ASBESTOS INFORMATION ASSOCIATION
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27 April 1977

Memorandum For: B. Iwarsson, Abex Corporation
W. Jones, Safeguard Automotive Corp.
J. Marsh, Raybestos-Manhattan, Inc.
J. Riopelle, Bendix Corporation
W. Sleeth, Royal Industries
E. Zacharias, Molded Materials Company

Subject: EPA Contracted Study with Syracuse University Research Corp -- Friction Materials

In May of 1975 the Environmental Protection Agency contracted with Syracuse University Research Corp. for an Industrial Chemical Market Input/Output Profile in connection with studies of its Office of Toxic Substances. The contract (initially listed in the amount of $99,700) has been discontinued because of lack of funds, we have learned. However, on the subject of asbestos in the study, the general sections, and a section on friction materials were completed and submitted to EPA in draft form.

This material is forwarded as a matter of interest. Please be advised that the paper is in draft form and has not been formally released by EPA. Therefore, it should not be quoted. The work by Syracuse University Research Corp. appears to be of high quality. Your comments will be appreciated.

R. H. Mereness
Executive Director

cc: Standards & Technical Committee (Rhodes, Weaver,Weber, Fenner)
Mr. Drislane, FMSI

RHM:v
Enclosures

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D R A F T

CHEMICAL MARKET INPUT/OUTPUT ANALYSIS OF ASBESTOS TO ASSESS SOURCES OF ENVIRONMENTAL CONTAMINATION

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Contract No. 68-01-3224 - Task III
SRC No. L1273-08

March 1977

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Prepared for:

Office of Toxic Substances
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Washington, D.C. 20460

NOTICE

This document is a preliminary draft. It has not been formally released by EPA and should not at this stage be construed to represent Agency policy. It is being circulated for comment on its technical accuracy and policy implications.

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1.0 INTRODUCTION

This study on the commercial market and environmental sources of asbestos was undertaken for the following reasons: (a) to consolidate the large volume of published literature in an attempt to describe the asbestos industry and the uses of asbestos in terms of marketing data and statistics; and (b) to examine the potential for asbestos emissions from final end-use products. Asbestos emissions from mining and milling operations and from industrial factories have been examined in reasonable detail by previous EPA reports. However, no comprehensive attempt has been made to examine the sources and quantities of asbestos which may be released to the environment from asbestos-containing products. Unfortunately, because of limited funds, this report considers only the asbestos emissions from friction materials such as brake linings and clutches.

2.0 DESCRIPTION OF ASBESTOS

2.1 Composition and Properties of Asbestos

"Asbestos" is not the name of a distinct mineral species but is a commerical term applied to fibrous varieties of several minerals differing widely in chemical composition, the fibers being diverse in length, strength, flexibility, and consequent usefulness (The Asbestos Factbook, 1970). The varieties of asbestos most used commercially are chrysotile, amosite, crocidolite, and anthophyllite. Chrysotile, which accounts for approximately 95% of all asbestos consumed commercially, is of the serpentine group of fibers, while the other varieties (crocidolite, amosite, anthophyllite, tremolite, and actinolite) are of the amphibole group of fibers. Among the amphibole asbestoses, amosite and crocidolite are the most important commercially; anthophyllite, tremolite, and actinolite account for only minor commercial consumption (Kover, 1976; Clifton, 1975). Sometimes the literature refers to the common asbestoses with jargon names: "white asbestos" for chrysotile and "blue asbestos" for crocidolite (Berger and Oesper, 1963).

While the asbestoses differ in chemical composition, they share similar polymeric silicate structure. The fibrile-like structures of the asbestoses result from linear chains of silicate tetrahedra. Chrysotile and amphibole asbestoses fundamentally differ by the number and shape of the silicate units. These differences can be visually identified from Figures 2.1 and 2.2, which are structure schematics of chrysotile and amphibole, respectively. Chrysotile consists of Si_2O_5 silicate units arranged in double layers and formed into a laminar structure. The chrysotile Si_2O_5 layers are joined by brucite (magnesium hydroxide) layers. This double layered structure is contorted in

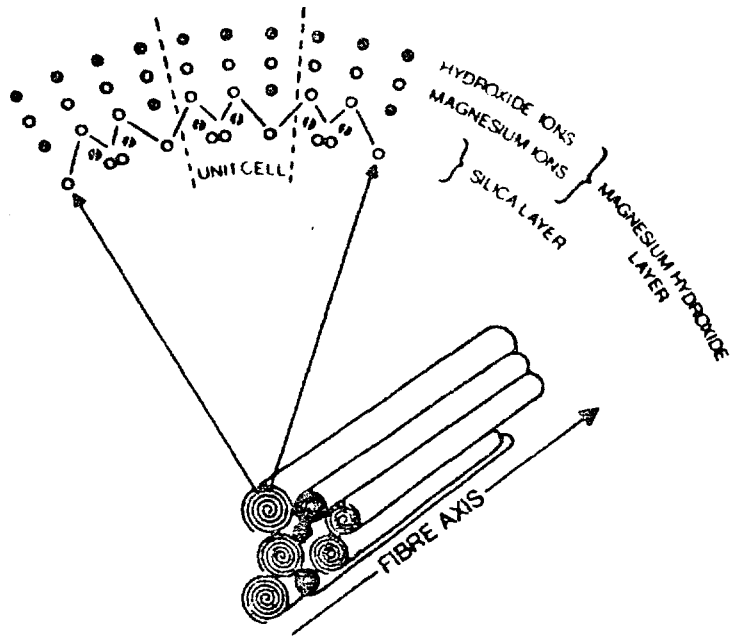

Figure 2.1. Schematic Diagram of the Structure of a Chrysotile Fibre Formed of Several Scrolls of Individual Crystallites (Each scroll is formed from a closely connected double layer having magnesium hydroxide units on its external face and silica units on its inner face. The details of a small section of the scroll show the structure of the double layer and of the unit cell based on $Mg_3(Si_2O_5)\ (OH)_4$.) (Kover, 1976)

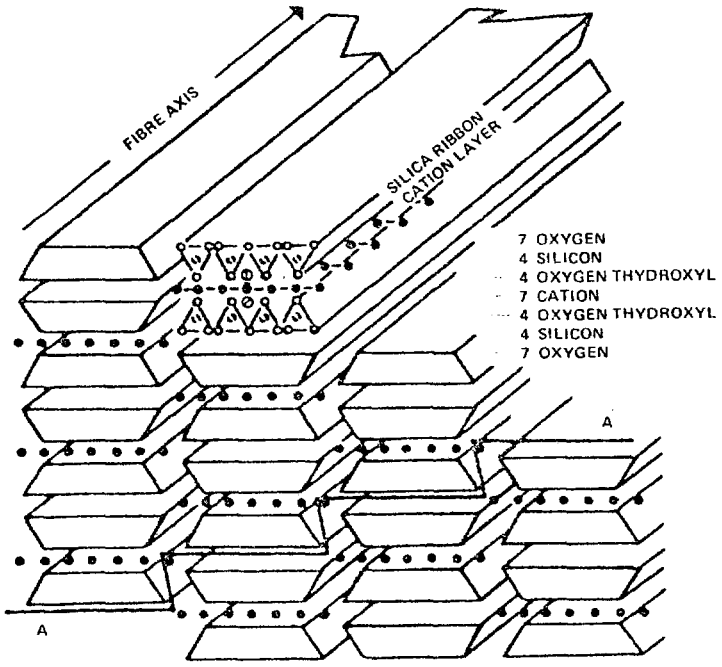

Figure 2.2. Schematic Diagram of the Crystal Structure of an Amphibole Fiber, Indicating the Unit Cell Based on $X_7Si_8O_{22}(OH)_2$ (The line A-A represents the edge of the preferred cleavage plane along which the fibres will split to form even smaller fibres.) (Kover, 1976)

tubes in which the brucite forms the outer fiber layer. The amphiboles contain silicate as Si_4O_{11} double chains in a banded structure. The chains are united by intercalcated cations and form as solid fibers (Berger and Oesper, 1963; Badolette, 1963; Kover, 1976).

Unlike the synthetic chemicals which usually exhibit unique chemical compositions, the asbestoses are composed of mixed inorganic oxides. The various asbestoses are characterized by ranges of these oxides rather than precise molecular formulas. Table 2.1 below gives the approximate chemical formula for each of the varieties of asbestos, while Table 2.2 lists the typical ranges of mixed oxide compositions for the asbestoses and a few related minerals.

Table 2.1. Approximate Chemical Formula of the Asbestoses
(The Asbestos Factbook, 1970)

Chrysotile	$3MgO\ 2SiO_2\ 2H_2O$
Crocidolite	$Na_2O\ Fe_2O_3\ 3FeO\ 8SiO_2\ H_2O$
Amosite	$1.5MgO\ 5.5FeO\ 8SiO_2\ H_2O$
Anthophyllite	$7MgO\ 8SiO_2\ H_2O$
Tremolite	$2CaO\ 5MgO\ 8SiO_2\ H_2O$
Actinolite	$2CaO\ 4MgO\ FeO\ 8SiO_2\ H_2O$

Since asbestos is a metamorphic mineral, its composition reflects the composition of the surrounding minerals and its formation conditions. Therefore, the oxide composition range differs for asbestoses of different geographical origin, as evident from Table 2.3. The asbestoses contain relatively few elements. In

Table 2.2. Chemical Composition of Common Fibrous Silicate Minerals (Kover, 1976)

	Typical ranges, wt-%								
	SiO_2	MgO	FeO	Fe_2O_3	Al_2O_3	CaO	K_2O	Na_2O	H_2O
Chrysotile	38-44	40-43	0-0.8	0.5-4	0.3-0.9	0-1.0	Trace	Trace	13-14
Crocidolite	49-53	0-3	13-20	17-20	0-0.2	0.3-2.7	0-0.4	4-8.5	2.5-4.5
Amosite	49-53	1-7	34-44	-----	-----	-------	0-0.4	Trace	2.5-4.5
Anthophyllite	56-58	28-34	3-12	-----	0.5-1.5	-------	-----	-------	1-6
Actinolite	51-56	15-20	5-15	0-3	1.5-3	10-12	0-0.5	0.5-1.5	1.5-2.5
Tremolite	55-60	21-26	0-4	0-0.5	0-2.5	11-13	0-0.6	0-1.5	0.5-2.5
Talc	60-63	30-32	0.6-2.5	0-1.5	0-2.5	0-1.4	-----	-------	0-0.3
Hornblende	39-54	3-25	0.2-23	0-9	4-15	9-13	0-1.7	0.5-4.3	0-2.6
Orthopyroxene	44-60	4-39	3.5-48	0-3	0-8	0.2-4.2	0-0.6	0-0.9	0-0.8

addition to silicate and water, they generally contain the oxides of magnesium, calcium, iron, and/or sodium. Aluminum and potassium oxides are sometimes present as trace "impurities." The "impurities" are defined as the oxides which are not accounted in the approximate chemical composition. They can either form part of the polymeric structure or occur as occlusions within the fibers (Berger and Oesper, 1963).

Table 2.4 describes some of the properties important in the commercial uses of asbestos. The properties of asbestos that give it commercial value are its fibrous structure, the great strength of its fibers, and its resistance to high temperatures and to certain types of chemical attack.

Chrysotile asbestos excels commercially due to its fineness of fiber, high flexibility, good heat resistance, general workability, and ample supply. The longer fibers can be spun easily into textile materials. However, chrysotile degrades faster than the amphiboles in water, acids, or alkalis. This results from the solubility and reactivity of the brucite. While amphiboles lose only ca. 9% of their weight in 4N HCl after eight hours at 100°C, chrysotile looses all magnesium hydroxide (60% of its weight) after only one hour in 1 N HCl at 95°C (Berger and Oesper, 1963). When chrysotile is extracted by the Soxhlet procedure for four hours with aqueous alkali (pH 10.33), it loses a high percentage of magnesium ion and yields magnesium silicate. Crocidolite, when treated by the same conditions, will leach only 4% silica and 6% sodium (Berger and Oesper, 1963). Because crocidolite and amosite fibers are highly acid-resistant, they are particularly valuable for use in chemical plant applications. Anthophyllite and tremolite fibers are too brittle to be spun or used as fibrous reinforcements but, because of their resistance to attack by certain chemicals, are used for filtering purposes in chemical processing plants and in laboratories.

Table 2.3. Chemical Composition of Asbestoses from Different Geographic Locations (The Asbestos Factbook, 1970)

Variety and Location	SiO_2 (Silica)	FeO (Ferrous Oxide)	Fe_2O_3 (Ferric Oxide)	Al_2O_3 (Alumina)	MgO (Magnesia)	CaO (Lime)	MnO (Manganese Oxide)	Na_2O (Sodium Oxide)	K_2O (Potassium Oxide)	H_2O- (Combined Water)	H_2O+ (Combined Water)
Chrysotile (Quebec)	40.2	1.0	0.5	2.9	39.9	1.1	0.1	0.1	0.1	0.8	13.4
Chrysotile (So. Rhodesia)	39.7	0.7	0.3	3.2	40.3	1.1	0.3	0.1	0.1	0.6	12.2
Chrysotile (Ural Mts.)	38.1	1.3	1.4	5.0	37.7	2.2	0.1	0.1	0.1	0.8	11.1
Crocidolite (Cape Province)	50.9	20.5	16.9	nil	1.1	1.5	0.1	6.2	0.2	0.2	2.2
Crocidolite (Australia)	52.8	14.9	18.6	0.2	4.6	1.1	Trace	6.0	0.1	0.2	2.8
Crocidolite (Bolivia)	55.7	3.8	13.0	4.0	13.1	1.5	Trace	6.9	0.4	Trace	1.8
Amosite (Transvaal)	49.4	40.6	0.1	nil	6.7	0.7	0.7	0.1	0.2	0.1	1.9
Anthophyllite (Finland)	59.1	6.7	1.0	0.9	29.7	0.1	0.2	0.1	0.1	0.5	2.4
Tremolite (Pakistan)	55.1	2.0	0.3	1.1	25.7	11.5	0.1	0.3	0.2	3.5	0.2
Actinolite (Cape Province)	53.8	25.3	2.0	1.2	4.3	10.2	0.4	0.4	0.1	0.2	2.6

Table 2.4. Physical, Chemical, and Mineralogical Properties of Varieties of Asbestos (Kover, 1976)

Property	Chrysotile	Crocidolite	Amosite	Anthophyllite	Tremolite	Actinolite
Chemical formula	$Mg_3Si_2O_5(OH)_4$	$Na_2Fe_3Si_8O_{22}(OH)_2$	$(FeMg)_7Si_8O_{22}(OH)_2$	$(FeMg)_7Si_8O_{22}(OH)_2$	$Ca_2Mg_3Si_8O_{22}(OH)_2$	$(CaMgFe)_5Si_8O_{22}(OH)_2$
pH	9.2 to 9.8	--	--	Neutral	--	--
Resistance to acids	Poor	Good	--	--	Good	Good
Veining	Cross and slip fibers	Cross fiber	Cross fiber	Slip, mass fiber unoriented and interlacing	Slip or mass fiber	Slip or mass fiber
Color	Green, gray, amber to white	Blue	Gray, yellow to dark brown	Yellowish brown, grayish white	Gray-white, greenish, yellowish, bluish	Greenish
Texture	Soft to harsh, also silky	Soft to harsh	Coarse but somewhat pliable	Harsh	Generally harsh, sometimes soft	Harsh
Luster	Silky	Silky to dull	Vitreous, somewhat pearly	Vitreous to pearly	Silky	Silky
Hardness[a]	2.5 to 4.0	4	5.5 to 6.0	5.5 to 6.0	5.5	6±
Flexibility	High	Good	Good	Poor	Poor	Poor
Spinnability	Very good	Fair	Fair	Poor	Poor	Poor
Tensile strength, lb. in.^{2}	824,000 max.	876,000 max.	16,000 to 90,000	4,000 and less	1,000 to 8,000	1,000 and less
Fusion point, °F	2,770	2,180	2,550	2,675	2,400	2,540
Specific heat, Btu/lb.°F	0.266	0.201	0.193	0.210	0.212	0.217

[a]Working Scale of Hardness: 1 - very easily scratched by fingernail, and has greasy feel to the hand; 2 - easily scratched by fingernail; 3 - scratch by brass pin or copper coin; 4 - easily scratched by knife; 5 - scratch with difficulty with knife; 6 - easily scratched by file; 7 - little touched by file, but will scratch window glass. All harder than 7 will scratch window glass.

Table 2.4. Physical, Chemical, and Mineralogical Properties of Varieties of Asbestos (Cont'd)

Property	Chrysotile	Crocidolite	Amosite	Anthophyllite	Tremolite	Actinolite
Electric charge	Positive	Negative	Negative	Negative	Negative	Negative
Filtration properties	Slow	Fast	Fast	Medium	Medium	Medium
Specific gravity	2.4 to 2.6	3.2 to 3.3	3.1 to 3.25	2.85 to 3.1	2.9 to 3.2	3.0 to 3.2
Cleavage	010 perfect	110 perfect	110 perfect	110 perfect	110 perfect	110 perfect
Optical properties	Biaxial positive, extinction parallel	Biaxial ±, extinction inclined	Biaxial positive, extinction parallel	Biaxial positive, extinction parallel	Biaxial negative, extinction inclined	Biaxial negative, extinction inclined
Refractive index	1.50 to 1.55	1.7 pleochroic	1.64±	1.61±	1.61±	1.63± weakly pleochroic
Resistance to destruction by heat	Good, brittle at high temperatures	Poor, fuses	Good, brittle at high temperatures	Very good	Fair to good	--
Temperature at ignition loss, °F	1,800	1,200	1,600 to 1,800	1,600	1,800	--
Magnetic content,%	0.0 to 5.0	3.0 to 5.9	0	0	0	--
Crystal structure	Fibrous and asbestiform	Fibrous	Prismatic, lamellar to fibrous	Prismatic, lamellar to fibrous	Long and thin columnar to fibrous	Long and thin columnar to fibrous
Crystal system	Monoclinic and orthorhombic	Monoclinic	Monoclinic	Orthorhombic	Monoclinic	Monoclinic
Mineralogical structure	In veins of serpentine, etc.	Fibrous in iron stones	Lamellar, coarse to fine fibrous and asbestiform	Lamellar, fibrous asbestiform	Long, prismatic and fibrous aggregates	Reticycled long prismatic crystals and fibers
Mineral association	In altered peridotite adjacent to serpentine and limestone near contact with basic igneous rocks	Iron rich silicious argillite in quartzose schists	In crystalline schists, etc.	In crystalline schists and gneisses	In Mg limestones as alteration product of magnesian rocks, metamorphic and igneous rocks	In limestones and in crystalline schists

Since asbestos is often used in the manufacture of insulation for electrical equipment, its electrical conductance is an important property. Its conductance is related to the magnetite (Fe_3O_4) content. As the content of this impurity increases, the asbestos conductance also increases (Berger and Oesper, 1963).

The thermal stability is limited by asbestos metamorphosis to other mineral forms. The fusion points listed in Table 2.4 are not melting points for the asbestoses, but correspond to the fusion temperature of the metamorphic products. Chrysotile, for example, is thermally transformed to the minerals olivine or enstatite at a rate dependent upon time and temperature. The transformation may be important to assess some environmental losses for certain uses, such as in brake linings (Berger and Oesper, 1963).

2.2 Asbestos Grading

Asbestos is graded by fiber length. It is not commonly graded by mineralogical content or other properties. The Quebec Standard for chrysotile is the most important, because most asbestos consumed in the U.S. is graded by this system. The Quebec Standard measures the distribution of fibers after sieving a 16 ounce sample through a system constructed of four boxes: three screens and a "pan" for fines:

Box Number	Screen Opening	Diameter of Wire
1	0.500"	0.105"
2	0.187"	0.063" (4 mesh)
3	0.053"	0.047" (10 mesh)

Asbestos fibers are graded in nine groups: Groups No. 1 and 2 are hand-cobbled crudes and the remainder are milled fibers. Group No. 1 is basically 3/4" staple and longer fibers, which makes the best spinning grade. Group No. 2 includes

spinning fibers of lower quality. The milled fibers are grouped according to the box distributions listed in Table 2.5 (Berger and Oesper, 1963; The Asbestos Factbook, 1970).

Other grading systems are also used for chrysotile and the amphibole asbestoses. They also grade fibers by length. U.S. mined asbestos basically follows the Quebec Standard. Table 2.6 describes the modifications used for Arizona and California mined asbestos.

2.3 Major Uses of the Asbestoses

The following discussion briefly describes the major uses for the asbestoses and the reasons why they are used. Market input/output data concerning the quantities consumed according to use and grade are given in Section 4.0.

2.3.1 Chrysotile

Chrysotile dominates the asbestos consumed in total quantity, value, and number of products. It accounts for about 95% of all the asbestos commercially consumed.

(a) Asbestos Textiles

The long chrysotile fibers (Grades No. 1, 2, and 3) are predominantly used for textile manufacture. The textile products can eventually be marketed as textiles such as safety clothing, drapes and curtains, wicks, etc. or they can be further processed with resins and other additives in the manufacture of friction materials, gaskets, laminated plastics, etc. (Kover, 1976; Hendry, 1965; The Asbestos Factbook, 1970; Clifton, 1975).

(b) Asbestos Cement

Medium sized chrysotile fiber (Groups No. 4 to 7) dominate in production of asbestos cement products (pipe and sheet). Asbestos cement

Table 2.5. Chrysotile Grades by the Quebec Standard Test
(The Asbestos Factbook, 1970)

Standard Grade Designation	Fiber Description
Group No. 1, Crude No. 1	- consists basically of crude 3/4" staple and longer
Group No. 2, Crude No. 2	- consists basically of crude 3/8" staple up to 3/4"
Group No. 2, Crude run-of-mine	- consists basically of unsorted crudes
Group No. 2, Crudes sundry	- consists of crudes other than above specified
Groups No. 3 through No. 9	- are "Milled Asbestos"

Guaranteed Minimum Shipping Test
(Distribution of 16 oz. of Fibers)

		Box 1	Box 2	Box 3	Pan (fines)
Group No. 3:	3F	10.5	3.9	1.3	0.3
	3K	7.0	7.0	1.5	0.5
	3R	4.0	7.0	4.0	1.0
	3T	2.0	8.0	4.0	2.0
	3Z	1.0	9.0	4.0	2.0
Group No. 4:	4A	0.0	8.0	6.0	2.0
	4D	0.0	7.0	6.0	3.0
	4H	0.0	5.0	8.0	3.0
	4J	0.0	5.0	7.0	4.0
	4K	0.0	4.0	9.0	3.0
	4M	0.0	4.0	8.0	4.0
	4R	0.0	3.0	9.0	4.0
	4T	0.0	2.0	10.0	4.0
	4Z	0.0	1.5	9.5	5.0
Group No. 5	5D	0.0	0.5	10.5	5.0
	5K	0.0	0.0	12.0	4.0
	5M	0.0	0.0	11.0	5.0
	5R	0.0	0.0	10.0	6.0
	5Z	0.0	0.0	8.6	7.4

Table 2.5. Chrysotile Grades by the Quebec Standard Test (Cont'd)

		Box 1	Box 2	Box 3	Pan (fines)
Group No. 6	6D	0.0	0.0	7.0	9.0
Group No. 7	7D	0.0	0.0	5.0	11.0
	7F	0.0	0.0	4.0	12.0
	7H	0.0	0.0	3.0	13.0
	7K	0.0	0.0	2.0	14.0
	7M	0.0	0.0	1.0	15.0
	7R	0.0	0.0	0.0	16.0
	7T	0.0	0.0	0.0	16.0
	7W	0.0	0.0	0.0	16.0
Group No. 8	8S	under 50 lbs/cubic foot loose measure			
	8T	under 76 lbs/cubic foot loose measure			
Group No. 9	9T	over 75 lbs/cubic foot loose measure			

Table 2.6. Modifications in Grading American Mined Asbestos (The Asbestos Factbook, 1970)

ASBESTOS GRADES IN ARIZONA

Source: Metate Asbestos Corporation, Globe, Arizona

The same "Guaranteed Minimum Shipping Tests" are used in Arizona as are used in Canada, with the following exceptions:

3Z (Soft Filter Grade) is held to - 0 10 4 2

Special Sugar Grade LX-222-NAW is held to about Canadian Grade 3T - 2 8 4 2

All other Arizona Grades follow Canadian grading procedures but add the following designations:

S	- Soft
H	- Harsh
AW	- Acid Washed
NAW	- Non-Acid Washed

ASBESTOS GRADES IN CALIFORNIA

Source: Coalinga Asbestos Company, Inc., Coalinga, California

The following short Chrysotile asbestos fiber grades are available from Johns-Manville Corporation's Coalinga Mine at Coalinga, California. While the chemical composition of Californian fibers is very similar to that of Canadian Chrysotile, they are typically lighter in color, lower in fines content and higher in surface area.

ULTRABESTOS Red Brand: a high surface area, high absorption, low fines general-purpose short fiber.

ULTRABESTOS Blue Brand: a high quality, low fines short fiber somewhat similar to Canadian Grade 7R. This Grade is prepared especially for use in vinyl floor tile.

Coalinga Floats: an extremely short fiber having a minus 200 mesh content of approximately 95% by the McNett test. (See page 23 for a description of this test.)

Coalinga Paperbestos-100: an extremely short fiber prepared for use in the papermaking industry as a pitch control and pigment retention aid.

Coalinga Asbaltic: a medium absorption short fiber for asphalt paving applications.

products account for the major portion of the asbestos consumption, both in tonnage of fiber and market value. The properties which contribute to its commercial position include fiber length and tensile strength (Kover, 1976; Carton, 1974; Berger and Oesper, 1963; Clifton, 1976).

(c) Asbestos Paper and Felt

Properties for which chrysotile is used in this product segment include its capacity for heat and electrical insulation, its chemical and thermal stability, its strength and flexibility (Kover, 1975; Carton, 1974; Hendry, 1965). Chrysotile grades from 3 to 7 are predominantly used (Berger and Oesper, 1963; Clifton, 1975).

(d) Composition Materials

The composition materials include plastics, asbestos-vinyl and asbestos-asphalt products, coatings, and compounds. Chrysotile is added to these products generally as a filler and reinforcement medium (Modic and Barsness, 1965; Seymour, 1968; Grove and Rosato, 1967). The longer fibers (including Grades No. 1 and 2) are used in the production of high grade laminated plastics. The short fibers (Grades No. 4 and shorter) dominate in the manufacture of most other composition materials (Clifton, 1975; Berger and Oesper, 1963). Although the quantity of fibers used in these products is large (the second largest consumption of fibers), the low value of the short fibers results in a low commercial value for asbestos used in this market segment.

(e) Friction Materials

The properties for which asbestos is used in friction materials include its capacity for thermal stability, its ability to act as a reinforcing agent, as a filler, for the regulation or inhibition of resin flow, its lower

abrasion than other fillers of its price range, and its dispersion of metal chips and other particulates (Hendry, 1965). While the fiber lengths of Grades No. 4 to 7 dominate the friction materials, some longer fibers are also used (Clifton, 1975).

(f) Packing and Gaskets

Chrysotile use in packings and gaskets is accounted for by its strength, resiliency, durability, toughness, and thermal stability (Hendry, 1965; Kover, 1976). Fiber length predominantly ranges from Grades No. 4 to 7, although some Grades 1 through 3 are also consumed (Clifton, 1975; Berger and Oesper, 1963; SRI, 1974).

2.3.2 Crocidolite

Crocidolite fibers are shorter and more brittle than chrysotile but have a slightly higher tensile strength. Crocidolite is principally consumed for the manufacture of asbestos cement products (Kover, 1976; Clifton, 1976). While it can be spun into fibers, its spinnability is not equivalent to chrysotile. Longer crocidolite fibers are sometimes mixed with chrysotile for textile production (Berger and Oesper, 1963). It is used as replacement for chrysotile fibers in some laggings, insulations, filter media, and packings exposed to corrosive (acid or alkali) substances (Fisher, 1967; Hendry, 1965; Kover, 1976). Long crocidolite fibers are also consumed in asbestos boards and papers (Berger and Oesper, 1963).

2.3.3 Amosite

Amosite has lower tensile strength than chrysotile or crocidolite by more than an order of magnitude. It is consumed mainly in asbestos cement products. Other major uses are in various thermal insulations, including pipe and boiler coverings, bulkhead linings in ships, and 85% magnesia insulation (Hendry, 1965; Kover, 1976).

2.3.4 Tremolite and Actinolite

Both tremolite and actinolite are of low tensile strength and are brittle. They have only minor commercial use. They are primarily consumed as cheap fillers and as filtering mediums. Tremolite is sometimes purified by acid treatment for special filtering purposes (Kover, 1976; Hendry, 1965).

2.3.5 Anthophyllite

Anthophyllite is also of minor commercial value. It is mainly used as a filler in rubber, plastics, adhesives, and asbestos cement products (Kover, 1976; Hendry, 1965; Clifton, 1975).

3.0 DESCRIPTION OF THE ASBESTOS INDUSTRY

3.1 Industry Structure

Figure 3.1 below is a simple illustration showing the movement of asbestos within the asbestos industry.

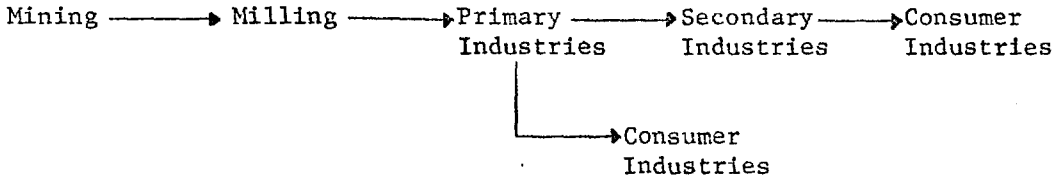

Figure 3.1. Asbestos Industry Structure

The following definitions have been adopted (Daly et al., 1976):

Primary Industries: those industries that start the manufacturing process with raw asbestos fiber and modify the fiber to produce an intermediate product (to be further processed or fabricated) or a finished product.

Secondary Industries: those industries that continue the manufacturing process with an intermediate asbestos product (one in which the fiber has previously been modified in a primary industry), and further process, modify, or fabricate it to produce either another intermediate product (to be further processed or fabricated) or a finished product.

Consumer Industries: those industries that purchase a finished asbestos-containing product (from a primary or secondary industry), and apply, install, erect, or consume the asbestos-containing product without further physical modification of the product.

This classification is depicted in Figure 3.2, which categorizes the various end uses by products.

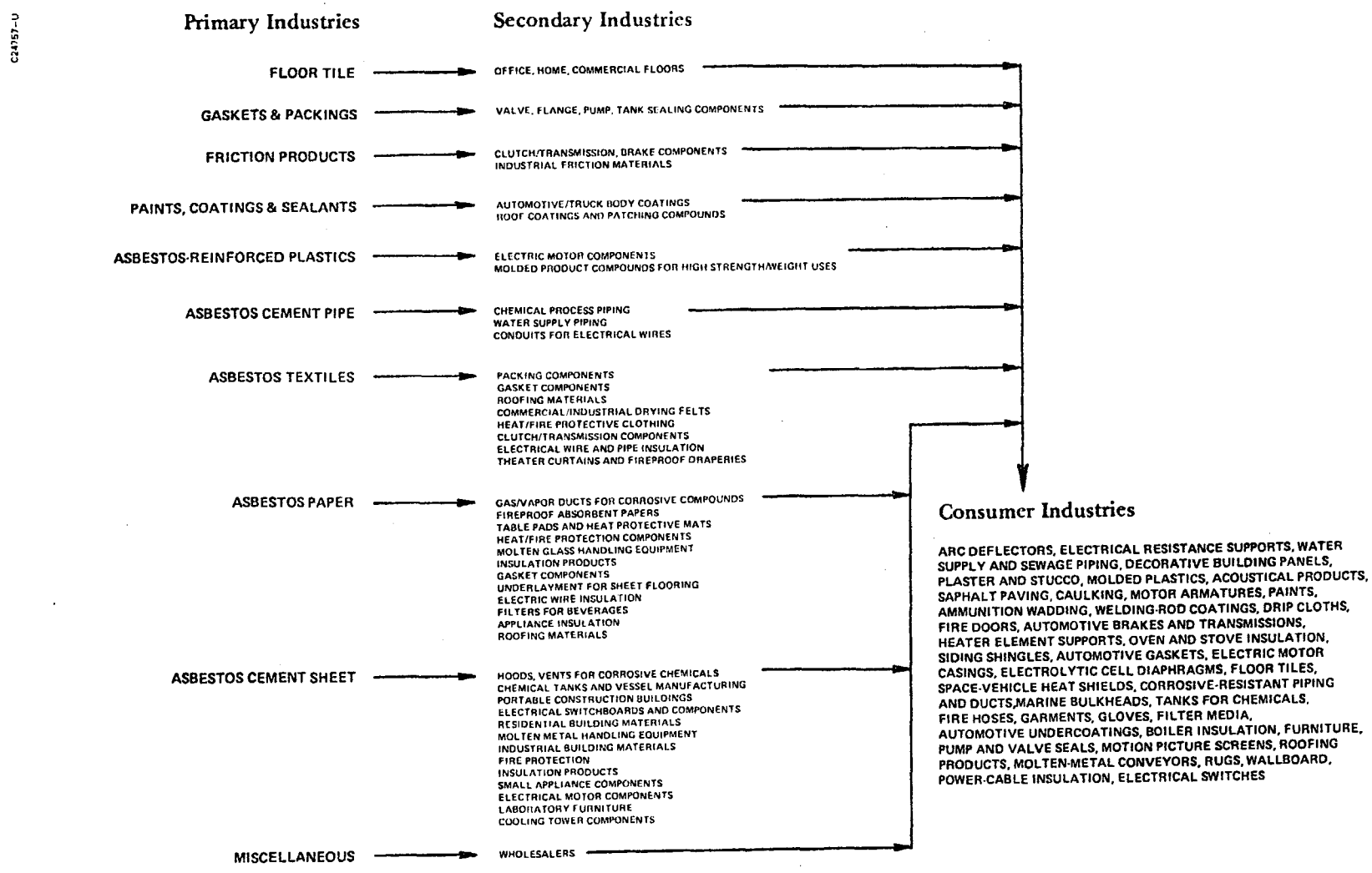

Figure 3.2. Asbestos Products Industry (Daly et al., 1976)

The first industry segment to come into contact with the asbestos is, of course, the mining segment. As far as the United States is concerned, however, this predominately occurs in Canada. From 1971 to 1975, between 80-85% of the asbestos consumed domestically was imported (see Sections 4.3 and 4.4); and of the imported asbestos, nearly 96% originated in Canada (Clifton, 1975). The milling segment of the industry is very closely connected to the mining segment because mills are usually located in close geographical proximity to the mines and, in general, the mines and mills are owned and operated by the same parent corporation. American mining and milling production is discussed in Section 5.1.

The interesting relationship is, however, the relationship between the mining segment of the industry and the primary industries, the product manufacturers who initially fabricate asbestos products. Table 3.1 lists the captive fiber sources in Canada and in the U.S. for the major domestic asbestos products manufacturing firms. Twenty of the largest U.S. asbestos products manufacturers are listed in Table 3.2. When Tables 3.1 and 3.2 are compared, it can be seen that four corporations (Johns-Manville, Raybestos-Manhattan, Jim Walter, and ASARCO) not only control large mining interests in Canada, but also control nearly 35% of the American asbestos products market.

According to the 1967 U.S. Census of Manufacturers, 81 firms operating 138 establishments were involved in asbestos products manufacturing (SIC 3292; this does not include asbestos paper-making establishments). The 1972 Census of Manufacturers lists 142 establishments for SIC 3292. When the asbestos paper-makers are included, it is estimated that approximately 85 firms are presently engaged in asbestos products manufacture (SRC estimate). In evaluating the asbestos products manufacturing industry, it is possible to arrive at the

Table 3.1. Captive Fiber Sources for the Major American Asbestos Product Manufacturing Firms (Igwe, 1974; Asbestos Magazine, Dec. 1975)

Company	Mine (Company)	Fiber-Producing Capacity (short tons/year)
	Canadian Mines	
ASARCO	Lake Asbestos of Quebec, Ltd.	150,000
Johns-Manville Products Corp.	Canadian Johns-Manville Co., Ltd.	835,000
Jim Walter Corp.	Carey-Canadian Mines, Ltd.	200,000
Raybestos-Manhattan, Inc.	Cassiar Asbestos Corp. (partial interest)	110,000
General Dynamics Corp.	Asbestos Corp., Ltd. (54% interest)	500,000
	American Mines	
Atlas Asbestos Co.	Atlas Asbestos Co.	25,000
Union Carbide Corp.	Union Carbide Mines	10,000
Johns-Manville Products Corp.	Coalings Asbestos Co.	(closed at present)

Table 3.2. Twenty of the Largest U.S. Asbestos Product Manufacturers (Economic Information Systems, 1976; Igwe, 1974; SRC Estimates)

Company	Estimated 1975 Asbestos-Product Sales ($ millions)	Approximate Percentage of the U.S. Market
1. Johns-Manville Corp.	240	18.0
2. Raybestos-Manhattan, Inc.	140	10.5
3. GAF Corp.	114	8.5
4. Bendix Corp.	72.5	5.5
5. Jim Walter Corp. (Celotex)	71	5.5
6. Armstrong Cork Co.	60	4.5
7. Illinois Central Industries (Abex Corp.)	60	4.5
8. Flintkote Co.	50	3.5
9. Asten-Hill Mfg. Co.	40.5	3.0
10. H.K. Porter Co.	37.6	3.0
11. Certain-Teed Corp.	33.1	2.5
12. Nicolet Industries	30.7	2.0
13. Kentile Floors Inc.	29.5	2.0
14. National Gypsum Co.	27.1	2.0
15. Royal Industries	24.5	2.0
16. Uvalde-Rock-Asphalt Co.	21.6	1.5
17. Sabine Industries	21.6	1.5
18. American Asbestos Textile	15.0	1.0
19. ASARCO Inc. (Cement Asbestos Products)	13.0	1.0
20. Gatke Corp.	11.6	1.0

conclusion that the industry may be dominated by several giant firms. From Table 3.2 it can be seen that the six largest firms control over 50% of the market. It should also be noted that the larger asbestos-based manufacturing firms are generally diversified into other product lines. Table 3.3 shows the percentage of some major manufacturers' product lines that are related to asbestos.

Table 3.3. Asbestos-Based Activity of Some Major Asbestos-Manufacturing Companies (Igwe, 1974; SRC Estimates)

Company	Estimated Annual Sales ($ millions)	Percent of Product Line Related to Asbestos
American Biltrite Rubber Co.	161	5
The Flintkote Co.	441	12
GAF Corp.		5
Johns-Manville Corp.	800	30
National Gypsum Co.	519	5
Jim Walter Corp.	880	8

3.2 Types of Plants

Asbestos products manufacturing plants are characterized by a high degree of specialization. The typical plant (especially of the minor manufacturers) is apt to be a single-product operation whose product is geared to service a specific industry. Table 3.4 lists the general statistics for

Table 3.4. Industry Specialization and Primary Product Class Specialization for Asbestos Product Producing Establishments: 1972 (SIC 3292) (1972 Census of Manufacturers, U.S. Bureau of the Census)

	Establishments	Establishments with 75% or More Specialization
Entire Industry	142	127
Primary Product Class		
Friction Materials	23	21
Asbestos-Cement Shingles and Clapboard	7	6
Vinyl Asbestos Floor Tile	18	17
Asbestos and Asbestos-Cement Products	55	42

establishment specialization in 1972. In Table 3.4 the measures of plant specialization are shown as: (1) industry specialization - the ratio of primary product shipments to total product shipments (primary plus secondary) and (2) product class specialization - the ratio of the largest primary product class shipments to total product shipments (primary plus secondary) for the establishment.

A survey of selected facilities shows that nearly all the large plants employing in excess of 100 workers belong to the major firms within the industry, such facilities also often generating relatively minor proportions of non-asbestos products (Igwe, 1974).

It is fair to state that the asbestos manufacturing industry in the United States is very mature, with most of the larger plants well over 25 years old and employing well-established technologies. For instance, asbestos-cement pipe manufacture was introduced in the United States about 1928 by the Johns-Manville Corporation at its Waukegan, Illinois, plant. Except for incorporation of sophisticated controls and materials handling systems, it is doubtful whether the technology, similar in principle to that employed in the manufacture of flat or corrugated sheeting, has changed to any fundamental extent since then. Similar comments may be applied to the manufacture of vinyl asbestos tiles (Igwe, 1974).

3.3 Numerical and Percentage Distribution of Plants, Employees, and Production

The numerical distribution of the establishments by size (expressed in terms of the number of employees) as given by the 1972 Census of Manufacturers is shown in Table 3.5. Total employment as a function of establishment size and total value of shipments as a function of establishment size for asbestos products manufacturing are given in Tables 3.6 and 3.7, respectively.

A comparison of Tables 3.5 and 3.6 shows that whereas establishments with less than 100 employees account for 53.4% of the number of asbestos products manufacturing establishments, these facilities employ only 7.8% of the work force. The relative minor contributions of the "less-than-100-employees" facilities are further illustrated when Table 3.5 is compared to Table 3.7. The industry segment with less than 100 employees per establishment contributes only 6.1% of the shipment values of asbestos products. The economic punch appears clearly to rest with the major manufacturing units.

There is the additional consideration that, for a given asbestos product, the manufacturing equipment tends to be of a given standard capacity.

Table 3.5. Asbestos Products Manufacture: Distribution of Plant Sizes (1972 Census of Manufacturers (SIC 3292), U.S. Bureau of the Census)

Average Number of Employees	Total Number of Establishments	Percent of Total
1 to 4	12	8.5
5 to 9	20	14.0
10 to 19	13	9.1
20 to 49	16	11.3
50 to 99	15	10.5
100 to 249	40	28.2
250 to 499	19	13.4
500 to 999	5	3.5
1000 to 2499	2	1.4
Total	142	

Table 3.6. Asbestos Products Manufacturing: Total Employment as a Function of Size of Facilities (1972 Census of Manufacturers (SIC 3292), U.S. Bureau of the Census)

Average Number of Employees	Total Number of Establishments	Percent of Total
1 to 4	40*	0.2
5 to 9	100	0.4
10 to 19	200	0.8
20 to 48	500	2.0
50 to 99	1,100	4.4
100 to 249	6,400	25.4
250 to 499	6,300	25.0
500 to 999	6,300	25.0
1000 to 2499	4,200*	16.7
Total	25,140	

* SRC Estimates

Table 3.7. Asbestos Products Manufacturing: Total Value of Shipments as a Function of Size of Facilities (1972 Census of Manufacturers (SIC 3292), U.S. Bureau of the Census)

Average Number of Employees	Value of Shipments ($ millions)	Percent of Total
1 to 4	0.7	---
5 to 9	4.9	0.5
10 to 19	7.4	0.8
20 to 49	15.8	1.6
50 to 99	30.7	3.2
100 to 249	246.8	25.6
250 to 499	255.6	26.5
500 to 999	201.5	20.9
1000 to 2499	200.0*	20.8
Total	963.4	

* SRC Estimate

Differences in plant capacities are therefore determined approximately by the number of installed machines, and capacity differences therefore occur in multiples of one standard machine capacity (Igwe, 1974).

4.0 MARKET INPUT/OUTPUT DATA

The salient statistics for asbestos are graphed in Figure 4.1, which covers the period from 1940 to 1975. Import and export data shown in Figure 4.1 represent shipments of unmanufactured asbestos only.

4.1 Mine Production

Table 4.1 lists the domestic and world mine productions from 1965 to 1975. U.S. mines shipped only 75% as much asbestos in 1974 as in 1973 and only 66% as much in 1975 as in 1973. The exact total output of 112,533 tons in 1974 was valued at $13,759,000 (Clifton, 1975).

Only four states produce asbestos: California, with 53% of the 1974 total, was the leader, followed in order by Vermont, Arizona, and North Carolina. The California segment of the asbestos industry has led the sharp decline in U.S. production. The closing, in early 1974, of Johns-Manville's (Coalings Asbestos Co.) mine was followed by the closing of H.K. Porter's (Pacific Asbestos Corp.) mine. These mine closures led to production of only 57% of the 1973 California state total, and only 55% of the 1973 dollar value of the fiber was realized (Clifton, 1975). The H.K. Porter mine was sold in October, 1975, to Calaveras Asbestos Ltd. and was to begin operation in mid-1976 (Asbestos Magazine, December, 1975).

All of the American mines produce the chrysotile variety of asbestos except the North Carolina mines which produce the anthophyllite variety. In total, the American mines produce approximately 15% of the asbestos used in the United States. The remainder is imported, mostly from Canada (see Section 4.3).

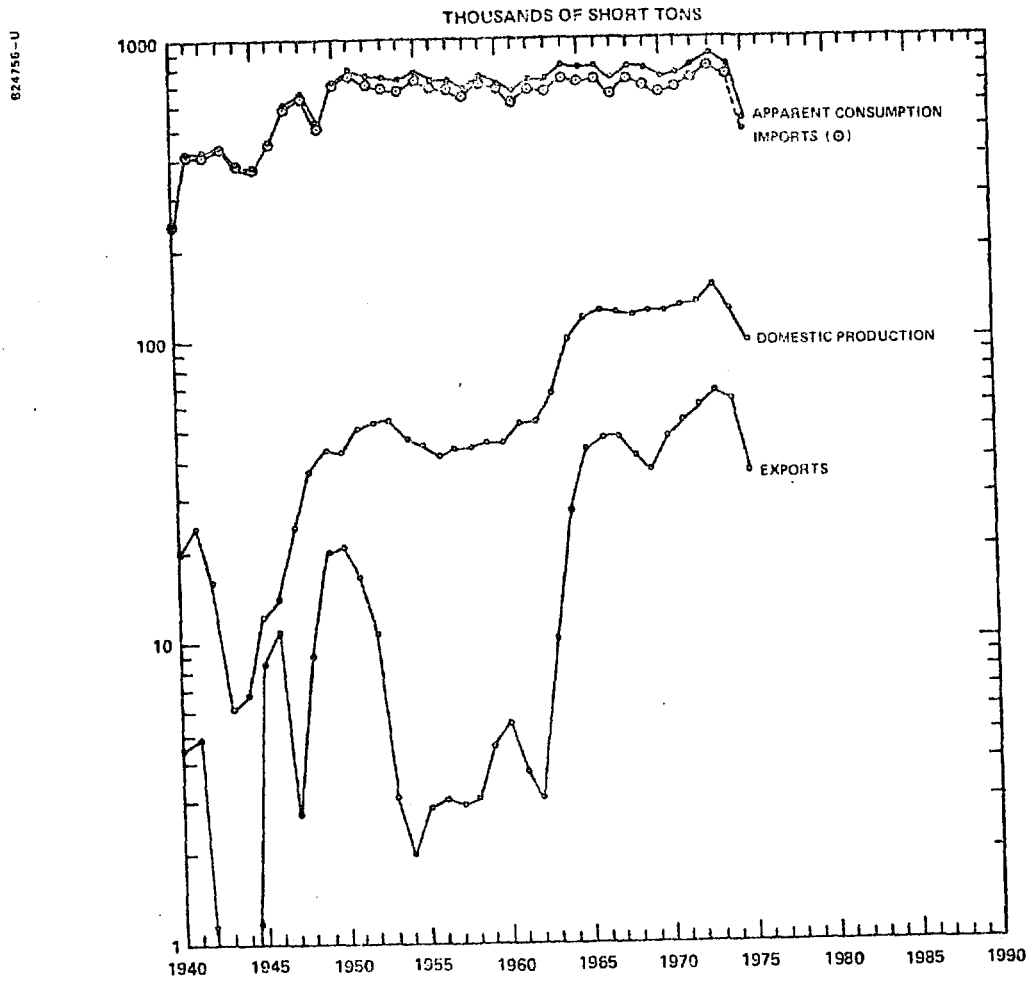

Figure 4.1. Asbestos - Salient Statistics (SRI, 1974; Clifton, 1974; U.S. Bureau of the Census, 1975 a, b)

Table 4.1. Mine Production of Asbestos (Clifton, 1975; Asbestos Magazine, December, 1975)

	(Thousand short tons)										
	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
World mine production:											
United States	118	126	123	121	126	125	131	132	150	113	99
Rest of world	2,984	3,149	3,084	3,170	4,042	3,672	3,816	4,050	4,448	4,423	4,996
Total	3,102	3,275	3,207	3,291	4,168	3,797	3,947	4,182	4,598	4,536	5,095

4.2 Exports

Table 4.2 below lists the American export of asbestos (unmanufactured) from 1965 to 1975.

Table 4.2. U.S. Export of Asbestos (Unmanufactured) for 1965 - 1975 (Clifton, 1975; U.S. Bureau of the Census, 1975 b)

Year	Asbestos Export in Thousands of Short Tons
1975	35
1974	62
1973	66
1972	59
1971	54
1970	47
1969	36
1968	41
1967	47
1966	47
1965	43

Tables 4.3a and 4.3b list the countries to which the exported asbestos (unmanufactured) was shipped in 1975 and in the first half of 1976, respectively, and the amounts shipped to each country. Unmanufactured asbestos includes asbestos fibers, not further processed than beaten, washed or graded to length and asbestos waste and refuse. Table 4.4 lists U.S. exports, by country, of asbestos manufactured products in 1975.

In 1975 U.S. exports of unmanufactured asbestos amounted to only 6.5% of the quantity of U.S. imports, while in 1974 the figure was only 8.1%. On the other hand, the dollar value of U.S. exports of manufactured asbestos products was nearly three times higher than the dollar value of U.S. imports of manufactured asbestos products.

Table 4.3a. U.S. Export -- By Country -- of Asbestos (Unmanufactured) in 1975 (U.S. Bureau of the Census, 1975 b)

2764015 Asbestos fibers, not further processed than beaten, washed, or graded to length

	Net Quantity (Short Tons)	Value (Dollars)
Canada	1,567	682,546
Mexico	6,881	2,349,846
Brazil	699	261,080
Belgium	463	140,181
France	206	204,242
West Germany	937	335,709
Rumania	494	101,420
Iran	721	252,817
Singapore	1,137	523,255
Japan	1,334	936,115
Other Countries	734	279,895
Total	15,173	6,067,106

2764030 Asbestos waste and refuse

Canada	3,629	188,856
Mexico	5,109	1,151,572
Colombia	706	124,078
Venezuela	391	70,978
Brazil	115	67,123
United Kingdom	815	131,681
France	458	101,436
West Germany	723	202,087
Italy	120	72,414
Iran	203	78,240
Singapore	615	577,569
Japan	3,842	700,350
Egypt	104	64,558
Other Countries	2,918	460,943
Total	19,748	3,991,885

*U. S. Bureau of the Census, 1975b

Table 4.3b. U.S. Export -- By Country -- of Asbestos (Unmanufactured) from January, 1976, to June, 1976 (U.S. Bureau of the Census, 1976 b)

2764015 Asbestos fibers, not further processed than beaten, washed, or graded to length

	Net Quantity (Short Tons)	Value (Dollars)
Canada	448	161,298
Mexico	4,883	1,283,987
Venezuela	119	40,302
Brazil	63	41,106
United Kingdom	41	32,000
The Netherlands	298	63,953
Belgium	328	76,115
East Germany	177	130,190
Greece	126	33,840
Rumania	371	101,135
Iran	140	39,033
Thailand	1,320	527,987
Indonesia	900	284,150
Taiwan	300	116,350
Japan	1,532	631,900
Algeria	840	292,428
Other Countries	595	104,760
Total	12,481	3,960,534

2764030 Asbestos waste and refuse

Canada	255	63,389
Mexico	5,430	1,113,082
Colombia	445	80,832
Venezuela	231	36,805
Brazil	378	77,447
United Kingdom	613	114,365
East Germany	400	209,904
Spain	120	57,831
Italy	49	54,279
Rumania	400	76,000
United Arab Emirants	192	125,195
Korean Republic	1,500	348,000
Japan	3,507	546,306
Algeria	760	57,054
Libya	149	101,058
Other Countries	646	158,559
Total	15,075	3,220,106

*U. S. Bureau of the Census, 1976b

Table 4.4. U. S. Exports--By Country--of Asbestos Manufactured Products in 1975 *

6618310 Asbestos-cement shingles and clapboard

	Net Quantity (Pounds)	Value (Dollars)
Canada	669,126	142,466
United Kingdom	589,890	109,149
West Germany	17,778,767	2,977,698
Italy	7,205,759	943,314
Saudi Arabia	228,577	78,228
Japan	234,704	66,185
Other Countries	1,847,108	331,776
Total	28,553,931	4,648,816

6618320 Articles of asbestos-cement or of fiber-cement except asbestos cement shingles and clapboard

Canada	21,936,513	3,867,321
Mexico	487,372	138,980
Salvador	455,804	64,879
Panama	5,266,390	715,851
Brazil	134,606	70,184
Sweden	305,303	375,555
West Germany	102,004	87,175
Iran	265,941	79,733
Saudi Arabia	4,511,035	999,724
Indonesia	33,478	161,793
Philipine Republic	360,441	70,893
Japan	418,104	242,323
The Pacific Islands	320,865	71,806
Algeria	2,094,038	185,964
Republic of South Africa	116,300	73,093
Other Countries	1,096,502	422,609
Total	37,904,696	7,627,883

6638105 Asbestos gaskets

1 Canada	172,100	500,993
Jamaica	32,955	98,785
Iran	39,551	68,213
Saudi Arabia	91,663	202,404
Republic of South Africa	14,105	79,183
Other Countries	184,962	660,608
Total	535,336	1,610,186

*U. S. Bureau of the Census, 1975b

Table 4.4. U. S. Exports--By Country--of Asbestos Manufactured Products in 1975* (Cont'd)

	Net Quantity (Pounds)	Value (Dollars)
6638115 Asbestos packing		
2 Canada	1,042,869	1,896,802
Mexico	393,093	291,741
Guatemala	25,828	68,294
Jamaica	49,803	278,425
Colombia	320,649	513,348
Venezuela	37,695	158,526
Surinam	42,645	142,790
Peru	151,358	396,141
Chile	123,234	205,258
Brazil	114,892	119,524
Sweden	15,451	94,047
Finland	30,289	279,984
United Kingdom	264,110	374,256
Ireland	81,400	366,739
The Netherlands	15,083	113,214
Belgium	20,239	139,314
France	41,189	177,591
West Germany	76,187	205,023
Switzerland	17,857	80,840
Spain	30,531	183,812
Italy	86,309	673,373
Greece	25,198	73,157
Iran	46,118	137,128
Israel	9,577	95,091
Kuwait	16,468	80,943
Saudi Arabia	466,441	256,331
India	145,126	64,691
Pakistan	13,920	64,832
Thailand	42,989	76,663
Singapore	153,448	408,972
Philippine Republic	229,895	551,008
Korean Republic	27,000	63,030
Taiwan	52,596	159,405
Japan	57,871	262,573
Australia	28,394	131,979
New Zealand	25,210	170,069
Nigeria	33,470	87,997
Republic of South Africa	35,719	242,818
Zambia	11,917	118,528
Other Countries	346,981	987,008
Total	4,749,049	10,791,265

*U. S. Bureau of the Census, 1975b

Table 4.4. U. S. Exports--By Country--of Asbestos Manufactured Products in 1975* (Cont'd)

	Net Quantity (Pounds)	Value (Dollars)
6638117 Asbestos insulation, heat or sound		
2 Canada	--	729,888
Mexico	--	188,096
Dominican Republic	--	60,990
Venezuela	--	282,149
Surinam	--	282,149
Peru	--	81,658
Brazil	--	214,532
United Kingdom	--	130,610
The Netherlands	--	102,618
Belgium	--	253,755
Iran	--	66,323
Pakistan	--	143,518
Singapore	--	364,906
Philippine Republic	--	74,620
Mainland China	--	916,153
Japan	--	98,572
Australia	--	99,706
New Zealand	--	248,444
Egypt	--	68,333
Ghana	--	65,383
Other Countries	--	812,154
Total	--	5,071,672
6638120 Asbestos textiles and yarns		
3 Canada	7,749,305	3,664,189
Mexico	1,249,110	747,770
Peru	122,520	220,267
Sweden	122,929	230,746
United Kingdom	85,929	207,598
Ireland	45,100	145,350
The Netherlands	487,222	127,799
West Germany	195,984	252,944
Italy	54,043	274,700
Japan	23,646	146,510
Australia	1,020,703	614,452
Other Countries	307,061	651,974
Total	11,463,552	7,284,299

*U. S. Bureau of the Census, 1975b

Table 4.4. U. S. Exports--By Country--of Asbestos Manufactured Products in 1975* (Cont'd)

	Net Quantity (Pounds)	Value (Dollars)
6638150 Asbestos protective clothing		
Mexico	--	76,580
Greece	--	200,311
Saudi Arabia	--	68,643
Other Countries	--	463,975
Total	--	809,509
6638160 Asbestos manufactures, other than friction materials, NEC		
Canada	--	2,230,745
Mexico	--	246,573
Panama	--	74,099
Jamaica	--	70,179
Venezuela	--	749,761
Peru	--	305,139
Chile	--	182,659
Brazil	--	83,043
Sweden	--	1,145,722
United Kingdom	--	2,528,018
The Netherlands	--	702,650
West Germany	--	866,848
Switzerland	--	124,542
Poland	--	81,315
Lebanon	--	83,372
Iran	--	66,238
Saudi Arabia	--	185,369
Korean Republic	--	110,313
Japan	--	439,217
Australia	--	92,913
New Zealand	--	200,613
Republic of South Africa	--	325,572
Other Countries	--	845,089
Total	--	11,739,989

*U. S. Bureau of the Census, 1975b

Tabla 4.4. U. S. Exports--By Country--of Asbestos Manufactured Products in 1975* (Cont'd)

	Net Quantity (Pounds)	Value (Dollars)
6638202 Asbestos clutch facings for automotive use, including linings		
Canada		506,277
Chile		63,447
United Kingdom		195,978
West Germany		226,888
Other Countries		281,518
Total		1,274,108
6638206 Asbestos clutch facings, NEC, including linings		
Canada		160,905
Other Countries		163,144
Total		324,049
6638215 Asbestos brake linings for automotive use		
1 Canada	5,726,553	4,681,018
Guatemala	55,287	95,364
Ecuador	76,894	114,637
Chile	26,188	63,495
Belgium	83,388	133,965
Greece	426,808	177,068
Lebanon	146,100	165,735
Iran	164,803	156,894
Singapore	133,140	82,093
Indonesia	118,415	73,897
Other Countries	700,518	869,554
Total	7,658,094	6,613,702
6638225 Asbestos brake linings, NEC		
6 Canada	1,487,000	1,594,737
Mexico	274,572	173,896
Brazil	20,913	148,892
The Netherlands	26,700	271,849
Japan	15,909	64,690
Australia	48,975	136,347
Other Countries	180,307	369,465
Total	2,054,376	2,759,876

*U. S. Bureau of the Census, 1975b

4.3 Imports

Table 4.5 below lists the American imports of asbestos (unmanufactured) from 1965 to 1975.

Table 4.5. U.S. Imports of Asbestos (Unmanufactured) for 1965 - 1975 (Clifton, 1975; U.S. Bureau of the Census, 1975 a)

Year	Asbestos Import in Thousands of Short Tons
1975	539
1974	766
1973	792
1972	736
1971	682
1970	649
1969	695
1968	737
1967	646
1966	720
1965	719

In 1975, 539,000 short tons of asbestos were imported into the U.S., as compared to 766,000 short tons in 1974. The decrease from 1974 to 1975 was due to a shortage of asbestos in the Canadian supply caused by: 1) a destructive fire at Thetford Mines, Quebec, 2) a landslide at Johns-Manville's Jeffrey Mine, Quebec, and 3) the 7-month-long strike of Quebec asbestos workers (Asbestos Magazine, December, 1975). During the first half of 1976, 329,000 short tons of asbestos were imported, a rate which is approximately midway between the 1974 and 1975 figures.

Tables 4.6a and 4.6b list U.S. imports, by country, of unmanufactured asbestos in 1975 and the first-half of 1976, respectively. Table 4.7 gives similar data for 1973 - 1974. Table 4.8 lists U.S. imports, by country, of manufactured asbestos products in 1975. A historical breakdown for asbestos imports of chrysotile, crocidolite, and amosite is included in Table 4.9, Asbestos Supply-Demand Relationships.

During the entire history of the asbestos industry in the U.S., domestic sources have been able to meet only a small percentage of U.S. requirements. Canada furnished 96% of all the asbestos tonnage imported by the U.S. (1969 - 1973), but only a small portion (3%) was spinning grade fibers. The comparatively small tonnages imported from Africa are more important than would appear on a tonnage basis because they consist largely of special kinds and qualities unobtainable elsewhere (Clifton, 1975).

4.4 Supply-Demand-Use

Table 4.9 gives the asbestos supply-demand relationships for 1965 - 1974. The U.S. supply is a combination of imports, domestic mine production, industry stockpiles, and governmental stockpile releases. The U.S. supply is distributed among industry and governmental stockpile acquisitions, exports, and industry demand. The relative importance of each is apparent from Table 4.9. The asbestos distribution by end use, grade, and type for 1974 is shown in Table 4.10. The major buyers of asbestos and asbestos ore are listed in Table 4.11.

4.5 Asbestos Fiber Prices

Asbestos prices are characterized by an erratic price history. Prices for Canadian asbestos increased about 8% in 1973, 39% in 1974, and 23% in 1975.

Table 4.6a. U.S. Imports--by Country--of Unmanufactured Asbestos in 1975

	Net Quantity Short Tons	Value (dollars)**		
		Customs	F.a.s.	C.i.f.
2764010	Asbestos, Amosite			
Rep SAF	3,894	1,539,951	1,542,143	1,872,035
Total	3,894	1,539,951	1,542,143	1,872,035
2764020	Asbestos, Crocidolite, Blue			
Mozambq	118	16,090	16,090	29,033
Rep SAF	11,570	4,942,886	4,942,181	6,100,733
Total	11,688	4,958,976	4,958,271	6,129,766
2764030	Asbestos, Chrysotile Crudes			
Canada	71	9,045	9,654	9,654
U King	277	82,982	82,982	121,299
Belgium	22	2,670	2,670	4,408
USSR	4,525	920,772	920,772	1,617,748
Rep SAF	940	663,658	663,658	760,556
Swazlnd	2,756	952,544	952,544	1,291,259
Rhodesia	1,633	1,521,421	1,520,611	1,753,361
Total	10,244	4,153,092	4,152,891	5,558,285
2764040	Asbestos, Chrysotile, Except Crudes and Spinning Fibers			
Canada	7,637	5,772,397	5,879,920	5,893,666
Rep SAF	115	99,572	99,572	109,296
Rhodesia	382	368,845	368,845	414,831
Total	8,134	6,240,814	6,348,337	6,417,793
2764050	Asbestos, Chrysotile, Except Crudes and Spinning Fibers			
Canada	490,615	91,014,320	96,411,691	96,526,478
Mexico	73	14,876	14,876	14,876
U King	58	11,396	11,890	11,890
USSR	86	38,640	39,805	40,214
Italy	44	12,540	12,540	16,461
Gaza St	152	25,914	25,914	25,914
Rep SAF	220	68,025	68,276	95,123
Rhodesia	32	22,871	22,871	27,614
Total	491,280	91,208,582	96,607,863	96,758,570
2764060	Asbestos, Unmanufactured, Crudes, Fibers, Stucco, Etc., NES			
Canada	5,222	776,931	858,340	859,639
Finland	329	32,841	32,298	51,915
Belgium	48	4,599	4,599	7,426
USSR	5,768	1,321,982	1,321,982	1,822,332
Italy	153	23,868	23,868	38,805
Rep SAF	1,237	391,099	424,487	533,022
Rhodesia	576	357,486	357,486	473,331
Total	13,333	2,908,806	3,023,060	3,786,470

*Source: U.S. Bureau of the Census, 1975a
**Customs Value: Value of imports appraised by U.S. Customs Service.
F.a.s. Value: Transaction value of imports at foreign port of exportation.
C.i.f. Value: Value of imports at the first port of entry in U.S.

Table 4.6b. U:S. Imports--by Country--of Unmanufactured Asbestos, January to June, 1976*

	Net Quantity Short Tons	Value (dollars)		
		Customs	F.a.s.	C.i.f.
2764010	Asbestos, Amosite			
Rep SAF	1,151	503,663	509,697	642,607
Oth Cty	20	469	669	669
Total	1,171	504,132	510,366	643,276
2764020	Asbestos, Crocidolite, Blue			
Rep SAF	4,712	2,315,466	2,388,971	2,606,013
Total	4,712	2,315,466	2,388,971	2,606,013
2764030	Asbestos, Chrysotile Crudes			
Canada	289	125,175	129,108	129,108
Mexico	234	125,486	126,948	126,948
U King	119	55,992	55,992	64,090
Rep SAF	351	193,918	193,913	220,191
Rhodesia	1,095	1,115,230	1,115,230	1,200,965
Total	2,088	1,615,801	1,621,196	1,741,302
2764040	Asbestos, Chrysotile Spinning Fibers			
Canada	2,394	2,053,568	2,110,240	2,111,611
Total	2,394	2,053,568	2,110,240	2,111,611
2764050	Asbestos, Chrysotile, Except Crudes and Spinning Fibers			
Canada	298,988	60,006,713	63,427,681	63,598,407
Fr Germ	1,086	202,826	202,826	257,094
Rep SAF	396	217,440	219,660	235,599
Oth Cty	17	3,919	3,919	3,919
Total	300,487	60,430,898	63,854,086	64,095,019
2764060	Asbestos, Unmanufactured, Crudes, Fibers, Stucco, Etc., NES			
Canada	8,759	1,450,342	1,571,118	1,572,326
Fr Germ	823	179,840	179,840	320,577
USSR	6,700	1,292,721	1,293,001	2,079,238
Rep SAF	1,953	898,889	920,675	981,292
Oth Cty	54	21,969	22,029	22,368
Total	18,289	3,843,761	3,986,663	4,975,801

*Source: U.S. Bureau of the Census, 1976a

Table 4.7. U.S. Imports for Consumption of Asbestos (Unmanufactured) by Class and Country (Clifton, 1974)

Year and country	Crude (including blue fiber)		Textile fiber		All other		Total	
	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)
1973								
Canada	1,991	$397	15,665	$6,020	746,988	$86,449	764,644	$92,866
Finland	--	--	--	--	1,027	93	1,027	93
Germany, West	79	21	--	--	--	--	79	21
Guyana	--	--	--	--	308	8	308	8
Italy	--	--	--	--	8	8	8	8
Malagasy, Republic	--	--	--	--	3	1	3	1
Mexico	--	--	--	--	43	7	43	7
Mozambique	51	27	--	--	5	1	56	28
Panama	--	--	--	--	12	11	12	11
Portugal	--	--	--	--	1	(1)	1	(1)
Rhodesia, Southern	845	423	--	--	--	--	845	423
South Africa, Republic of	21,629	4,510	8	1	3,427	733	25,064	5,244
Swaziland	200	122	130	73	--	--	330	195
Yemen	--	--	--	--	50	11	50	11
Yugoslavia	--	--	--	--	8	8	8	8
Total	24,795	5,500	15,803	6,094	751,875	87,320	792,473	98,914
1974								
Brazil	--	--	--	--	20	2	20	2
Canada	115	13	26,768	10,416	712,228	106,085	739,111	116,514
Finland	--	--	--	--	557	74	557	74
Germany, West	99	85	--	--	1	1	100	86
Italy	--	--	1	4	--	--	1	4
Mexico	--	--	--	--	55	11	55	11
Portugal	--	--	--	--	4	2	4	2
Rhodesia	1,717	1,010	4	2	--	--	1,721	1,012
South Africa, Republic of	20,307	5,157	66	16	3,291	510	23,664	5,683
Swaziland	480	361	--	--	--	--	480	361
U.S.S.R	--	--	--	--	451	123	451	123
Total	22,718	6,576	26,839	10,438	716,607	106,808	766,164	123,822

[1] Less than ½ unit.

Table 4.8. U.S. Imports--by Country--of Manufactured Asbestos Products in 1975*

	Net Quantity Pounds	Value (dollars)		
		Customs	F.a.s.	C.i.f.
6618340	Asbestos & Hydraulic Cement Articles NES			
Canada	12,176,880	1,700,400	1,773,749	1,773,779
Mexico	282,803	73,555	73,564	73,564
Guatmal	532,566	43,941	43,941	60,097
Colomb	15,259,038	1,494,207	1,494,215	1,760,082
U King	9,246	5,350	5,368	5,995
Belgium	7,395,456	1,858,386	1,858,022	2,168,971
W Germ	4,149,943	377,706	377,705	564,244
Japan	145,941	30,725	30,725	36,848
Austral	246,333	56,234	59,555	70,473
Total	40,198,206	5,640,504	5,716,844	6,514,053
6638000	Asbestos Articles, NES, and Asbestos Yarn, Sliver, Rope, Etc., With or Without Wire			
Canada		3,988,524	4,010,223	4,019,687
Mexico		2,624,027	2,478,821	2,617,067
Venez		40,381	40,381	42,674
Brazil		841,938	831,938	872,701
Sweden		128,742	128,721	142,887
Norway		6,369	6,369	7,749
Finland		8,499	8,499	9,149
Denmark		12,780	12,189	12,594
U King		4,373,180	4,380,595	4,794,464
Nethlds		11,139	11,139	11,578
Belgium		32,774	32,795	35,867
France		137,475	137,897	147,444
W Germ		1,282,955	1,278,071	1,346,141
Switzld		6,187	6,187	7,168
Spain		495,545	495,545	531,694
Italy		156,022	156,022	172,358
Yugoslv		17,664	17,664	19,251
Greece		1,140	1,140	1,226
India		5,261	5,261	5,919
Phil R		1,000	1,000	1,555
Kor Rep		257,256	244,970	255,633
China T		1,094,659	1,075,207	1,154,996
Japan		1,149,464	1,135,904	1,228,451
Rep SAF		119,527	119,527	120,127
Total		16,792,508	16,616,065	17,558,380

*Source: U.S. Bureau of the Census, 1975a

Table 4.9. Asbestos Supply-Demand Relationships, 1965-74 (Thousand short tons) (Clifton, 1975)

	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
Total	3,102	3,275	3,207	3,291	4,168	3,797	3,947	4,182	4,598	4,536
Components of U S supply:										
Domestic mines	118	126	123	121	126	125	131	132	150	113
Government release	12	1	1	1	5	11	8	16	7	29
Imports, chrysotile	681	669	618	703	669	626	660	724	771	747
Imports, crocidolite	21	27	15	14	11	9	7	5	13	11
Imports, amosite	17	24	13	20	15	14	15	7	8	8
Industry stocks, Jan 1	18	22	19	17	18	23	21	30	96	103
Total U S supply	867	869	789	876	844	808	842	914	1,045	1,011
Distribution of U S supply										
Government acquisition	12	2	1	...	...	7	...	...	...	...
Industry stock Dec 31	17	15	20	18	24	20	29	46	103	103
Exports	43	47	47	41	36	47	54	59	66	62
Industry demand	795	805	721	817	784	734	759	809	876	846
U.S demand pattern										
Flooring products	200	202	179	204	196	184	191	202	218	153
Asbestos cement pipe	151	153	134	155	149	139	144	154	166	222
Roofing products	79	80	71	82	79	73	76	81	87	76
Friction products	71	72	65	74	71	66	68	73	79	80
Asbestos cement sheet	55	56	51	57	55	51	53	57	64	95
Packing and gaskets	24	24	22	25	24	22	23	24	26	29
Insulation	24	24	22	25	24	22	23	24	26	14
Paper products	16	16	14	16	16	15	15	16	18	63
Textiles	16	16	14	16	16	15	15	16	18	20
Other	159	162	145	163	154	147	151	162	174	94
Total U S demand	795	805	721	817	784	734	759	809	876	846

Table 4.10. Asbestos Distribution by End Use, Grade, and Type, 1974 (Short tons) (Clifton, 1974)

	Chrysotile							
	Group 1 & 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Total chrysotile
Asbestos cement pipe	...	...	92,600	20,300	...	72,300	...	185,200
Asbestos cement sheet	...	...	10,900	15,800	52,000	11,800	...	90,500
Flooring products	...	...	...	49,000	...	104,500	...	153,500
Roofing products	...	...	3,700	11,100	12,700	46,300	...	73,800
Packing and gaskets	100	1,900	7,500	7,500	1,400	10,300	...	28,700
Insulation, thermal	...	100	900	100	3,400	2,800	...	7,300
Insulation, electrical	...	...	400	1,600	...	2,700	...	4,700
Friction products	...	5,600	1,300	29,500	6,300	36,500	300	79,600
Coatings and compounds	...	...	100	400	300	36,700	400	37,900
Plastics	400	1,000	900	800	...	7,500	6,300	16,900
Textiles	700	14,200	3,900	800	...	800	...	20,400
Paper	...	...	5,500	400	23,900	33,300	...	63,100
Other	...	300	1,100	...	2,300	32,700	...	36,400
Total	1,200	23,100	128,800	137,300	102,300	398,300	7,000	798,000

	Crocidolite	Amosite	Anthophyllite	Total asbestos
Asbestos cement pipe	36,400	1,100	200	222,900
Asbestos cement sheet	...	4,300	...	94,800
Flooring products	...	...	...	153,500
Roofing products	...	1,700	...	75,500
Packing and gaskets	100	...	...	28,800
Insulation, thermal	...	1,800	...	9,100
Insulation, electrical	...	...	...	4,700
Friction products	...	...	200	79,800
Coatings and compounds	...	...	...	37,000
Plastics	200	...	700	17,800
Textiles	...	...	...	20,400
Paper	200	...	...	63,300
Other	400	500	...	37,300
Total	37,300	9,400	1,100	845,500

Table 4.11. Buyers of Asbestos and Asbestos Ore (Compiled from data furnished by U.S. Bureau of Mines, Washington, D.C.)

Armstrong Cork Co., West Liberty & Charlotte St., Lancaster, Pa. 17604
Asbestos Textile Co., 165 West Wacker Dr., Chicago, Ill. 60601
Carlisle Corp., 621 North College, Carlisle, Pa. 17013
Celotex Corporation, L'Anse, Mich. 49946
Certain-Teed Products Corp., 120 East Lancaster Ave., Ardmore, Pa. 19003
Firestone Tire & Rubber Co., 1200 Firestone Pky., Akron, Ohio 44317
Flintkote Co., The, Inc., 400 Westchester Ave., White Plains, New York 10604
Foseco, Inc., 20200 Sheldon Rd., Brook Park, Ohio 44403
GAF Corp., 140 West 51st St., New York, N.Y. 10020
Garlock Inc., 250 Main St., Palmyra, N.Y. 14522
Gatke Corp., Box 308 East Winona, Warsaw, Ind. 46580
Hooker Chemical Corp., Kenton, Ohio 43326
International Vermiculite Co., Girard, Ill. 62640
Johns-Manville Corp., Greenwood Plaza, Denver, Colo. 80217
Mead Corp., 118 West First St., Dayton, Ohio 45402
Minnesota Mining & Mfg. Co., 3M Center, St. Paul, Minn. 55101
National Gypsum Co., Inc., 325 Delaware Ave., Buffalo, N.Y. 14202
Owens-Corning Fiberglass Co., Berlin, N.J. 08009
Pittsburgh Corning Corp., No. 1 Gateway Center, Pittsburgh, Pa. 15207
H.K. Porter Co., Inc., 601 Grant St., Pittsburgh, Pa. 15219
Raybestos Manhattan, Inc., Bridgeport, Conn. 06601
Rogers Corp., Rogers, Conn. 06263
Standco Brake Lining Co., 2701 Clinton Dr., P.O. Box 93, Houston, Tex. 77020
U.S. Gypsum Co., 101 South Wacker, Chicago, Ill. 60606
U.S. Plywood Corp., South River, N.J. 08882

Table 4.12 lists the average annual asbestos price from 1954 to 1974 and compares it to a figure based on constant 1973 dollars. Table 4.13 lists recent prices for various grades and origins of asbestos. The remarkable disparity of grade prices is evident from Quebec chrysotile fiber prices. Grade No. 7 (shorts) was priced at $89 per ton, while Grade No. 1 (crudes) cost $3496 per ton.

4.6 Future Outlook

The best projections for future use of asbestos are reported by Clifton (1975). The information and projections contained in this subsection come directly from Clifton (1975).

The domestic demand for asbestos is expected to increase at a slow rate; the low rate of annual growth is expected to be 0.9%, while the high rate is expected to be 3.0%. The U.S. demand for asbestos in the year 2000 is projected to be about 1.25 times that of 1973 (876,000 short tons). Projection trends for the U.S. demand are illustrated in Figure 4.2. The forecast for U.S. demand of asbestos by end use is given in Table 4.14.

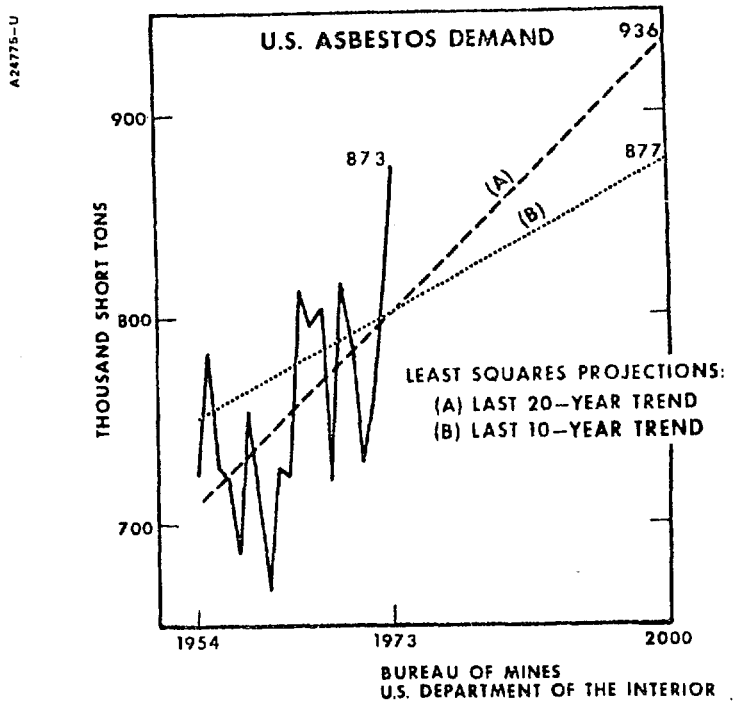

Figure 4.2. U.S. Asbestos Demand, and Projected Trends to 2000 (Clifton, 1975)

Table 4.12. Time-Price Relationship for Asbestos (Clifton, 1975)

Year	Average Annual Price, Dollars Per Short Ton	
	Actual Price	Constant 1973 Dollars
1954	82.34	141.72
1955	84.61	143.65
1956	89.78	147.42
1957	88.09	139.38
1958	90.50	139.66
1959	91.17	138.35
1960	94.62	141.44
1961	95.60	141.00
1962	94.85	138.26
1963	92.44	133.00
1964	98.70	140.00
1965	97.92	136.38
1966	100.63	136.35
1967	101.91	133.74
1968	98.93	124.75
1969	110.03	132.41
1970	115.64	132.01
1971	117.54	128.32
1972	116.63	123.16
1973	122.22	122.22
1974	122.27	110.90

Table 4.13. Recent Prices of Various Asbestoses
(Asbestos Magazine, December, 1975)

ARIZONA *As of April 17, 1975*	*Per Ton of 2000 Lbs., F.O.B. Globe, Arizona U.S. Dollars*
No. 1 Crude (Soft)	$2000.00
No. 2 Crude (Soft)	1500.00
AAA	1100.00
Group No. 3—Nonferrous Filtering—Plastic	715.00— 800.00
Group No. 4—Nonferrous Filtering—Plastic	700.00— 800.00
Group No. 7—White Shorts	100.00— 200.00

QUEBEC *As of December 1, 1975*	*Per Ton of 2000 Lbs., F.O.B. Mine Canadian Dollars*
No. 1—Crude	$3496.00
No. 2—Crude	1899.00
No. 3—Spinning Fiber	891.00— 1463.00
No. 4—Asbestos Cement Fiber	492.00— 829.00
No. 5—Paper Fiber	278.00— 392.00
No. 6—Paper and Shingle Fiber	236.00— 244.00
No. 7—Shorts	89.00— 198.00

CASSIAR *As of August 1, 1975*	*Per Ton of 2000 Lbs., F.O.B. North Vancouver, B.C. Canadian Dollars*
Cassiar Mine	
C-1	$2916.00
AAA Grade—Nonferrous Spinning Fiber/Canadian Group 3	1685.00
AA Grade—Nonferrous Spinning Fiber/Canadian Group 3	1340.00
A Grade—Nonferrous Spinning Fiber/Canadian Group 3	1020.00
AC Grade—Nonferrous Spinning Fiber/Canadian Group 3	735.00
AK Grade—Asbestos Cement Fiber/Canadian Group 4	524.00
AS Grade—Asbestos Cement Fiber/Canadian Group 4	454.00
AX Grade—Asbestos Cement Fiber/Canadian Group 5	416.00
AY Grade—Asbestos Cement Fiber/Canadian Group 5	292.00
AZ Grade—Asbestos Cement Fiber/Canadian Group 6	216.00
Clinton Mine	
CP Grade—Asbestos Cement Fiber/Canadian Group 4	492.00
CT Grade—Asbestos Cement Fiber/Canadian Group 4	445.00
CY Grade—Asbestos Cement Fiber/Canadian Group 5	292.00
CZ Grade—Asbestos Cement Fiber/Canadian Group 6	216.00

VERMONT *As of January 1, 1976*	*Per Ton of 2000 Lbs., F.O.B. Morrisville, Vermont U.S. Dollars*
Grade 4T—Fiber	$ —$ 418.00
Grades 5D thru 5R—Fiber	275.00— 324.00
Grade 6D—Waste	— 200.00
Grades 7D thru 7T—Shorts	83.00— 160.00
Grade 7TF—Floats (Shorts)	— 72.00
Grade 8S—Shorts	— 54.00
Hooker No. 1—in 50-lb. woven poly bags/*eff. 12/1/75*	970.00
Hooker No. 2—in 100-lb. woven poly bags/*eff. 12/1/75*	485.00

Table 4.14. Projections and Forecasts for U.S. Asbestos Demand By End Use, 1973 and 2000 (Thousand short tons) (Clifton, 1975)

End Use	1973	2000			
		Contingency Forecasts for United States			
		Forecast Base	Forecast Range		Probable
			Low	High	
Asbestos cement pipe	166	475	178	479	190
Asbestos cement sheet	64	100	65	104	68
Flooring products	218	360	233	372	236
Roofing products	87	150	93	148	94
Packing and gaskets	26	75	64	75	66
Friction products	79	150	110	144	118
Insulation	26	30	30	39	34
Paper	18	45	21	40	27
Textiles	18	20	19	24	21
Other	174	400	199	387	260
Total	876	---	1,012	1,812	1,114

5.0 MINING AND MILLING

5.1 U.S. Mines and Mills

Although asbestos deposits are located throughout the United States (Figure 5.1), asbestos is mined in only a few states. The map in Figure 5.2 designates the location of mines which are operating or which have been closed recently. In order of decreasing annual production, the mining states are California, Vermont, Arizona, and North Carolina. Table 5.1 lists the American mines which are operating or have recently closed, along with the associated mills. All of the mines produce chrysotile asbestos with the exception of the Powhattan mine in North Carolina which produced anthophyllite asbestos.

The largest mines are the Vermont Asbestos Group mine (formerly owned by GAF Corp.) in Vermont and the Calaveras Asbestos Ltd. mine (formerly controlled by H.K. Porter Co.) in Copperopolis, California (Asbestos Magazine, December, 1975). The inactive Coalinga Asbestos Co. mine (Johns-Manville) was the second largest mine in California and the third largest nationally. Environmental regulations are cited as the prime reasons for the closing of the Johns-Manville mine (Clifton, 1976; Harwood and Blasznak, 1974; Asbestos Magazine, December, 1974, 1975). Although the Powhattan mine in North Carolina was reported as inactive since 1973 (Harwood and Blasznak, 1974), a conversation with a Powhattan employee suggests that the mine is currently being operated.

Potential mining has been discussed for Alamore, Texas (tremolite asbestos), Sonora, California, and the Yukon region of Alaska (Asbestos Magazine, December, 1972, 1974).

It should be noted that actual mining production data for each mine cannot be accurately collected for proprietary reasons. Since California had,

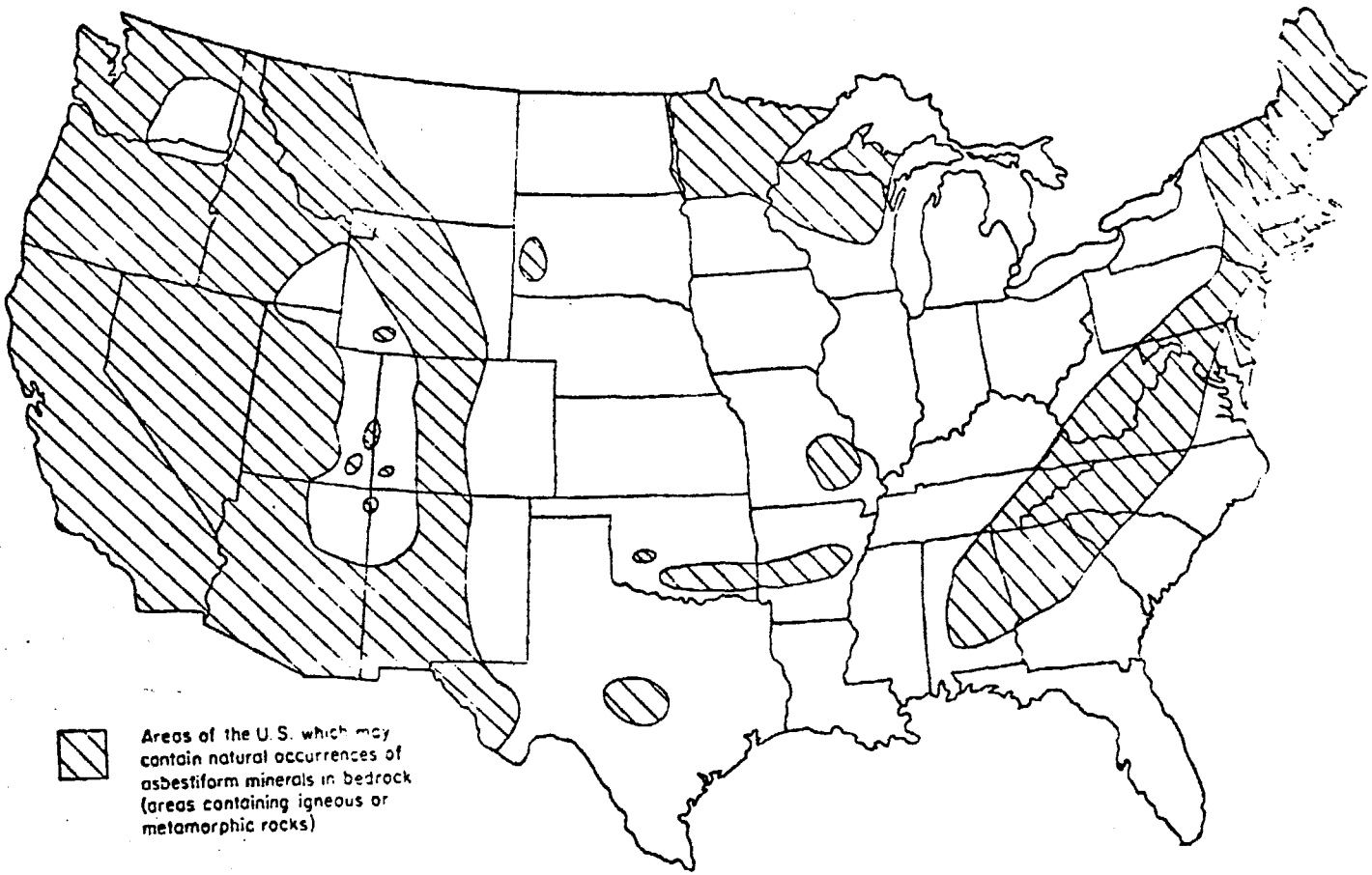

Figure 5.1. Possible Areas of Asbestos Deposits (Harwood and Blasznak, 1974)

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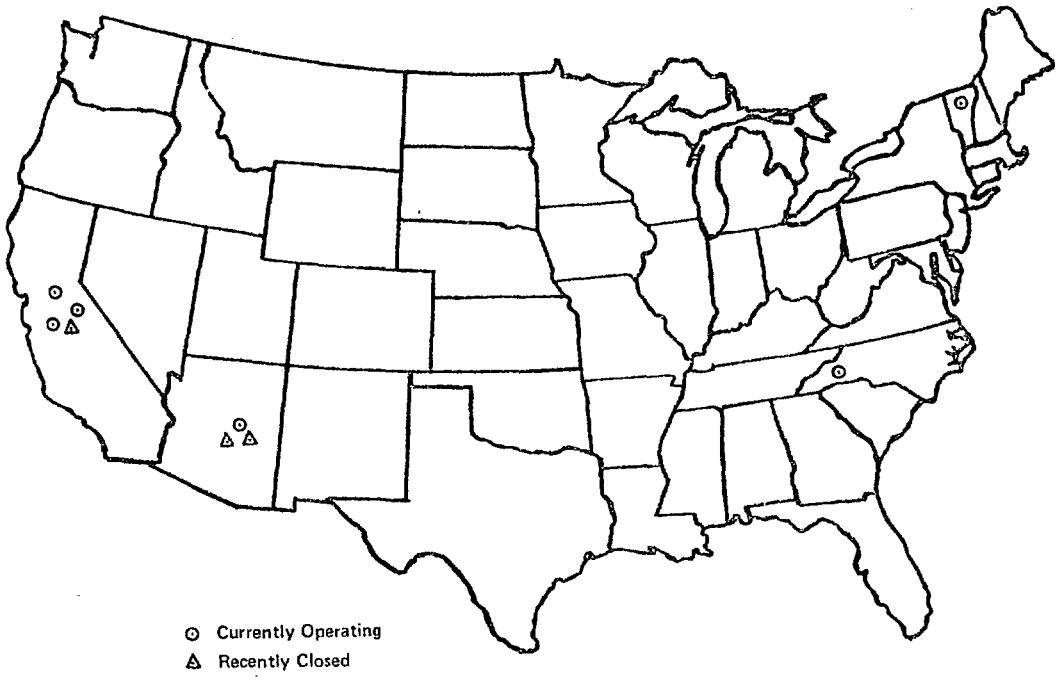

Figure 5.2. Asbestos Mines in the United States

Table 5.1. American Asbestos Mines and Mills (Harwood and Blasznak, 1974; Clifton, 1974, 1975; Asbestos Magazine, December, 1972 - 1975) Note: All mines are open pit except those in Arizona, which are underground.

Operating Company	Mine Location	Employees*	Mill Location	Employees*	Estimated Production (Short Tons)	Comments
1. Atlas Asbestos Co.	Fresno County, Calif.	20	Coalinga, Calif.	50	25,000/yr.	Used in vinyl-floor tile
2. Calaveras Asbestos Ltd.	Calaveras County, Calif.	36	Copperopolis, Calif.	135	220/day	Used in asbestos-cement pipes and sheets
3. Union Carbide	San Benito County, Calif.	36	King City, Calif.	50	110/day	Used in reinforcing thermoplastics (Calidria); Japan is a major consumer
4. Coalinga Asbestos Co., div. of Johns-Manville	Fresno County, Calif.	20	Coalinga, Calif.	50	110/day	Closed in June, 1974
5. Vermont Asbestos Group	Hyde Park, Vt.	58	Hyde Park, Vt.	143	220/day	Used in heat-resistant materials, mostly by GAF; purchased in 1975 from GAF
6. Jacquays Mining Corp.	Gila County, Ariz.	8	Globe, Ariz.	5	3,000/yr.	Used for electrical and filter media; most is exported to Japan
7. Asbestos Mfg. Co.	Gila County, Ariz.	--	Globe, Ariz.	---	Closed	Closed
8. Netate Asbestos Co.	Gila County, Ariz.	--	Globe, Ariz.	---	Closed	Closed
9. Powhattan Mining Corp.	Burnside, N.C.	4	Baltimore, Md.	8	700/yr.**	---

* 1973 figures (Harwood and Blasznak, 1974)
** Mill capacity figure

until recently, several operating mines, the Bureau of Mines has reported annual production for the state. But as a result of recent mine closings, the annual California production report might be terminated (Clifton, 1976). Table 5.1 contains estimates of Harwood and Blasznak (1974) for several individual daily mine productions and the estimate of Asbestos Magazine for annual production of two mines. Based upon the combined data of Harwood and Blasznak, Clifton, and Asbestos Magazine, we estimate that at the present time about 55-65% of the asbestos mined in the U.S. is mined in California, 35-45% comes from Vermont, and less than 5% is mined in Arizona and North Carolina. Until recent mine closings and sales altered the California production, California had accounted for nearly 70% of the domestic fiber.

The lower limit for economical asbestos production is estimated at 4% asbestos containing ore (Berger and Oesper, 1963). Clifton (1975) evaluated the effect of continuous mine operations on the percent fiber recovery by a linear regression analysis of Quebec mine data (see Figure 5.3). He forecasts that as the age of a mine increases, the percent fiber recovery decreases. This will result in an increasing fiber production cost until mining is no longer profitable. By reason of analogy, the Quebec data should be generally true for U.S. mines, especially the Vermont mine, which is an outcrop of the Quebec deposits. Based on the above data, the Vermont mine appears close to being mined out.

5.1.1 Ore Characteristics

The chrysotile asbestos content of ore varies between deposit locations. The lowest concentration is deposited in the Vermont ore which consists of less than 4% asbestos by weight, and the highest concentration is deposited in the Coalinga, California, district which is approximately 60% by weight asbestos.

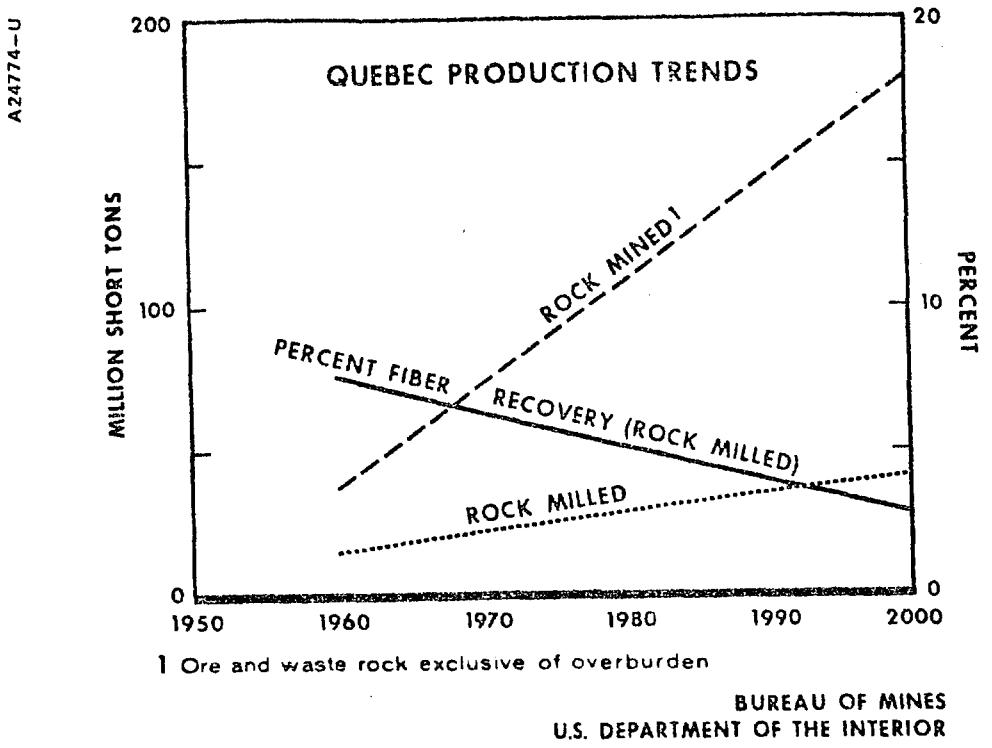

Figure 5.3. Quebec Production Trends, From Analysis of 1951 - 1970 Data (Clifton, 1975)

The Vermont ore deposit is an outcrop of the large Quebec deposits in Canada. While the Vermont deposit contains some spinning grade fibers (Harwood and Blasznak, 1974), most fiber is shorter grade and is consumed in the manufacture of heat resistant products (Asbestos Magazine, December, 1973).

The Calaveras Asbestos Ltd. mine in Copperopolis, California, produces the normal long fibered form of chrysotile asbestos which is primarily used in asbestos-cement products (Harwood and Blasznak, 1974; Asbestos Magazine, December, 1975). Three mines, the Coalinga (Johns-Manville), Atlas, and Union Carbide, are in close proximity to each other near Coalinga, California. They work an ore body which is 10 miles long and 0.25 miles wide. The ore from these mines is atypical of asbestos. Instead of a fibrous vein structure, the asbestos is in a platy, slippery form known locally as desert leather (Harwood and Blasznak, 1974). The fibers from this tract are short and therefore are used in floor tile and reinforced thermoplastics (Asbestos Magazine, December, 1971, 1975). Arizona produces an exceptionally high quality, low iron content asbestos, most of which is used for electrical insulation and for filtering media (Asbestos Magazine, December 1975). Most of the Jacquay Mine production is exported to Japan (Harwood and Blaszak, 1974).

6.0 FRICTION MATERIALS

Friction materials are used in practically all industries as a key component in clutches for transmitting torque, brakes for slowing down or stopping motion, or as torque limiters. Although friction applications to automobile brakes and clutches are the most important commercially, asbestos-friction applications are not limited to brakes and clutches in automobiles, trucks, busses, construction equipment, and railroad cars. Rather, these applications are found wherever motion must be controlled. The following examples show the diversification of friction material usage: farm tractors, presses, hoists, tensioning devices in production of wire and plastic rope and cable, lift trucks, machine tools, shuttlecars, specialized mining equipment, chainsaws, drilling equipment, spinning and knitting equipment, x-ray machines, wheel brakes, tape recorders, typewriters, bicycle brakes, snowblowers, and washing machines (Daly et al., 1976). Asbestos is an important ingredient in these friction material products because it imparts strength, good friction properties, can withstand high temperatures, and is a good insulator.

6.1 Statistics

6.1.1 Use Quantity and Shipment Values

From Table 4.9 (p. 46), it can be seen that U.S. demand for asbestos in friction products has ranged from sixty-five to eighty thousand short tons annually from 1964 to 1974. This amounts to approximately 9% of the total U.S. asbestos demand (consumption).

The trend in the value of shipments of asbestos friction materials is shown in Table 6.1. During the five year period from 1967 to 1972, shipment

Table 6.1. Value of Shipments of Asbestos Friction Materials (U.S. Bureau of the Census, 1972 Census of Manufacturers)

SIC Product Code		Product	Total Product Shipments, including interplant transfers (millions dollars) 1972	1967	1963
32922	--	Asbestos Friction Materials - Total	209.5	144.4	177.7
		Brake Linings:			
32922	11	Woven, containing asbestos yarn, tape, or cloth	10.2	13.5	--
32922	15	Molded, including all non-woven types	113.1	95.6	--
32922	21	Disc Brake Pads	14.2	--	--
		Clutch Facing:			
32922	51	Woven, containing asbestos yarn, tape, or cloth	19.9	17.2	--
32922	55	Molded, including all non-woven types	48.5	16.1	--
32922	00	Asbestos Friction Materials, n.s.k.	3.6	2.0	--

values increased by 45%, as compared to a 23% increase for the four-year period from 1963 to 1967. Using an annual figure of 9% for shipment value increases, the total product shipments of asbestos friction materials would be approximately $271.3 million in 1975 and $295.7 million in 1976.

Table 6.1 also gives a breakdown for the major asbestos friction material products. In 1972, brake linings accounted for nearly 59% of shipment values while clutch facings accounted for slightly over 32% of the shipment values. If disc brake pads are included along with brake linings, then asbestos brake-materials account for 65.6% of the total value of asbestos-friction materials. Clearly then, "brakes" are by far the most important commercial product in the friction material category.

6.1.2 Industrial Firms

Table 6.2 lists the U.S. manufacturers of asbestos-bearing friction materials along with their respective sales of friction materials in 1975. The larger firms include not only the essentially captive producers, such as the Delco-Moraine and Inland Divisions of General Motors Corporation and the Cycleweld Division of Chrysler Corporation, but also the diversified industrial product manufacturers, such as Raybestos-Manhattan, Bendix, Abex, and H.K. Porter. In addition, the list includes many smaller, typically single-plant firms, which manufacture friction products for both the original equipment and replacement market.

The first eight firms listed on Table 6.2 account for nearly 75 to 85% of the total estimated sales of asbestos friction products in 1975. This ratio is consistent with the historical pattern for the industry, which indicates that in the 1954 to 1967 period, the eight largest firms accounted for between 86 and 91% of the industry's value of shipments (Margolin and Igwe, 1975; U.S. Bureau of the Census, 1972).

Table 6.2. U.S. Manufacturers of Asbestos-Bearing Friction Materials (Economic Information Systems, Inc., 1976; Margolin and Igwe, 1975; SRC Estimates)

Company	Plant Location	Estimated 1975 Sales of Friction Materials ($ million)
Raybestos-Manhattan, Inc.	Stratford, Conn. Mannheim, Pa. Crawfordsville, Ind. Fullerton, Calif.	110.0
Bendix Corporation	Troy, N.Y. Cleveland, Tenn.	72.5
Abex Corporation	Cleveland, Ohio Troy, Michigan American Brakeblok Division Winchester, Va.	60.1
General Motors Corp.	Delco-Moraine Div. Dayton, Ohio Inland Division Dayton, Ohio	30.0
H.K. Porter Co.	Huntington, Indiana Richmond, Ky.	26.0
Chrysler Corporation	Cycleweld Division Trenton, Michigan	---
Borg Warner Corporation	Spring Division Bellwood, Ill.	---
World Bestos Co.	New Castle, Ind.	18.8
National Friction Products Corp.	Logansport, Ind.	10.2
Gatke Corporation	Warsaw, Ind.	10.0
Carlisle Corporation	Ridgeway, Pa.	9.7
Maremont Corporation	Grizzly Products Division Paulding, Ohio	8.7

Table 6.2. U.S. Manufacturers of Asbestos-Bearing Friction Materials (Cont'd)

Company	Plant Location	Estimated 1975 Sales of Friction Materials ($ million)
Scandura, Inc.	Charlotte, N.C.	----
Mar Pro Corporation	Grizzly Brake Division Chicago, Ill.	----
Standco Industries	Houston, Texas	8.7
Forcee Mfg. Corporation	Tappahannock, Va.	----
Royal Ind. Brake Products, Inc.	Danville, Ky.	5.7
Auto Friction Corp.	Lawrence, Ma.	5.7
L.J. Miley Co.	Chicago, Ill.	5.5
Friction Products Co.	Medina, Oh.	4.0
United States Brake Lining Corp.	Miami, Fla.	2.9
Brassbestos Mfg. Corp.	Patterson, N.J.	1.7
Southern Friction Material Co.	Charlotte, N.C.	----
Reddaway Mfg. Co.	Newark, N.J.	1.7
Molded Ind. Friction Corp.	Prattville, Ala.	----
Auto Specialties Mfg. Co.	St. Joseph, Mich.	----
Lasco Brake Products Co.	Oakland, Calif.	<1
California Blok Co.	Gardena, Calif.	<1
MGM Brakes, Inc.	Cloverdale, Calif.	<1
Wheeling Brake Block Mfg. Co.	Wheeling, W.Va. Bridgeport, Ohio	<1

Table 6.2. U.S. Manufacturers of Asbestos-Bearing Friction Materials (Cont'd)

Company	Plant Location	Estimated 1975 Sales of Friction Materials ($ million)
Baldwin-Ehnet Hill, Inc.	Trenton, N.J.	<1
Thiokol Chemical Corp.	Trenton, N.J.	<1
P.T. Brake Lining Co.	Lawrence, Mass.	----
Hunt/Airheart Products, Inc.	Chatsworth, Cal.	----
Re-Bilt Auto Products Corp.	Brooklyn, N.Y.	----

One important discrepancy in figures should be explained. For 1972, the U.S. Bureau of the Census listed the total value of shipments of asbestos friction products as $209.5 million which was projected as $271.3 million for 1975 in Section 6.1.1. From Table 6.2, the estimated sales of asbestos friction materials in 1975 total nearly $370 million for the listed figures; the companies with no listed figures may total another $50 million. The difference from the value of shipments as reported by the Bureau of the Census and the estimates given in Table 6.2 are due to variations in definition and reporting coverage. Shipment value does not include freight charges and excise taxes which are included in the actual sale cost. Also, the Bureau of the Census figures are based upon surveys at 23 asbestos-friction material establishments. Table 6.2 contains 44 establishments. Although the Bureau of the Census survey probably includes most of the larger establishments, the ones which were not surveyed are not available.

6.1.3 Plants

Figure 6.1 shows the geographical dispersion of friction materials plants in the U.S. Not surprisingly, they tend to be concentrated in and around the major metropolitan centers of the Northeast and Midwest, with a few plants located in California to primarily cater to the needs of the automobile assembly plants in that part of the country.

As would be expected of a mature industry, most of the plants and equipments are old, usually over forty years of age, with the possible exception of newer captive facilities belonging to the automobile manufacturers. Production processes have changed only marginally over the years, and labor rather than capital intensity appears to be the norm in most of the older plants (Margolin and Igwe, 1975).

Figure 6.1 Geographical Dispersion of U.S. Friction Materials Plants (Modified from Margolin and Igwe, 1975)

6.1.4 Future Projections for Asbestos Use (Clifton, 1975)

Asbestos demand for friction products was projected to the year 2000 at an annual growth rate of 1.50 percent. This figure was based on a formula derived from least-squares regression analysis of total asbestos demand modified by the estimated growth in the automobile industry and economic indicators, which showed the best correlation.

Asbestos is an important part of many types of friction materials for use in automobiles, trucks, and other transportation equipment. Modern industry could scarcely function without asbestos friction materials. In addition to using asbestos in brake linings, today's motor cars, equipped with automatic transmissions, get their drive from metal transmission disks, which are covered with a super-tough paper containing crocidolite asbestos. The average automobile with power shift contains from 8 to 12 of the paper lined disks. Although the quantity of asbestos in each transmission is small, the output of more than 8 million automatic transmissions annually requires disk paper production in hundreds of tons.

A new composition disk-brake-shoe unit containing asbestos, designed to meet the critical braking requirements for the new 150-mile-per-hour passenger train systems, has been developed.

Based on an estimated forecast of the number of motor vehicles produced in the year 2000 (approximately double 1973 production) and on the assumption that the use of asbestos per vehicle will remain at present levels, the forecast for asbestos demand in user-operated vehicles is projected to 118,000 tons. An increased number of public transportation vehicles and equipment using parts made of asbestos or maintaining the present quantity used per vehicle could result in a demand as high as 144,000 tons.

6.2 Manufacturing Process Technology

Several different processes are used to manufacture asbestos brake linings and clutch facings. Manufacture can be accomplished by a molding process, in a dry or wet-mixed state, or by a woven process; these processes, which are described below, are taken from Gregg (1974). The raw materials used for forming asbestos-friction materials are discussed in Section 6.3.

6.2.1 Molded Products

6.2.1.1 Dry-Mix Process

The manufacturing steps typically used in dry-mix molded brake lining manufacture are shown in Figure 6.2. The bonding agents, metallic constituents, asbestos fibers, and additives are weighed and mixed in a two-stage mixer. The mix is then hand-tamped into a metal mold. The mold is placed in a preforming press which partially cures the molded asbestos sheet. The asbestos sheet is taken from the preforming press and put in a steam preheating mold to soften the resin in the molded sheet. The molded sheet is formed to the proper arc by a steam-heated arc former, which resets the resin. The arc-formed sheets are then cut to the proper size. The lining is then baked in compression molds to retain the arc shape and convert the resin to a thermoset or permanent condition. The lining is then finished and, after inspection, is packaged. The finishing steps include sanding and grinding of both sides to correct the thickness, edge grinding, and drilling of holes for rivets. Following drilling, the lining is vacuum-cleaned, inspected, branded, and packaged (Gregg, 1974).

6.2.1.2 Wet-Mix Process

Figure 6.3 shows the major steps in the manufacture of wet-mixed molded brake linings. The name "wet mix" process is a misnomer and refers

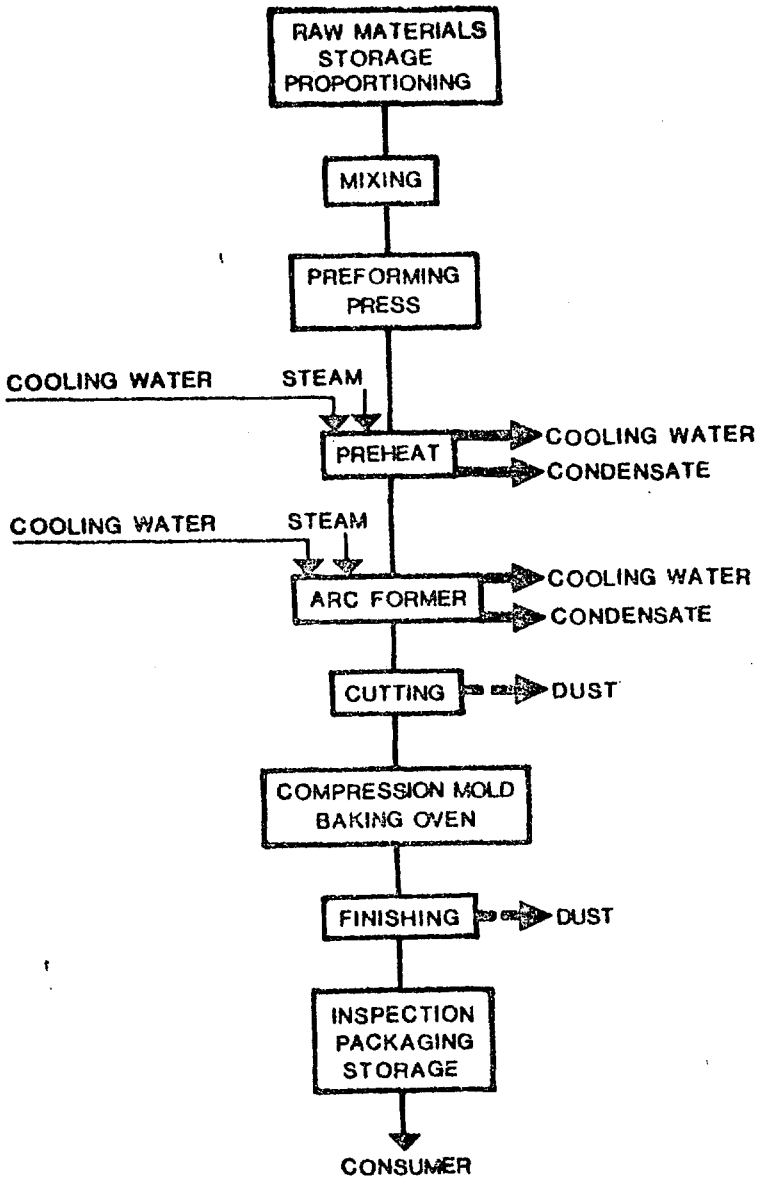

Figure 6.2. Dry-Mixed Brake Lining Manufacturing Operations (Gregg, 1974)

to the use of a solvent. The ingredients of the molded lining are actually relatively dry. After weighing, they are mixed in a sigma blade mixer. The mixed ingredients are then sent to grinding screens where the particle size of the mixture is corrected. The mixture is conveyed to a hopper and is forced from the hopper into the nip of two form rollers which compress the mixture into a continuous strip of friction material. The strip is cut into the proper lengths and then arc-formed on a round press bar. The cutting and arc forming operations are done by separate units. The linings are then placed in racks and either air-dried or oven-dried to remove the solvent. An alternative process is to place the arc-formed linings in metal molds for baking in an oven. From the ovens, the linings are finished, inspected, and packaged (Gregg, 1974).

Molded clutch facings are produced in a manner similar to the wet-mixed process. The rubber friction compound, solvent, and asbestos fibers are introduced into a mixer churn. After the churn mixes the ingredients, the mixture is conveyed to a sheeter mill which forms a sheet or slab of the materials. The sheet is then diced into small pieces by a rotary cutter. The pieces are placed in an extrusion machine which forms sheets of the diced material. The sheets are cut into the proper size and then punch-pressed into doughnut-shaped sheets. The scraps from the punch press are returned to the extrusion machine. The punched sheets are placed on racks and sent to a drying oven and then a baking oven for final curing and solvent evaporation. The oven-dried sheets are finally sent to the finishing operations. Figure 6.4 illustrates the steps in the manufacture of molded clutch facings (Gregg, 1974).

6.2.2 Woven Products

Woven clutch facings and brake linings are manufactured of high strength asbestos fabric that is frequently reinforced with wire. The fabric is

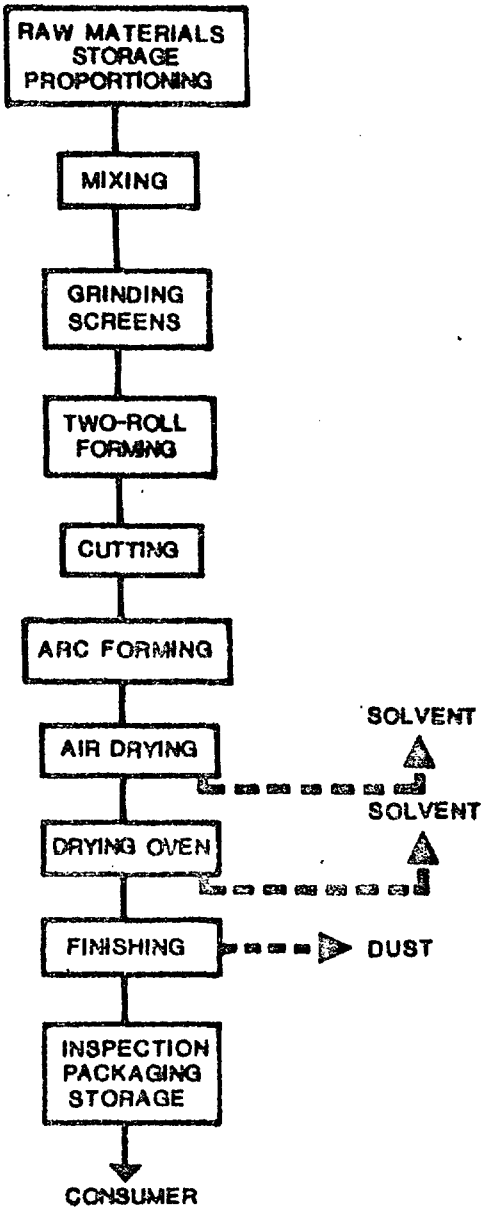

Figure 6.3. Wet-Mixed Molded Brake Lining Manufacturing Operations (Gregg, 1974)

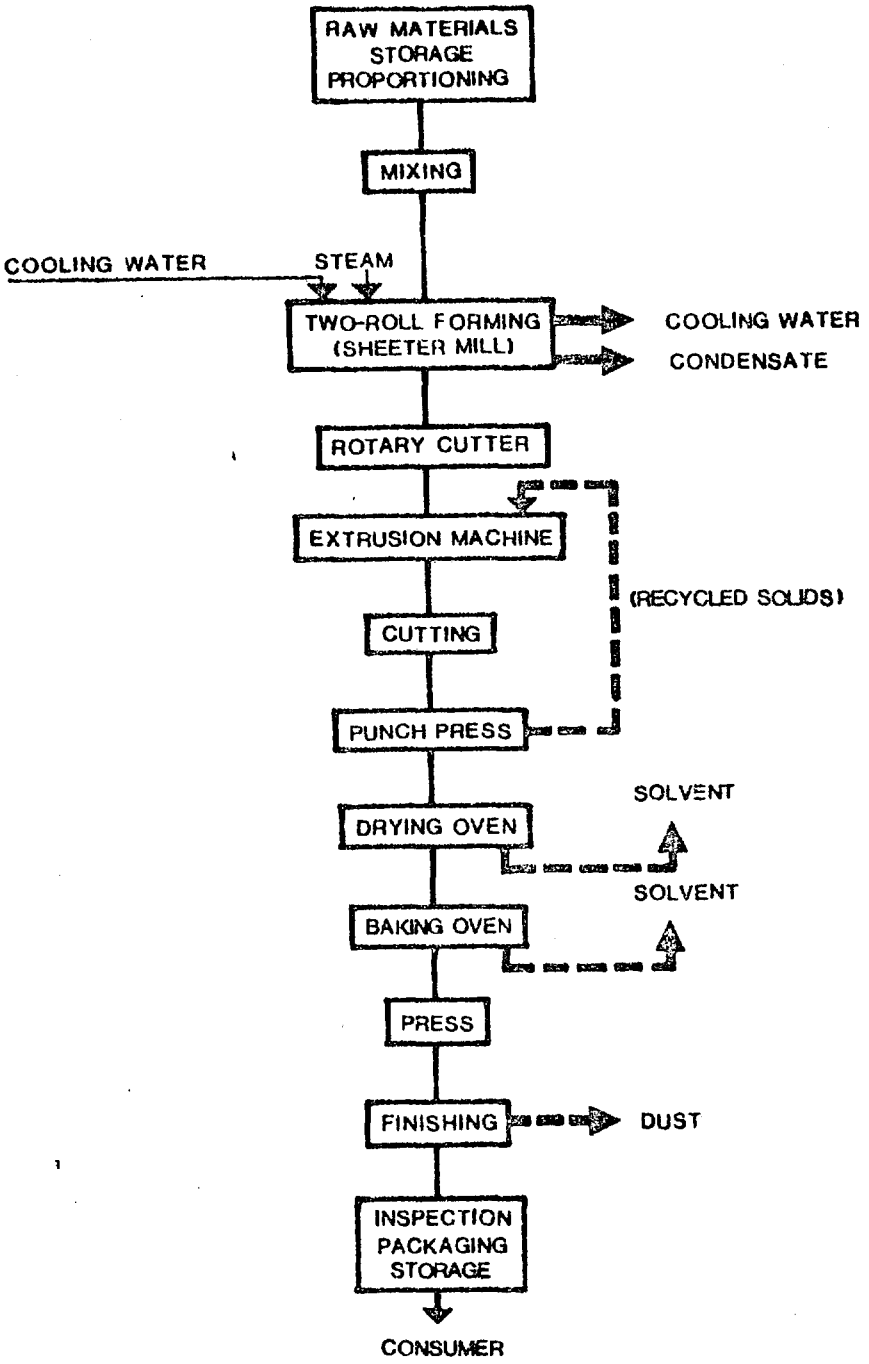

Figure 6.4. Molded Clutch Facings Manufacturing Operations (Gregg, 1974)

predried in an oven or by an autoclave to prepare it to be impregnated with resin. The fabric can be impregnated with resin by several techniques: 1) immersion in a bath of resin, 2) introducing the binder in an autoclave under pressure, 3) introducing dry impregnating material into carded fiber before producing yarn, and 4) imparting binder into the fabric from the surface of a roll. After the solvents are evaporated from the fabric, it is made into brake linings or clutch facings. Brake linings are made by calendering or hot pressing the fabric in molds. The linings are then cut, rough ground, placed in molds, and placed in a baking oven for final curing. Following curing, the lining is finished, inspected, and packaged (Gregg, 1974).

Figure 6.5 illustrates the manufacture of woven clutch facings. The treated fabric is cut into tape-width strips by a slitting machine. The strips are wound around a mandrel to form a roll of the fabric. The roll is pressed in a steam-heated press and then baked in an oven to cure the resin in the clutch facing. Following curing, the clutch facing is finished, inspected, and packaged (Gregg, 1974).

6.3 Composition of Friction Materials

Many raw materials, including some whose exact roles are regarded as proprietary knowledge, are used in varying quantities in the manufacture of friction materials. The major, or foundation constituent, of practically all organic friction materials is asbestos fiber. The asbestos usually used in friction materials is chrysotile from Quebec or Vermont (Jacko and DuCharme, 1973); grades 3-7 are used; however, grades 5 and 7 account for nearly 83% of the total (Clifton, 1975). Asbestos is used because of its thermal stability, relatively high friction level, and reinforcing properties.

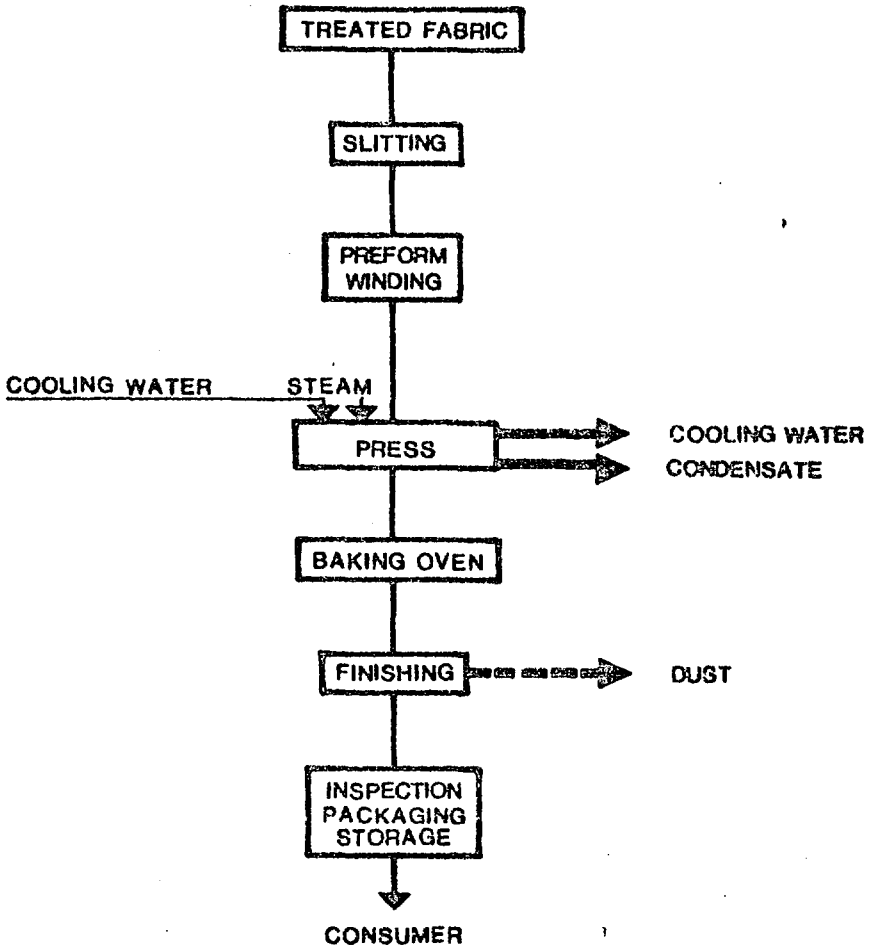

Figure 6.5. Woven Clutch Facings Manufacturing Operations (Gregg, 1974)

Asbestos alone does not offer all of the desired friction properties. Therefore, other materials, known as property modifiers, are added to the asbestos fibers. Modifiers are varied in type and content to provide desired levels of effectiveness, wear, fade, recovery, and noise. A binder is also added to hold the other materials together with adequate strength.

6.3.1 Binders

Table 6.3 lists binders and property modifiers which are used in automotive brake linings. The binders used in the automotive industry today are primarily phenolic-type resins which are noted for high binding efficiency and ability to withstand pyrolytic breakdown (Rohl et al., 1976). They are prepared as the condensation product between the appropriate phenol (sometimes modified) and formaldehyde in the presence of an acidic catalyst to yield the novolak. When mixed with an appropriate curing agent, they polymerize at elevated temperatures to an insoluble, infusible mass (Jacko and DuCharme, 1973). Other resin systems in wide use are based on elastomers, drying oils, or combinations.

6.3.2 Property Modifiers

Perhaps the widest range of materials used in friction products are the property modifiers. Table 6.3 indicates the range and diversity of these modifiers. In general, property modifiers can be divided into two classes: non-abrasive modifiers and abrasive modifiers (Jacko and DuCharme, 1973).

6.3.2.1 Non-Abrasive Modifiers

Non-abrasive friction modifiers can be classified further as low friction and high friction. The most common and best known of the high friction materials is known as friction dust. This is a cured resinous material. The most frequently used variety is derived from cured or polymerized

Table 6.3. Binders and Property Modifiers In Automotive Brake Linings (Rohl et al., 1976; Jacko and DuCharme, 1973; various patent literature; Bark et al., 1975)

Binders	Property Modifiers	Use Function
Phenolic-type resins	Graphite	Lower friction coefficient and noise
Natural rubber	Coke	"
Buna N rubber	Coal	"
Nitrile rubber	Carbon black	"
Tire scrap	Gilsonite	"
Pitch		
Cork	Rottenstone (SiO_2)	Remove decomposition deposits
Gilsonite	Quartz (SiO_2)	"
Elastomers	Wollastonite ($CaSiO_3$)	"
Drying oils	Brass Chips	"
	Zinc and compounds	"
	Alluminum	"
	Limestone ($CaCO_3$)	Improve wear resistance
	Clays	"
	Silicas	"
	Barite	"
	Lead and compounds	Lubricant to prevent grabbing
	Friction dusts	See discussion in Section 6.3.2.1
	Antimony compounds	Not available
	Calcium compounds	"
	Copper and compounds	"
	Barium hydroxide	"
	Potassium dichromate	"
	Magnesium carbonate	"
	Iron oxide	"
	Cryolite (Na_6AlF_3)	"
	Fluorspar	"
	Cardolite	"
	Nickel	"
	Naptha	"
	Sulfur	"
	Methylethyl ketone	"
	Molybdenum disulfide	Lubricant
	Calcium fluoride	Lubricant

cashew-nut-shell liquid, chemically a phenolic compound. When heated with hardening agents, such as hexamethylenetetramine or formaldehyde, it becomes sufficiently hard or polymerized to be granulated. Many other cured resinous or polymeric materials, some with fillers, are also used. Certain friction dusts are combinations of these materials and cashew resin. Ground rubber is normally used in particle sizes similar to, or slightly coarser than, those of the cashew friction dusts for noise, wear, and abrasion control (Jacko and DuCharme, 1973).

Carbon black, graphite, petroleum coke flour, or other carbonaceous materials may also be added as friction modifiers to lower the friction coefficient or to reduce noise. These materials are normally used in the form of fine powders or particles, although graphite is sometimes used in coarse particles or pellets. The amount of friction modifier added is dependent upon the properties desired in the final composite (Jacko and DuCharme, 1973).

6.3.2.2 Abrasive Modifiers

Abrasive modifiers, such as alumina and the silicas, are usually used in relatively small amounts and only in very fine particle sizes (generally 100 mesh or finer). Particle size is limited by the fact that large particles of such hard materials would groove and wear the mating surfaces. Minerals are generally added to improve wear resistance at minimum cost. Those most commonly used are ground limestone (whiting) and barytes (barium sulphate), though various types of clay, finely divided silicas, and other inexpensive or abundant inorganic powders may also perform this function. Such materials are inorganic in nature and tend to detract from noise properties and mating surface compatibility (Jacko and DuCharme, 1973).

Metals or metal oxides may also be added to perform specific functions. Brass chips are frequently found in heavy-duty friction materials

where, as scavengers, they break up undesirable surface films. Zinc and aluminum are also used. Zinc chips, in relatively small amounts, can contribute significantly to recovery of normal performance following fade (Jacko and DuCharme, 1973).

6.3.3 Composition

The average composition of a typical automobile and truck brake lining is shown in Table 6.4a. Individual mixes may vary considerably from these averages.

Table 6.4a. Average Brake Lining Composition (Lunch, 1968)

Ingredient	Automobile	Truck
Asbestos	55	33
Resins and Polymers	28	48
Oxides and Pigments	9	16
Metals	3	2
Carbon, Graphite, etc.	5	1
	100%	100%

Manufacturers are very reluctant to release their exact compositions due to proprietary considerations. A search of patent literature reveals limited information, although several examples from the patent literature are given in Table 6.4b.

6.3.4 Summary

The tables and examples given in Section 6.3 have been included to illustrate the wide variety of compositions which are possible for fabrication of automotive and truck brake linings. Brake linings have been singled out

Table 6.4b. Brake Lining Compositions from Patent Literature

Example No. 1*		Example No. 2**	
Asbestos	55	Asbestos	60
Barite	10	Phenolic resin	15
Phenolic resin binder	20	Nitrile rubber	3
Brass	5	Cashew dusts	12
Magnesium carbonate	8	Calcium fluoride	7
Limestone	8	Copper iodide	3
Organic calcium powder	10		

Example No. 3***		Example No. 4****	
Asbestos	35	Asbestos	50
Barite	2.5	Tarry residue	12
Graphite	7	Barite	20
Brass	13	Phenolic resin	20
Phenolic resin	7	Graphite	2
Lead oxide	11.5		
Buna N rubber	8		
Naphtha	7		
Copper sulfide	12.5		
Methyl ethyl ketone	4		

* Sakata et al., 1974 (Hitachi)
** Toyota Central Research and Development Labs, 1971
*** Keller, 1969 (Abex)
**** Mitchell, 1974 (duPont)

from the asbestos-friction products for examination because of their dominance of the asbestos-friction products market as shown in Table 6.1. When the variations of compositions are coupled with the variations of manufacturing process methods (as described in Section 6.2), it is possible to view a brake lining made by company A as substantially different from a brake lining made by company B, although the intended use applications may be the same. From this standpoint, it is entirely reasonable to speculate that asbestos emissions during automotive brake use may vary in concentration, depending upon composition and process manufacture of the individual linings.

6.4 Asbestos Emissions from Brake Lining Use

Asbestos has been identified in over 200 air samples taken from the atmosphere of 49 cities in the United States (Nicholson et al., 1973); asbestos was present in every sample taken. Asbestos has also been found in air samples from European cities (Holt and Young, 1973) and from air samples collected in Australia (Alste et al., 1976). The asbestos manufacturing industry may not be the source of the asbestos emissions found in urban air samples cited above. According to Holt and Young (1973), "the object of our investigations was only to determine whether asbestos fibres are present in the atmosphere of towns where there is no asbestos industry. The result was positive in every case."

The source of asbestos emissions, in the absence of asbestos mining and industry, is a matter of speculation. Holt and Young (1973) and Selikoff et al. (1972) suggest that the asbestos source may be construction which uses building materials made from asbestos. Alste et al. (1976) consider, as a source, that asbestos emitted from automobile brake linings is a "strong possibility." Alste et al. (1976) found that the air concentration of asbestos

was much higher at points where considerable braking occurred, as compared to points of virtually no braking. This result is apparently in agreement with measurements made in New York City which found that the asbestos air concentrations contiguous to a toll booth were three to five times higher than background levels (Anderson et al., 1973; Nicholson et al., 1971). This subsection will consider the possibility of asbestos emissions from brake lining use.

6.4.1 Published Literature

A number of articles and publications (Alste et al., 1976; Rohl et al., 1976; Jacko and DuCharme, 1973; Jacko et al., 1973; Bush et al., 1972; Hatch, 1970; Hickish and Knight, 1970; Lynch, 1968) have discussed the asbestos emissions from the use of brake linings. Table 6.5 gives a brief summary of this published data in terms of methodologies and results. As can be seen from Table 6.5, there are important discrepancies in the results obtained.

6.4.1.1 Discrepancies in Asbestos Content of Emissions or Debris

Lynch (1968), Hatch (1970), Hickish and Knight (1970), and Jacko and DuCharme (1973) reported figures in the range of 1% or less for the asbestos content of emissions or debris resulting from brake lining use. Bush et al. (1972) and Rohl et al. (1976) arrived at figures which are substantially higher, 44% and 2-15% asbestos content, respectively. While Alste et al. (1976) did not arrive at a percent figure, they did conclude that the major effect of braking appears to be separation of bunches of fibres and reduction of their average length, but not alteration of their crystal structure. This conclusion may certainly result in a relatively high asbestos content for wear debris.

Table 6.5. Summary of Published Data - Asbestos Emissions from Brake Lining Use

Publication Source	Method Used to Collect Emission or Debris Samples	Method Used to Determine Asbestos Content of Emission Debris Samples	Asbestos Particle Size Distribution	Asbestos Content of Emission or Debris
Lynch, 1968	Laboratory simulations utilizing brake-testing machines or dynamometers. Samples collected on 0.8 μ pore size membrane filters.	Electron micrographs	Not discussed	<1%, except under severe-stress conditions
Hatch, 1970	A dust cloud was generated by using compressed air jets to remove dust from brake linings in an auto repair garage. Samples were collected by means of a hand pump located in center of dust cloud.	Not stated	94% of fibers fell in 2-5 μm length category. Only 6% were longer than 5 μm.	~1%
Hickish and Knight, 1970	Samples were collected directly from debris remaining as brake dust and from membrane filters exposed during brake cleaning operations utilizing compressed air. Filter pore size is not given.	Not stated	Not discussed	1.6% and less
Bush et al., 1972	Laboratory simulations utilizing a disc brake assembly mounted on an inertial dynamometer. Samples were collected on suitable filter paper.	Neutron activation	Not discussed	~44% (this figure is not accurate; see discussion in Section 6.4.1.1)
Jacko and DuCharme, 1973 (contains same data as Jacko et al., 1973)	Samples were generated by operating a standard American car on a dynamometer simulating driving conditions. Brake and clutch assemblies were enclosed by specially designed collectors. Samples were collected from 1) dropouts during use, 2) dust retained in lining assemblies, and 3) airborne samples collected on membrane filters.	Optical and electron microscopy	30% of fibers were from 0.25-0.50 μm in length; 60% were longer than 0.5 μm.	0.23% overall average (an independent check done by Batelle Labs gave a figure of 0.171%)

Table 6.5. Summary of Published Data - Asbestos Emissions from Brake Lining Use (Cont'd)

Publication Source	Method Used to Collect Emission or Debris Samples	Method Used to Determine Asbestos Content of Emission Debris Samples	Asbestos Particle Size Distribution	Asbestos Content of Emission or Debris
Rohl et al., 1976	Ten samples of automobile brake drum dusts were collected from maintenance shops in the New York area.	X-ray diffractometry		2-15%; average of 3-6%
		Transmission electron microscopy, selected area electron diffraction, and electron microprobe analyses	80% of fibers were shorter than 0.4 μm length.	Consistent with, but lower than, quantitative determination made by X-ray diffractometry; no percentages are given
Alste et al., 1976	Samples were taken from fresh and worn brake linings and from the atmosphere near a freeway.	Electron microscopy and electron diffraction	Majority were ≤2 μm in maximum linear dimension.	No percent figure given; however, conclusion was that major effect of braking appears to be in separating bunches of fibres and reducing their average length, but not in altering their crystal structure

The 44% figure computed by Bush et al. (1972) is based upon a neutron activation analysis, which is a technique for finding the elemental composition of a sample by irradiating the sample with neutrons, thereby causing the elements to become radioactive. Bush et al. is careful to point out that chrysotile asbestos is a magnesium silicate and neither magnesium or silicon are able to be determined utilizing the particular technique. Therefore, asbestos content of the wear debris was determined by means of a scandium concentration. Scandium was a trace element ($\sim$ 4 ppm) present in the chrysotile used in the experiment. Neutron activation can be a very precise and useful technique for determining elemental composition; unfortunately, the asbestos content of any particular wear debris sample cannot be computed by an elemental analysis. Chrysotile asbestos is a unique crystal structure of a magnesium silicate (see Section 2.1); heat or other physical means can destroy this unique structure, thereby creating a different compound with different properties. However, the elemental composition of the different compound will be identical with chrysotile. Both Rohl et al. (1976) and Jacko and DuCharme (1973) determined that the magnesium:silicon ratio of an asbestos friction material is the same before use and after use (as determined from wear debris via chemical analyses). Therefore, the 44% asbestos content figure computed by Bush et al. (1972) does not represent the asbestos content, but rather it represents the magnesium silicate content. When considering wear debris from friction materials, neither neutron activation nor chemical analyses are useable techniques for analysis of asbestos concentration.

The major conflict to be resolved is the high asbestos content suggested by Alste (1976) coupled with the 2-15% asbestos content figure

obtained by Rohl et al. (1976) versus the 1% and less figures obtained by the remaining publication sources listed in Table 6.5. The difference of results appears to be based upon collection methodologies, analysis techniques, and interpretations.

6.4.1.2 Collection Methodologies and Particle Size Distribution

The first major consideration of methodology is the type of samples which were collected; that is, samples produced by laboratory simulations versus samples produced during actual, real-life use. Jacko and DuCharme (1973) and Lynch (1968) collected laboratory samples produced by simulations while Alste et al. (1976), Rohl et al. (1976), Hatch (1970), and Hickish and Knight (1970) collected real-life samples. There may be an open debate as to which collection method produces the best final results. Laboratory simulations, as conducted by Jacko and DuCharme (1973), allow entire brake assemblies to be enclosed, and therefore, all conditions could be monitored or controlled and all emissions can be collected. On the other hand, samples collected from real-life use are not only relevant, but they may provide the truest indication as to the asbestos emitted from brake lining use. Conditions encountered during actual use may not be totally reproducible in the laboratory; hence, the asbestos emission factors may be significantly different.

Another area of consideration is the asbestos particle size distribution in the wear debris. Rohl et al. (1976) determined that approximately four-fifths of the wear debris fibers are shorter than 0.4 μm in length while Jacko and DuCharme (1973) found that 30% of the fibers were from 0.25-0.50 μm in length. According to Rohl et al., some of the discrepancies between their data and those of Jacko and DuCharme may be attributed to Jacko and DuCharme's

use of lower magnification (22,000X vs. 42,000X), at which fibers shorter than 0.20 μm may not be easily seen or identified on the electron microscopic screen. Hatch (1970) also produced size distribution figures, finding that 94% of the fibers fell in a 2-5 μm length range; however, there is no indication that Hatch attempted to look for fibers shorter than 2 μm. Alste et al. (1976) found that the majority of particles, which consisted of small bundles of fibers, had a maximum dimension of $\leq$ 2 μm.

The best available data (Rohl et al., 1976; Jacko and DuCharme, 1973; Alste et al., 1976) indicates that a very high percentage of the asbestos present in brake lining wear debris is shorter in length than 2 μm, with a substantial portion shorter than 0.5 μm.

6.4.1.3 Analysis Techniques

Hickish and Knight (1970) fail to discuss analysis techniques used to determine the asbestos content in their wear debris and, also, do not fully describe collection methods. Under these circumstances, it is difficult to accept their results at face values. Hatch (1970) is deficient in analysis methodology also, although it appears that he used electron microscopy in sizing particles down to 2 μm. Since the Rohl et al. (1976), Jacko and DuCharme (1973), and Alste et al. (1976) studies are the best studies yet conducted on brake lining asbestos emissions, a closer examination of the three is warranted.

As seen from Table 6.5, Rohl et al. determined their 2-15% asbestos content from X-ray diffractometry (both continuous and step-scan modes were used). According to Jacko and DuCharme, "asbestos is readily identified when alone or in simple mixtures at high concentrations by the following analytical methods: X-ray diffraction, thermal methods, microscopy, and infrared

analysis. However, in complex mixtures, or at very low concentrations, the analysis for asbestos is very difficult. In brake wear debris, the problem is compounded because the reaction products of asbestos, fosterite and olivine, have similar elemental ratios and similar X-ray diffraction patterns. The only sensitive method which can be used is microscopy." This conclusion by Jacko and DuCharme is apparently based upon the assumption that samples that they were going to produce would contain 1% or less asbestos; an accompanying table estimated the asbestos content of wear debris to be less < 1%. Apparently they did not use X-ray diffraction because they assumed the asbestos concentration would be too low. In the percent range reported by Rohl et al., namely 2-15%, X-ray diffraction is very likely an appropriate technique for quantitative chrysotile determination. Two published reports (Goodhead and Martindale, 1969; Crable, 1966) of X-ray diffraction techniques for determination of asbestos in dusts support the contention that chrysotile can be quantified with good accuracy in the percent ranges reported by Rohl et al.

Rohl et al. further verified chrysotile presence by transmission electron microscopy and selected area electron diffraction. "Chrysotile was found, both in fiber and fibril form, with unaltered structure and chemical composition. Its frequency of occurrence was consistent with, but lower than, the quantitative determination made by X-ray diffraction analysis. However, it should be noted that X-ray diffraction analysis is based on both free fibers and fibers present in clumps; the latter would obscure the presence of discreet fibers on electron microscopy study."

Alste et al. (1976) determined the presence of chrysotile asbestos by electron microscopy and electron diffraction and concluded that the

major effect of braking appears to be in separating bunches of fibers and reducing their average length but not in altering their crystal structure. This is an important result in terms of the following consideration: If only 15%, or downwards to less than 1%, of wear debris is asbestos, what happens to the major portions of the asbestos originally present in the brake lining? Lynch (1968), Hatch (1970), and Hickish and Knight (1970) present a prevalent theory that "hot spots" created during braking cause the local asbestos fibers to undergo thermal degradation which results in thermal metamorphosis of the asbestos into a different mineral, such as fosterite (olivine). Jacko and DuCharme (1973) assumed that 20-40% of the wear debris composition would be olivine. However, according to Alste et al. (1976) concerning wear debris from brake linings, "there was no indication from the diffraction pattern of the presence of fosterite;" this result was in agreement with Rohl et al. (1976) who also could not verify the presence of fosterite. Rohl et al. (1976) and Jacko and DuCharme (1973) discussed other forms of brake lining wear, in addition to thermal wear, such as abrasive wear and macroshear wear. However, the end result is probably this: the asbestos present in the original brake lining, excluding the asbestos which is emitted in the wear debris, is converted by thermal or other physical processes into magnesium silicates or other recrystallized magnesium silicate structures different from asbestos. In addition to unaltered chrysotile fiber in the wear debris, Rohl et al. (1976) observed partially altered and completely recrystallized fibers. Holt and Young (1973) reported that some of the asbestos fibrils collected in European city air appeared to have been heated.

6.4.1.4 Other Considerations

The Rohl et al. (1976) study is based upon a wider and more random sampling than that of Jacko and DuCharme (1973). Rohl et al. selected

wear debris samples from ten random automobiles undergoing brake maintenance while Jacko and DuCharme's wear debris samples came only from original auto equipment, a partial relining, and a relining for the car tested on the dynamometer. Alste et al. (1976) also collected random samples of wear debris from an auto repair shop, but apparently from only a few cars at most (a much smaller sampling than Rohl et al.).

Neither Rohl et al. (1976), Jacko and DuCharme (1973), nor Alste et al. (1976) considered, or tested, brake linings manufactured by different companies, different technical processes, or different compositions in any systematic manner which would be representative of the entire brake lining industry. Hence, there has been no experimental study conducted which can confirm or refute the supposition that brake linings made by different companies, processes, and compositions may contribute varying amounts of asbestos emissions into the environment.

6.4.2 Emission Quantities

Table 6.6 gives the estimated annual asbestos emissions for vehicles as computed by Jacko and Du Charme (1973). These figures are based, in part, upon Jacko and DuCharme's figure of less than 1% (∿0.2%) asbestos content of emission debris. They also made the following estimations:

(1) The total amount of asbestos contained in all of the automotive brake friction materials sold each year is about 103 million pounds which corresponds to ∿118 million pounds prior to grinding and drilling.

(2) The total amount of asbestos contained in all automotive clutch friction materials sold each year is about 4.5 million pounds.

Table 6.6. Estimated Asbestos Emissions* by Jacko and DuCharme (1973) from Vehicles

	Number of Vehicles	Total Annual Asbestos Emissions (lb)	Distribution of Total (lb)		
			Drop-Out	Airborne	Retention
Passenger Cars	96,400,000	60,400	49,470	2,230	8,700
Light Trucks	17,100,000	32,300	28,420	940	2,940
Medium Trucks and Buses	2,600,000	16,300	14,330	470	1,500
Heavy Trucks	1,200,000	32,900	28,920	950	3,030
Miscellaneous (motorcycles, trailers, etc.)	6,615,000	16,300	14,330	470	1,500
Totals		158,200	135,470	5,060	17,670
Percent of Total			85.6	3.2	11.2

* Includes both brake linings and clutches

(3) The combined total of brake and clutch friction material worn away annually is 123.6 million pounds (117 (brakes) + 66 (clutches) = 123.6). Assuming an average asbestos content of 60%, the amount of asbestos worn away as friction material wear debris is ∿74 million pounds.

Based upon available data from other sources (Clifton, 1975; U.S. Bureau of the Census, 1972, 1975), the estimations made above are quite reasonable and are probably good figures to use in emission computations.

Table 6.7 lists the estimated asbestos emissions using the Rohl et al. (1976) figure for the asbestos content of wear debris. Computations were made using the same assumptions and method as Jacko and DuCharme (1973); the only variation is the use of different asbestos content percentages. Rohl et al. (1976) arrived at an average asbestos content figure of 3-6% (therefore, a median of 4.5% is listed in Table 6.7) and high-low values of 2-15%.

A comparison of Table 6.6 and 6.7 reveals that the total annual asbestos emissions reported in Table 6.7 (4.4% median) is nearly 22 times higher than the total reported in Table 6.6. The focal point of the difference is the percentage of asbestos which survives in the wear debris.

Jacko and DuCharme (1973) determined that approximately 3% of the asbestos emission become airborne. Based upon sample concentrations collected at freeway exits, Alste et al. (1976) concluded that only a small fraction of the total dust formed becomes airborne, which is consistent with Jacko and DuCharme.

6.4.3 Human Exposure to Asbestos Emissions During Brake Lining Maintenance and Repair

In the United States, an estimated work force of at least 900,000 auto mechanics and garage workers is potentially exposed to asbestos in

Table 6.7. Estimated Asbestos Emissions from Vehicles Using Rohl et al. (1976) Figures for Asbestos Content of Wear Debris

Asbestos Content of Wear Debris	Total Annual Asbestos Emissions (lb)	Distribution of Total (lb)		
		Drop-Out	Airborne	Retention
2% (low)	1,520,000	1,300,000	49,000	171,000
15% (high)	11,400,000	9,800,000	360,000	1,280,000
4.5% (median of average 3-6%)	3,420,000	2,930,000	110,000	380,000

the servicing of both brake and clutch linings (Rohl et al., 1976). Measurable concentrations of asbestos fiber have been observed and reported in the work environment of workmen involved with brake and clutch linings maintenance and repair (Hickish and Knight, 1970; Hatch, 1970; Boillat and Lob, 1973; Rohl et al., 1976).

When a vehicle is brought into a repair shop for brake lining inspection or replacement, the wheel is removed and the loose dust is removed from the drums and back plates, generally by means of a compressed air jet. A cloud of dust is produced by this air jet which is visible for several minutes. Table 6.8 lists the fiber concentrations which were measured as a result of the dust cloud by the most relevant study (Rohl et al., 1976) to American standards of exposure; also given are concentrations measured for common truck servicing operations.

The result of the Rohl et al. (1976) study indicates that it is common for OSHA asbestos-fiber concentration standards to be exceeded during brake cleaning operations. It should be noted that fiber counts made during this study were in accordance with procedures adopted by OSHA. Essentially, the analysis consists of counting fibers 5 to 100 μm using phase contrast microscopy at a magnification of 400X.

Section 6.4.1.2 revealed that most of asbestos present in wear debris is much smaller than 5 μm. Rohl et al. (1976) estimated that 80% of the fibers present are shorter than 0.4 μm. Accepting these results, it is obvious that the asbestos exposure during brake servicing may be a great deal higher than is indicated by OSHA test standards.

Table 6.8. Asbestos Concentration During Automobile and Truck Brake Service* (Rohl et al., 1976)

Operation	Distance (ft)	Number of Samples	Fiber Concentration (fibers/ml) Mean	Range
Auto - Blowing dust out of brake drums with compressed air	3-5	4	16.0	6.6-29.8
	5-10	3	3.3	2.0-4.2
	10-20	2	2.6	0.4-4.8
Truck - Renewing used linings by grinding	3-5	10	3.8	1.7-7.0
Truck - Beveling new linings	3-5	5	37.3	23.7-72.0

* Fibers 5-100 μm in length, counted by optical microscopy.

6.5 Alternatives to Asbestos as a Friction Material

6.5.1 The Role of Asbestos in Friction Linings

Originally, automotive brake linings were made from a cotton textile material which was impregnated with drying oils and cured to form a strip of material which was flexible, conformable, and mechanically very strong. The main purpose of the drying oil was to protect the cotton from attack by atmospheric oxygen, which, even at the temperatures reached by early brakes, would have resulted in burned cotton had its surface been exposed to the air. As brake operating temperatures increased, it was found that cotton started to degrade and lose its strength even though still protected from oxygen attack. In other works, the cotton suffered thermal degradation instead of oxidative degradation (Hatch, 1970).

Around 1910, a technological breakthrough was achieved when it was discovered that asbestos could be woven and used to replace cotton because asbestos neither burns nor loses its strength below about 500°C. When braking operations became more severe, in the 1940's, brake linings began to be manufactured by moulding powdered resins with short asbestos fibers. This made possible the inclusion of various property modifiers to aid in the braking operations (Hatch, 1970). As described in Section 6.2, this is the current method of brake lining manufacture.

Any alternative material to asbestos in brake linings has to compete with asbestos's properties of strength, high temperature protection, insulation, and good frictional properties.

6.5.2 Alternatives in Brake Linings

At this time, there are no commercially available, asbestos-free brake linings intended for use in automobiles with drum brakes (Aldrich, 1977; Rosenburg, 1977). This is not the case when considering disc brake pads, as will be explained later. Currently, nearly all of the major brake lining manufacturers are engaged in research and testing programs to develop asbestos-free drum brake linings for automobiles; commercial success has not been achieved. It should be noted that, if by "alternative" we mean a new or better fiber which might shortly be available as a replacement for asbestos in conventional brake linings, the chances are actually quite remote.

The possible asbestos alternatives which are being tested and considered are discussed below (Hatch, 1970; Aldrich, 1977; Rosenburg, 1977):

(1) Glass Fiber - overall strength is lower than that of asbestos, but strong enough for friction material applications. Unfortunately, at the temperatures reached by braking operations, glass fiber melts, even in depth below the operating surface.

(2) Steel Wool - compared to asbestos, the overall strength is lower and the cost is much higher. In addition, the material hardness of steel wool damages the brake drums.

(3) Mineral Wools - overall strength is very low and brittle to the extent of limiting mixing processes.

(4) Carbon Fiber - the main properties of carbon fibers are generally good, but still somewhat inferior to asbestos. A major consideration is the cost, which is a great deal more than asbestos.

(5) Sintered Metals and Cermets - these materials are now being used to manufacture brake linings for railroad cars and airplanes. Eventually, these materials may be developed into practical applications for automobiles. At this time, the wear-resistance is not good enough for automotive uses and the cost is too high.

There are two good reasons why the industry is attempting to develop asbestos-free products. First, there is the possibility of a governmental ban on asbestos applications which emit asbestos fibers into the atmosphere. And secondly, asbestos-free manufacture would eliminate the need for asbestos-environmental control devices in the workplace and would eliminate a health hazard to employees, thereby eliminating a substantial expense. Some American brake lining manufacturers are currently maneuvering around the second reason above by establishing manufacturing plants in foreign countries whose pollution regulations are much less stringent than in the United States. The friction products containing asbestos can then be imported into the U.S.

6.5.3 Alternatives in Disc Brake Pads

It is purely fortuitous that the friction materials used in disc brakes are designed to a stronger shape than in drum linings; that is, more or less square or circular pads of considerable thickness are supported by a metal plate of adequate thickness. Therefore, the friction material does not have to stand up to handling during assembly, does not have to withstand riveting, and

could, from the point of view of bulk mechanical strength alone, be made without a high loading of fibrous reinforcement of any kind. There remains, however, thermal shrinkage and thermal shock, and in order to prevent the formation of tensile cracks normal to the operating surface, a percentage of asbestos fibre is still retained (Hatch, 1970).

Nevertheless, it cannot be said that the use of asbestos in disc brake pads remains a technical necessity (Hatch, 1970); in fact, commercially available disc pads have been developed for automotive uses which do not use asbestos (Aldrich, 1977). Table 6.9 lists a typical composition for this asbestos-free disc pad. Cost of the asbestos-free pad is somewhat higher than the asbestos pad.

Table 6.9. Asbestos-Free Composition of a Disc Brake Pad (Aldrich, 1973)

	(vol. %)
Carbon	45
Iron Powder	25
Steel Fiber	10
Phenolic Resin	20

(manufactured by common methods)

6.5.4 Alternatives in Clutches

Borg-Warner Corporation, a major manufacturer of clutches, is currently engaged in the testing of asbestos-free friction materials intended for use in clutches (Rosenburg, 1977). The asbestos-free materials being tested have been developed by the major friction-material producers such as Raybestos-Manhattan and Abex. To date, none of the alternatives tested have been as good as asbestos.

6.6 Summary and Conclusions for Asbestos Friction Applications

(1) Chrysotile asbestos fiber is a major component of brake and clutch lining friction materials. Asbestos is used because it imparts strength, good friction properties, can withstand high temperatures, and is a good insulator.

(2) The annual U.S. demand for asbestos in friction products has historically ranged from 65-80 thousand short tons, or approximately 9% of the total U.S. asbestos demand. Projections calculated from 1972 figures released by the U.S. Bureau of the Census indicate that the shipment value of all asbestos-friction products is currently about $300 million.

(3) At present, nearly 118 million pounds (59 thousand short tons) of chrysotile asbestos are consumed annually for fabrication of automotive brake linings.

(4) Asbestos usually used in friction materials is chrysotile from Quebec and Vermont. Length grades 5 and 7 account for nearly 83% of the total use.

(5) Approximately 35 corporations operating a total of 44 plant establishments are currently engaged in manufacturing asbestos-friction material products.

(6) The eight largest corporations (headed by Raybestos-Manhattan, Bendix Corporation, and Abex Corporation) control from 75-85% of the asbestos-friction material market.

(7) Several different process technologies are used to manufacture asbestos brake linings and clutch facings. Manufacture can be accomplished by a molding process, in a dry or wet-mix state, or by a woven process.

(8) A wide variety of ingredient compositions are used for the fabrication of automotive brake linings. In addition to the 30-60% typical asbestos content, at least 43 different inorganic and organic compounds have been listed for use by previous publications and patent literature, as property modifiers and binders.

(9) It may be reasonable to speculate that asbestos emissions resulting from automotive brake lining use may vary in concentration, depending upon the ingredient composition and the process method used to manufacture the individual lining.

(10) Among the studies which have examined asbestos emissions or wear debris from brake linings, the best appear to be Rohl et al. (1976), Jacko and DuCharme (1973), and Alste et al. (1976). These studies utilized different methodologies and arrived at different results. Rohl et al. (1976) examined random samples of brake lining wear debris from automobiles used under real-life conditions and determined, by X-ray diffractometry, that 2-15% of the wear debris was asbestos. Jacko and DuCharme (1973) produced samples of wear debris by means of laboratory simulation utilizing a car on a dynamometer, with specially designed collection apparatus, and concluded, by electron microscopy, that the wear debris contained, on average, only 0.2% asbestos. Using real-life samples examined by electron microscopy and electron diffraction, Alste et al. (1976) concluded that the major effect of braking appears to be in separating bunches of fibers and reducing their average length, but not in altering their crystal structure. This disparity in results, computed by very qualified researchers, leads to the conclusion that additional work is required in determining a more consistent evaluation of asbestos in wear debris from brake linings in terms of content percentage.

(11) There has been no experimental study conducted which can confirm or refute the supposition that brake linings made by different companies, processes, and compositions may contribute varying amounts of asbestos emissions into the environment. This supposition is offered as a suggestion which may be beneficial in the explanation of the different results obtained by Rohl et al. (1976), Jacko and DuCharme (1973), and Alste et al. (1976).

(12) According to Jacko and DuCharme (1973), the total asbestos contribution to the environment as a result of brake and clutch lining wear is nearly 158,000 lbs/yr, of which 5,060 lbs/yr is airborne. Utilizing the results obtained by Rohl et al. (1976) for asbestos content of wear debris, we can calculate that the total environmental contribution, on average, would be 3,420,000 lbs/yr, of which 110,000 lbs/yr would be airborne. Obviously, the differences are significant.

(13) A very high percentage of the asbestos emitted in wear debris is shorter than 5 μm in length. In fact, Rohl et al. (1976) found that nearly 80% of this asbestos is shorter than 0.4 μm. This is an extremely important consideration when dealing with exposure to workers, such as brake service mechanics, who come into direct contact with this airborne wear debris. OSHA standards count only fibers from 5-100 μm in length; therefore, any measurements made by OSHA standards would seriously underestimate the asbestos exposure to the workers. Rohl et al. found that even under OSHA test standards, asbestos fiber concentrations would periodically exceed OSHA regulations during brake maintenance and repair. Therefore, a potentially serious asbestos exposure exists for the estimated 900,000 persons employed as auto mechanics and garage workers.

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