767	4,793	4,693	4,906	4,699	4,337	4,080	4,157
					COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY						
Domestic mines	136	99	89	105	92	93	93	80	76	64	70
Imports	719	695	489	597	551	570	513	327	338	242	196
Industry stocks, Jan. 1	145	139	110	104	104	40	83	85	84	85	85
Total U.S. supply	1,000	933	688	806	747	703	689	492	498	391	351
Distribution of U.S. supply:											
Industry stocks, Dec. 31	139	110	104	104	40	83	85	84	85	65	79
Exports	60	56	33	43	35	42	43	49	64	59	55
Industrial demand	801	767	551	659	672	619	561	359	349	247	217
					U.S. DEMAND PATTERN						
Asbestos cement pipe					115	106	96	42	42	38	26
Asbestos cement sheet					27	25	22	23	20	11	10
Coatings and compounds					36	33	30	11	13	25	23
Flooring products					150	138	125	70	67	49	45
Friction products					57	53	48	52	51	53	48
Insulation:											
Thermal					17	15	14	6	6	—	—
Electrical					4	4	3	3	1	1	1
Packing and gaskets					28	25	23	12	19	14	12
Paper products					7	7	6	1	2	2	2
Plastics					8	7	7	2	1	—	1
Roofing products					70	64	58	24	16	7	6
Textiles					10	9	8	2	2	1	1
Other					143	133	121	111	109	46	42
Total[2]					672	619	561	359	349	247	217

[1]Comparable data unavailable prior to 1977.
[2]Data do not add to totals shown because of independent rounding.

The spinning grades of chrysotile asbestos produced in Zimbabwe were of great importance during World War II and the early postwar years because they constituted the principal source of low-iron chrysotile suitable for shipboard electric-cable insulation. They are of renewed importance as the only current source of substantive amounts of spinning-grade low-iron chrysotile. There are indications, however, that Brinco Mining Ltd. can resume mining of these coveted fibers from newly found resources at its Cassiar Mine in Canada.

Production of both amosite and crocidolite in the Republic of South Africa have decreased significantly because of the economic and environmental factors affecting the entire asbestos industry.

U.S. and World Consumption

The nine largest uses of asbestos in 1983 were friction products, 22%; flooring products, 21%; asbestos cement pipe, 12%; coatings and compounds, 11%; packing and gaskets, 6%; asbestos cement sheet, 5%; roofing products, 3%; plastics, 1%; and textiles, 1%. Other products used 18% of the asbestos. Friction products usage was 79% of that in 1979; flooring products, 37%; asbestos cement pipe, 12%; coatings and compounds, 115%; packing and gaskets, 63%; asbestos cement sheet, 91%; roofing products, 9%; plastics, 33%; and textiles, 16%.

Dramatic decreases in demand occurred during the past decade for asbestos usage in pipe, roofing, flooring, sheet, and textiles. Consumption in friction products has decreased only slightly since 1973, and this has become the largest end use. Total U.S. consumption decreased by 73% during the past decade.

Total world production, and probably consumption, has changed little during the past decade. Apparently, markets in countries with mature economies have been replaced by some in developing countries.

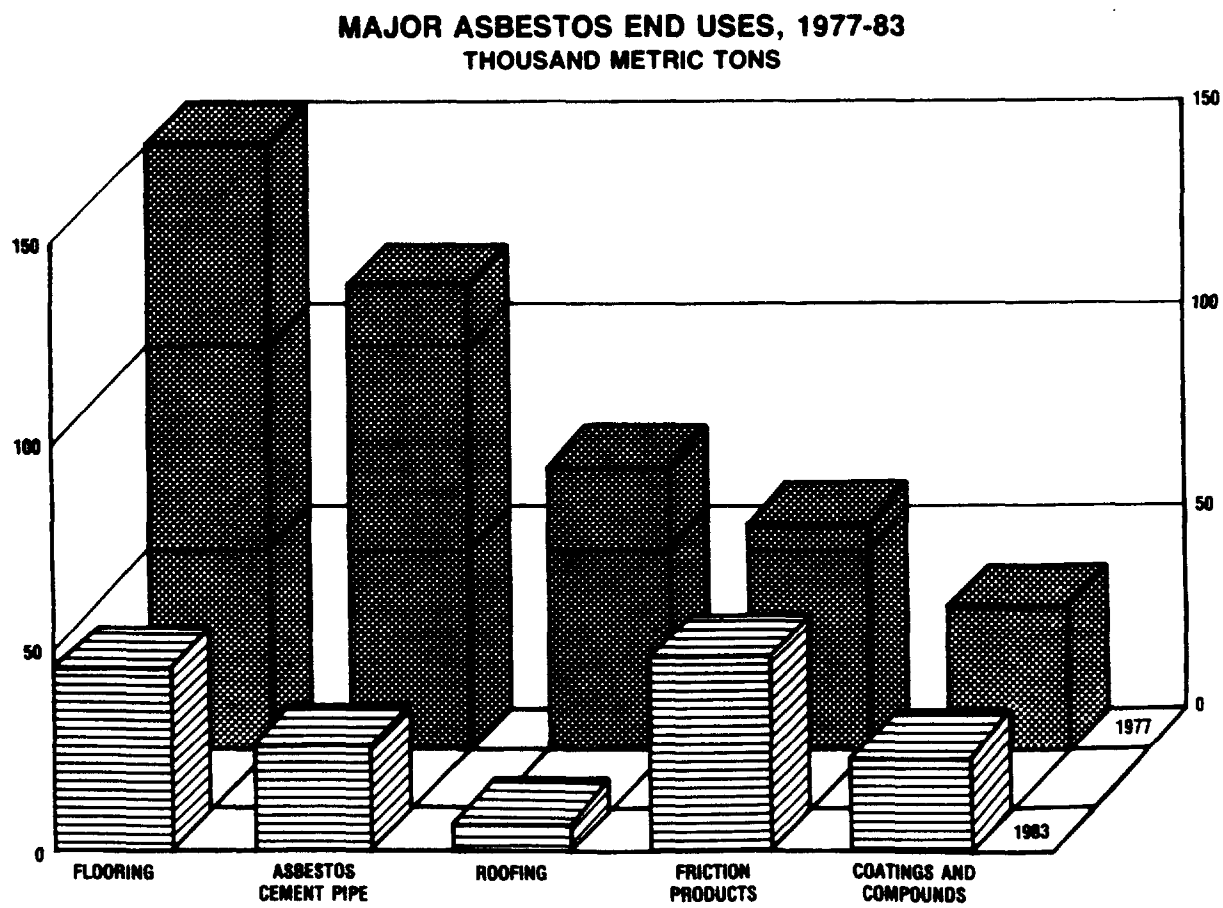

Figure 4.—Trend showing the decline of major asbestos uses during the 1977-83 period. Table below gives end-use data in thousand metric tons.

Year	Flooring	Asbestos cement pipe	Roofing products	Friction products	Coatings and compounds
1977	150	115	70	57	36
1978	138	106	64	53	33
1979	125	96	58	48	30
1980	70	42	24	52	11
1981	67	42	16	51	13
1982	49	38	7	53	25
1983	45	26	6	48	23

World Trade

If one were to remove from consideration the asbestos produced in China, nearly all of which is used domestically, that produced in the U.S.S.R., most of which is used domestically or in other Council for Mutual Economic Assistance countries, and Brazil's domestically consumed production, then a truer picture of Canadian prominence emerges. The world supply breakdown in 1983 then becomes Canada, 50%; the Republic of South Africa, 12%; Zimbabwe, 11%; Italy, 7%; Greece, 6%; and the United States, 4%.

Recycling

Asbestos fibers cannot be recycled in their common role of reinforcing a host matrix because removal from the matrix destroys the fibers.

There are few asbestos uses, mainly textile, that have uncombined fibers in the end product. When these products are no longer useful, neither is the asbestos because physical and/or chemical changes may have transformed it into a different mineral with less strength and/or shorter fibers that are of less value than the reclamation costs. Thus, asbestos is a nonrecyclable natural resource.

Substitutes

There is a great and continuing interest among present and potential manufacturers of both organic and inorganic fibers in acquiring some portions of the asbestos market. The environmental problems with asbestos make markets vulnerable to substitutes. Few substitutes, however, will be able to meet certain criteria sufficiently to acquire any substantial part of the asbestos market, even if the substitute is environmentally acceptable. A substitute must approach the strength, chemical inertness, durability, and cost of asbestos.

Ironically, the material that comes closest to meeting those criteria uses asbestos as the major raw material. The Quebec Government's Société Nationale de l'Amiante (SNA) has an asbestos substitute that, if it fulfills initial promise, could meet environmental objections and be substitutable across the board. The new material, "Chrysophosphate," is made by altering the surface characteristics of chrysotile asbestos by a phosphating process. Chrysophosphate is claimed to have greatly reduced biological reactivity compared with chrysotile with virtually no change in physical and engineering characteristics and little increase in cost.

BYPRODUCTS AND COPRODUCTS

Until recent times the only byproduct of record from asbestos production was a carefully designed mix of particle size blend of serpentine rock traction product from Vermont asbestos tailings that was excellent for use on ice and snow. Environmental fears killed that market.

Quebec's SNA, however, views the mountains of tailings from asbestos production as an already mined and variably crushed natural resource. This organization has a magnesium metal plant in operation using this resource. It has also demonstrated that, using the tailings as a sulfur scrubber, a new source of magnesium sulfate is the product of a successful pollution abatement effort at a smelter.

STRATEGIC CONSIDERATIONS

During World War II, controls were in effect to restrict exports of asbestos needed in the military program. These controls were removed by executive order on September 10, 1945. During the Korean war, the supply situation again became acute, and in 1950 and 1951 controls were invoked that required licenses for export of all grades of asbestos. The license requirement was removed for the nonspinning grades in 1953 and for spinning fibers in 1954; however, export licenses are still required for shipments to centrally controlled economy countries.

Table 5.—Stockpile status, March 31, 1984
(Metric tons)

Material	Goal	Total inventory
Asbestos, chrysotile	2,722	9,754
Asbestos, amosite	15,422	34,923
Asbestos, crocidolite	0	754

Chrysotile and amosite are the only types of asbestos having current strategic stockpile goals. The stockpile goal for chrysotile had been reduced to zero in 1976, but a 1977 moratorium on disposals preserved some stock prior to the new goal of 2,722 tons set in 1980.

The United States has been historically dependent upon foreign sources for about 90% of its requirements for all grades and types of asbestos. The only current source of low-iron, spinning-grade chrysotile asbestos is Zimbabwe. The only source of commercial grades and quantities of amosite is limited to an area in the Transvaal, Republic of South Africa. The United States is completely dependent on foreign sources for crocidolite. Although the United States is an asbestos-importing country, there is some export trade, because domestic chrysotile producers have a significant markets in Japan and Latin America. There are some reexports of foreign fibers.

ECONOMIC FACTORS

Prices

Depressed markets and high producer inventories of the last few years have caused negotiated asbestos prices to be lower than listed prices. Unit values calculated using import data have more realistically represented the domestic market prices. The average constant dollar value of imported asbestos increased significantly during the late 1970's but then returned to below the 1963 level. The average unit value of exported asbestos was $360 per metric ton in 1983.

Tariffs and Taxes

No tariffs are levied on imported asbestos, and no special taxes are levied on the asbestos industry.

Depletion Provisions

Producers are granted a depletion allowance of 22% on domestic production and 10% on foreign production.

Table 6.—Customs unit values of imported asbestos
(Dollars per metric ton)

	1979	1980	1981	1982	1983
Canada:					
Chrysotile:					
Cement	238	251	272	234	257
Crude	201	158	—	380	199
Spinning	868	843	927	917	932
Other	292	296	373	334	384
South Africa, Republic of:					
Amosite	499	1,811	728	771	840
Crocidolite	711	686	676	646	629

Table 7.—Time-price relationships for imported asbestos

Year	Average annual U.S. producer price, dollars per metric ton: Actual price	Based on constant 1983 dollars
1963	102	307
1964	109	323
1965	108	313
1966	111	312
1967	112	306
1968	109	285
1969	121	301
1970	127	300
1971	130	292
1972	129	278
1973	135	275
1974	135	253
1975	159	273
1976	226	368
1977	274	422
1978	273	391
1979	264	348
1980	281	340
1981	307	339
1982	268	279
1983	276	276

OPERATING FACTORS

Environmental Requirements

In 1970, Congress enacted the Clean Air Act. A provision of that act allowed the Administrator of the Environmental Protection Agency (EPA) to designate substances as "hazardous air pollutants." One of three substances named to the first list on March 31, 1971, was asbestos. EPA was the first Federal agency to address the growing controversy about the effects of asbestos dust upon the health of humans.

There is no consensus about a permissible exposure limit (PEL), or even a method of measuring exposure levels. EPA has indicated that no acceptable method exists to measure asbestos in the ambient air. The Occupational Safety and Health Administration (OSHA) of the U.S. Department of Labor uses a membrane filter and microscopy; the standard PEL is two fibers with an aspect (length to width) ratio of 3:1 or greater and greater than 5 micrometers in length per milliliter of air. The method used by the Mine Safety and Health Administration (MSHA) approaches the OSHA method and uses the two-fiber level.

Since 1981, a spate of actions have been taken by the regulatory agencies aimed at minimizing the perceived hazards of asbestos exposure. The following are among the significant ones:

In the Federal Register (FR) of May 27, 1983, the EPA published its rule on asbestos in school buildings. Under the rule, inspections and identification of friable asbestos-containing material are required of all public and private elementary and secondary schools. Inspection results must be maintained and communicated to a school's parent-teacher association. Employees must be notified of the location of friable asbestos materials and be provided with instructions on exposure reduction.

On July 27, 1983, in testimony before the Senate Subcommittee on Toxic Substances and Environmental Oversight, the EPA testified that within 1 year it would propose a ban on certain asbestos products. On February 1, 1985, the EPA announced its intention to refer the occupational safety or consumer risks associated with asbestos to OSHA and the Consumer Product Safety Commission (CPSC). This action, in effect, places on indefinite hold EPA's pending proposals to ban certain asbestos-containing products (asbestos cement pipe, flooring felts, roofing felts, and vinyl asbestos tile) and the phaseout of the remaining uses of asbestos over a 10-year period.

OSHA published in the Federal Register of November 4, 1983, its Emergency Temporary Standard (ETS), which lowers, by a factor of four, the permissible level of workplace exposure to asbestos. The ETS was challenged in the Fifth Circuit Court of Appeals by the asbestos industry, and on November 23, it was stayed. On March 7, 1984, the court issued the following ruling: "We determine the ETS to be invalid because the record, considered as a whole, does not indicate that the risk the ETS seeks to eliminate is 'grave,' as OSHA itself has defined it, or that the ETS is 'necessary,' as those terms are used in the ETS statute."

By notice in the FR of April 10, 1984, OSHA published its long-awaited proposal to revise the standard for occupational exposure to asbestos. In addition, OSHA's 1975 proposal was formally withdrawn and replaced by this action.

The regulatory text of the proposal is limited to two alternative PEL, 0.2 fiber per cubic centimeter and 0.5 fiber per cubic centimeter; requirement for an employee information and training program; and warning signs to be displayed at each location where a revised PEL may be exceeded. OSHA plans to adopt a new PEL, which reflects evidence that will be produced in the record concerning health risk and technical and economic feasibility and which may be higher or lower than the limits proposed. Hearings on the proposal were held during 1984. As part of a requested review, the U.S. Department of the Interior strongly suggested that the ASTM asbestos definition previously discussed in this report be adopted as the Federal definition.

Toxicity

There remain many conflicting reports on the health effects of asbestos and conflicts in the evaluation of the validity of such. The few areas of consensus are as follows:

1. Prolonged occupational exposure to heavy concentrations of asbestos dust, in the absence of personal protective devices, can measurably increase the changes of a person contracting a type of pneumoconiosis called asbestosis.
2. Exposure to asbestos may increase the chances of contracting the very rare type of cancer called mesothelioma.
3. Asbestos workers exposed to heavy concentrations of dust without respiratory protection, and who are also heavy smokers, have increased chances for contracting lung cancer.

Employment

Asbestos production in the United States has never been great. Reduction to two full-time mines and one part-time mine has not reduced the work force significantly. It is very difficult to judge the effect on the manufacturing plants of the reduction in asbestos use. Employment has been reduced in those asbestos-dependent industries such as asbestos cement pipe.

Energy Requirements

The Bureau of Mines conducted a comprehensive study of the energy used in the asbestos-mining industry in 1973 (table 8). The survey covered all producers in Arizona, California, North Carolina, and Vermont. Mining conditions have changed little since then. On a tonnage basis, energy used per ton of usable asbestos was equivalent to 1,500 kilowatt hours. Estimated cost was $3.5 million or $25.86 per ton calculated in 1983 dollars. The ease of mining the Coalinga, CA, deposit kept the energy requirements low.

Data extracted from a University of Illinois study demonstrate that asbestos extraction energy costs of a large Canadian mine and mill are higher than those of the average U.S. producer (*4*). Energy requirements per ton were 3,112 kilowatt hours. These data differ from a report from Battelle Columbus laboratories (*1*), which found the energy used per ton of asbestos produced to be 2,725 kilowatt hours.

Table 8.—Energy used by the U.S. asbestos mining industry

Source and unit		Used in mining	Used in milling	Total used	Total (thousand kilowatt hours)
Heavy fuel oil	thousand gallons	852	1,345	2,197	98,358
Natural gas	million cubic feet	—	168	168	50,738
Electricity	thousand kilowatt hours	2,641	44,974	47,615	47,615
Diesel oil	thousand gallons	412	133	545	22,147
Liquid petroleum gas	do	14	168	182	6,987
Gasoline	do	52	12	64	2,343
Total energy, thousand kilowatt hours		59,192	166,994	226,186	226,186

Table 9.—Energy consumed in the production of 1 metric ton of cleaned and graded chrysotile asbestos[1]

Stage and type of fuel	Amount	Equivalent thousand Btu
Mining:[2]		
Electric	42 kilowatt hours	550
Diesel fuel oil	11.12 gallons	1,852
Bunker 6C oil	1.48 gallons	270
Kerosene	0.04 gallon	8
Gasoline	0.51 gallon	77
Total		2,757
Primary crushing: Electric	7 kilowatt hours	87
Secondary crushing	75 kilowatt hours	983
Drying:		
Electric	42 kilowatt hours	550
No. 2 fuel oil	0.54 gallon	90
Bunker 6C oil	15.40 gallons	2,859
Propane	0.12 gallon	13
Total		3,512
Milling and grading: Electric	249 kilowatt hours	3,269
Grand total		10,608

[1]Mine-plant transportation not included.
[2]Based on a large Quebec mine with a 3 to 1 ore ratio, 6% fiber per ton of ore, and 25 to 30 inches of mine precipitation per year.

Source: University of Illinois. (*5*).

A study of the energy content of three cladding materials was done in the United Kingdom in 1979 for the Asbestos Information Centre (*7*). The study started at the mines for the raw materials and ended at the building site. All relevant and significant energy expenditures and credits were calculated.

The summary data showed that for each square meter of corrugated asbestos cement sheet laid, a total of 16.42 kilowatt hours of energy was used, for a square meter of corrugated aluminum sheeting, 68.92 kilowatt hours was used, and for a square meter of plastic coated corrugated sheet steel, 123.5 kilowatt hours was used.

PROBLEMS

It is difficult to separate environmental and economic causes for the decline in asbestos consumption in the United States and other mature market economy countries. It is true that the construction industry, which is the largest user of asbestos products, was hit hard by recession in the early 1980's and has yet to fully recover. It is also true that many countries have stopped just short of banning asbestos from the marketplace altogether because of the perceived health effects.

If, as some European prognosticators suggested, the decline in asbestos consumption was 70% economic and 30% environmental, then a return to a normal economy should result in recapture of 70% of the lost market, an optimistic assumption. Preliminary 1984 U.S. data reveal a 10% upturn in asbestos consumption.

The legal expenses incurred by the asbestos companies are high and act as a deterrent to retention of old markets and capture of new ones. The Manville case is illustrative of the problem. On August 26, 1982, the Manville Corp., formerly Johns-Manville Inc., filed a bankruptcy petition under Chapter 11 of the Federal Bankruptcy Code. Manville at that time was the largest producer of asbestos among the market economy countries, from its Canadian mines, and the largest manufacturer of asbestos-containing products in the United States. The purpose of the bankruptcy filing was to relieve the burden of 16,500 outstanding lawsuits against Manville in the asbestos-related disease area. Manville was also hopeful of legislative relief, which had, as of yearend 1984, failed to materialize. Since that time, Manville has sold all of its asbestos-producing mines and its asbestos-using manufacturing plants.

OUTLOOK

The 1965 edition of Mineral Facts and Problems predicted that U.S. asbestos consumption should reach 800,000 metric tons by 1970 and could, in the absence of a recession, reach 900,000 metric tons by 1975. The former was not reached until 1973, and the latter, never. Based on an anticipated healthy economy and with no forebodings of worsening environmental problems, that edition predicted that domestic production would continue to supply 10% of the Nation's needs. The recessions and environmental problems in the intervening years have drastically reduced domestic demand. With lowered demand, domestic production has increased its share of consumption, even with decreasing production, because transportation costs have given it a decided economic advantage over imports.

Demand

Consistent end-use data are available for only 7 years, not a long enough time series upon which to base a reliable statistical projection. That these 7 years were during periods of environmental pressures with some recessionary years exaggerates the downward trend. The forecast was derived by contingency forecasting of the major end-use demands, considering possible shifts caused by changing technology, dwindling resources, and environmental problems during the forecast period. It is important to remember that these forecasts come from the very low 1983 base.

It is forecast that domestic asbestos demand bottomed out in 1983 and that year's demand, 217,000 tons, will double by 2000 equal to an average annual growth rate of 4.4%. This is only superficially positive because demand in 2000 would only reach 57% of that in 1973. The rise in 1984 consumption, about 10%, may indicate that some markets may have begun to recover.

Rest-of-world demand is expected to show a slightly greater growth than that of the United States because the developing countries have a much greater new construction potential, and probably fewer environmental restraints. This average annual growth rate from 1983 to 2000 is estimated to be 4.5%. The low end of the range corresponds to an average annual growth rate of 3% and reflects a less rapid improvement in living standards in developing countries.

About one-half of asbestos consumption in the United States during 1983 was by the construction industry, and this ratio is expected to persist throughout the forecast period. Domestic de-

Table 10.—Projections and forecasts for U.S. asbestos demand by end use—2000
(Thousand metric tons)

End use	1983	2000			
		Statistical projections[1]	Contingency forecast for United States		
			Forecast range		Probable
			Low	High	
Asbestos cement pipe	26	0	25	150	100
Asbestos cement sheet	10	0	0	30	16
Coatings and compounds	23	61*	25	70	50
Flooring products	45	0	25	90	70
Friction products	48	2	50	160	120
Insulation	1	—	0	5	2
Packing and gaskets	12	0	0	30	10
Paper	2	0	0	10	2
Plastics	1	0	10	50	25
Roofing products	6	0	0	10	5
Textiles	1	0	0	4	2
Other	42	0	0	100	43
Total[2]	217	—	185	700	450

[1]Statistical projections, provided by the Branch of Economic Analysis, are derived from regression analyses based on 9-year or 23-year historical time series data and from forecasts of economic indicators, such as the GNP and FRB index. A statistical projection of zero indicates that demand will vanish at or before the year 2000, based on the historical relationship. Projection equations with a coefficient of determination (R-squared) less than 0.70 are indicated by an asterisk (*).

[2]May not add to totals shown because of independent rounding.

Table 11.—Summary of forecasts of U.S. and rest-of-world asbestos demand, 1990 and 2000
(Thousand metric tons)

	1983	2000 Forecast range		Probable		Probable average annual growth rate 1983–2000 (percent)
		Low	High	1990	2000	
United States:						
Total	217	185	700	310	450	4.4
Cumulative	—	3,400	7,300	1,900	5,600	—
Rest of world:						
Total	3,940	6,500	12,500	5,400	8,300	4.5
Cumulative	—	88,000	130,000	33,000	102,000	—
World:						
Total	4,157	6,685	13,200	5,710	8,750	4.5
Cumulative	—	91,400	137,300	34,900	107,600	—

mand for asbestos in the construction industry was forecast to increase to the year 2000 at an average annual rate range of 0.0% to 3.5% on the basis of total new construction.

Asbestos Cement Pipe.—These products, if asbestos for this use is banned, would have a negative growth rate. The low end of the forecast range, though, is thought to be zero growth. The high end could reach nearly 11% average annual growth rate with improvement of the environmental picture and if the money for needed sanitary and water systems is found. The probable demand in 2000 should nearly reach the 1977 high with an 8.3% average annual growth rate.

Asbestos Cement Sheet.—This product, which could disappear from the marketplace with a negative rate, has, as the high end of the forecast range suggests, a 6.7% average annual growth rate, or will, most probably, recapture lost markets at a 2.8% growth rate.

Coatings and Compounds.—Asbestos did not lose its place in this market as seriously as it did in other markets. The fact that the fibers are encapsulated and these products are nonfriable helped. This use could remain virtually static, recapture markets at a 6.8% average annual growth rate or, most probably, advance at a 4.7% average annual growth rate.

Flooring Products.—Asbestos in these products could continue to decline at a negative 3.4% rate, respond robustly to the tempering of the perceived environmental threat at a 4.2% rate of increase, or, most likely, recapture markets at a 2.7% average annual growth rate.

Friction Products.—In the total absence of viable substitutes, asbestos uses in these products have responded only to economic, not environmental, pressures. At worst there would be no growth, at best a 7.3% growth rate, and most probably a 5.6% average annual growth rate.

Insulation.—Asbestos could lose all of its markets in this area, recover markets at a healthy 14.5% growth rate, or most probably recover them at a 10% average annual growth rate.

Packing and Gaskets.—Asbestos could lose its entire share of this market to the substitutes now available, recover most of the lost market leading to a 5.6% growth rate, or, most probably, continue to lose markets at an average annual negative growth rate of 1.0%.

Paper.—Asbestos in paper could easily lose its entire share of this market. Economic and technical factors could, however, with a more objective environmental view, allow the market to respond at a 10% growth rate. A zero growth rate, however, is likely.

Plastics.—Asbestos has never achieved the share of this market that its tensile strength and low cost would suggest in these products, in which it is fully encapsulated. At the least it should more than recapture its former market share and this would require a growth rate of 14.5%. A market in 2000 of 50 times greater than that in 1983 is below some industry forecasts. A market of 25 times that of 1983 seems most probable.

Roofing Products.—The asbestos markets in roofing products have declined greatly in recent years. A total loss of market represents the low end of the forecast range. Also possible, as the high end of the range, is market recovery at a 3.7% growth rate. Most likely is a zero or slightly negative growth.

Textiles.—Asbestos in textiles has lost most of the market because of high visibility and perceived peril. Total loss of market is quite possible as is partial recovery at an 8.5% growth rate. Most likely is a 4.2% average annual growth rate.

Other.—The many small markets covered here may be the most vulnerable to environmental pressure, and many probably will vanish while new uses may appear. However, the availability of low-cost, short-fiber asbestos in large quantities from domestic

Table 12.—Adequacy of U.S. and world asbestos reserves
(Thousand metric tons of asbestos)

	United States	Rest of world	World total
Reserves	4,000	106,000	110,000
Cumulative demand, 1983-2000	5,600	102,000	107,600

sources will likely impact significantly on the mineral filler market for a wide range of end products, particularly in products that must withstand high-temperature or corrosive conditions. Therefore, these markets could vary from total loss to an average annual growth rate of 5.3% or higher, but will most probably have a near-zero growth rate.

Adequacy of Supply

The United States has been dependent on foreign supplies of asbestos for certain essential and strategic grades. Canada supplies most of our requirements for chrysotile, with South Africa supplying amosite and crocidolite. Advancing technology in the use of substitutes could shift the U.S. position from heavy reliance on foreign supplies for this mineral.

Domestic resources of chrysotile are found mostly in California, Vermont, and Arizona. Although deposits are known to exist also in Montana, Oregon, Wyoming, and a few other States, production from these has been negligible. California has the greatest potential of becoming a substantial producer of short-fiber asbestos.

U.S. and Canadian chrysotile resources are more than ample to meet the high end of the forecast domestic demand for the year 2000. Small domestic requirements for amosite will continue to come from the Republic of South Africa unless deposits of a similar asbestos are discovered in other countries, or unless adequate substitutes become available at competitive prices, thereby providing acceptable options to the consumers. Crocidolite asbestos will also be obtained from the Republic of South Africa, and perhaps from Australia or Bolivia, so long as it remains competitive with chrysotile. However, substitution is practicable in its end uses, and continuation of a crocidolite supply is not particularly critical.

Possible Supply-Demand Changes

U.S. domestic demand for asbestos is controlled primarily by the perceived health threat. The absence of more stringent environmental restrictions on the use of asbestos could significantly increase demand. New potential users of asbestos are currently discouraged by the environmental problem, and it is not expected that demand will ever again approach that of the late 1970's. The concept of again having worldwide scarcities is remote. The present Canadian reserve base assures an adequate supply well into the next century.

Possible Technological Progress

Little or no applications research is under way to improve asbestos markets. Large laboratories such as the former one operated by Johns-Manville are no longer supporting this type of research.

Quebec's SNA Crysophosphate asbestos substitute may have promise. This reportedly environmentally safe substitute is fabricated from asbestos. New products are also being developed from asbestos mining wastes by SNA. Lowering the effective recovery cost of asbestos might aid in the marketing of this unique, versatile, and low-cost raw material.

Table 13.—Comparison of U.S. asbestos production and demand, 1963–83, 1990, and 2000
(Thousand metric tons)

Year	U.S. demand	U.S. production
1963	657	60
1964	738	92
1965	721	107
1966	730	114
1967	654	112
1968	741	110
1969	711	114
1970	686	113
1971	689	119
1972	734	120
1973	795	136
1974	788	103
1975	[e]700	89
1976	680	105
1977	609	92
1978	619	93
1979	561	93
1980	359	80
1981	349	76
1982	247	64
1983	217	70
1990	[1]310	[2]78 [e]85
2000	[1]450	[2]62 [e]80

[e]Estimated.
[1]Probable forecast from table 11.
[2]21-year trend projection.

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