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EPA

Chemical Market Input/Output Analysis of Selected Chemical Substances to Assess Sources of Environmental Contamination

Task III Asbestos

EPA 560/6-78-005 TR 77-515

CHEMICAL MARKET INPUT/OUTPUT ANALYSIS OF SELECTED CHEMICAL SUBSTANCES TO ASSESS SOURCES OF ENVIRONMENTAL CONTAMINATION:
TASK III. ASBESTOS

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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 1967 to 1976. This amounts to approximately 9% of the total U.S. asbestos demand (consumption).

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

[redacted]

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
E.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-Ehret 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 millic 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; th 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 surve 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 mater plants in the U.S. Not surprisingly, they tend to be concentrated in and aro the major metropolitan centers of the Northeast and Midwest, with a few plant located in California to primarily cater to the needs of the automobile assem plants in that part of the country.

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

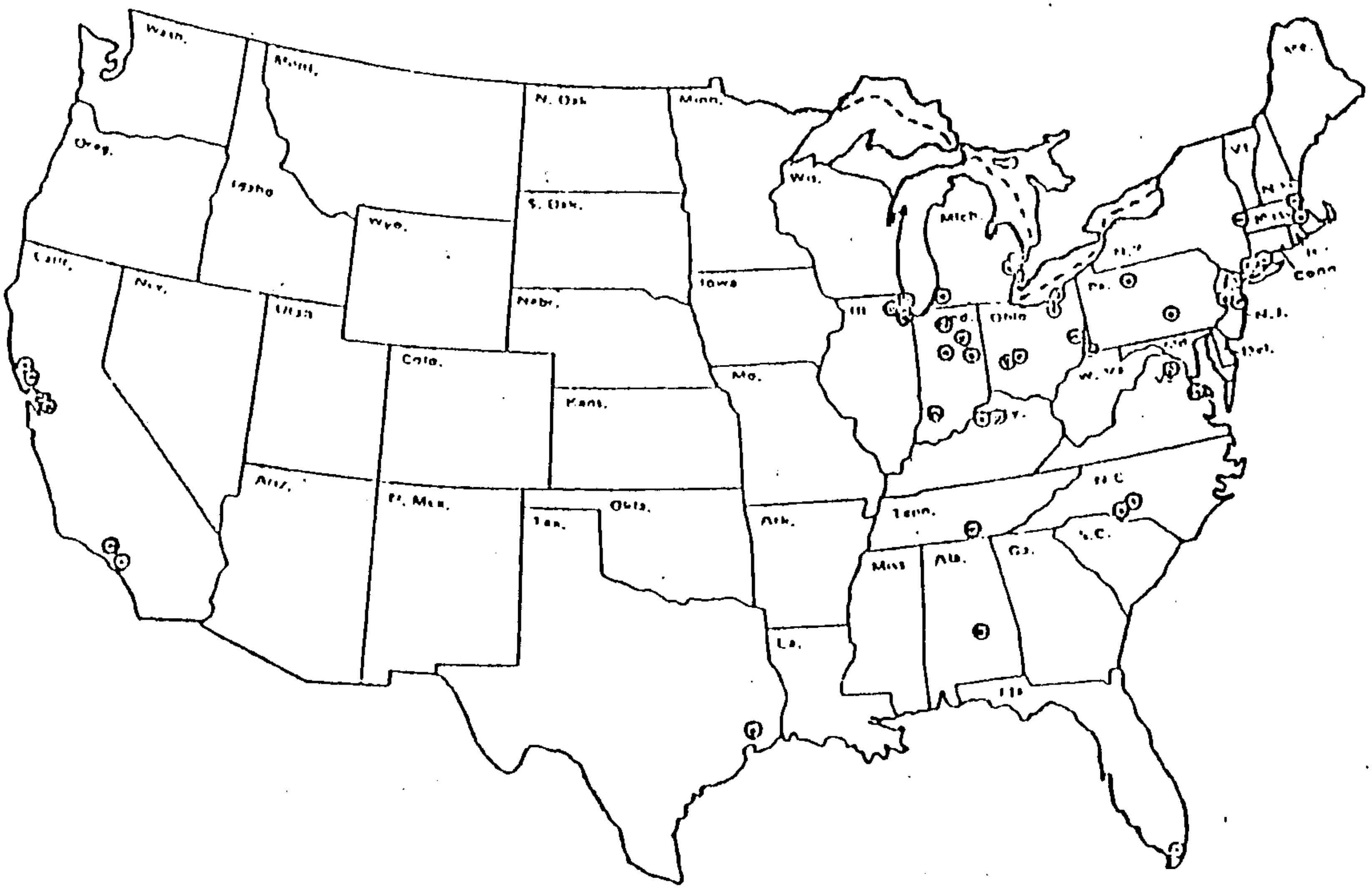

Figure 6.1 Geographical Dispersion of U.S. Friction Materials Plants (Modified from Margolin and Igwe, 1975)

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

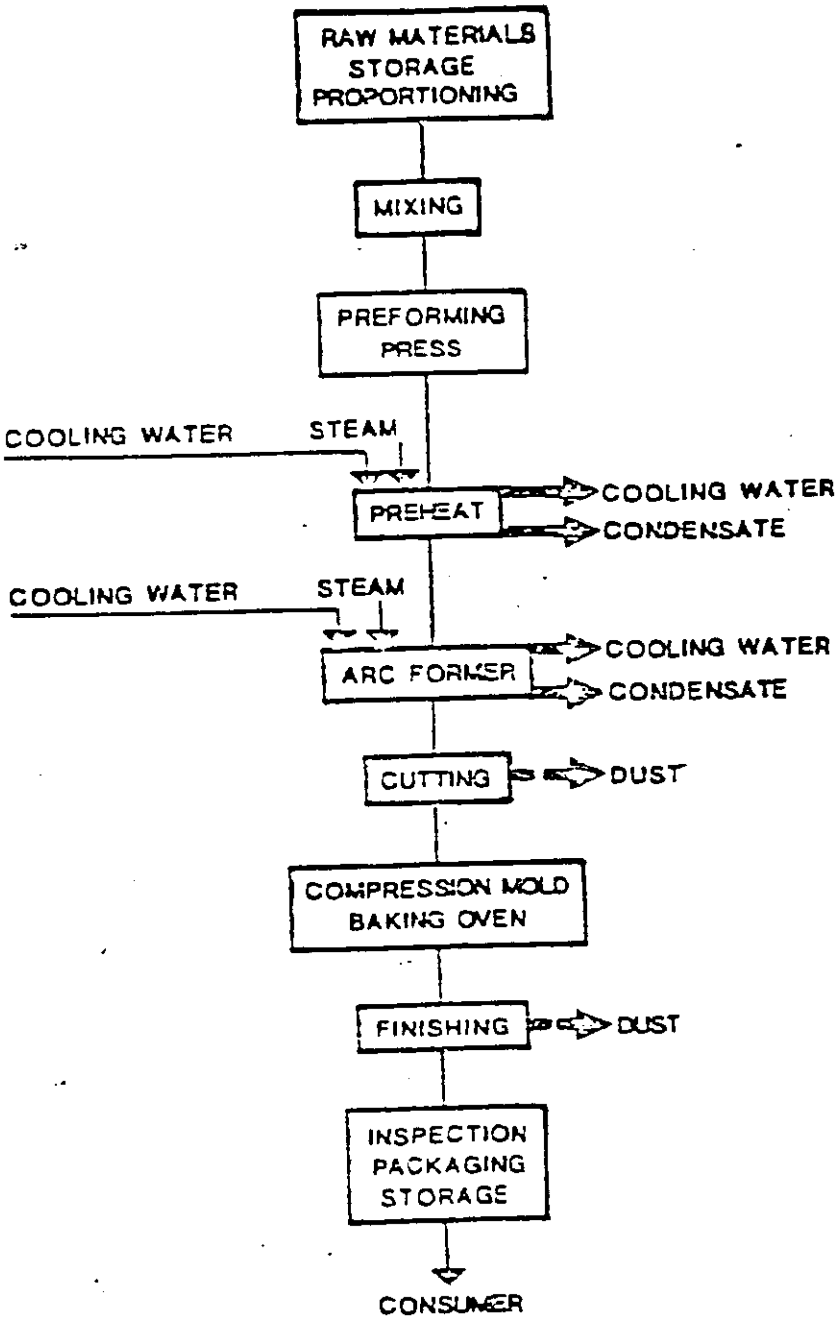

Figure 6.2. Dry-Mixed Brake Lining Manufacturing Operations (Gregg, 1974)

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

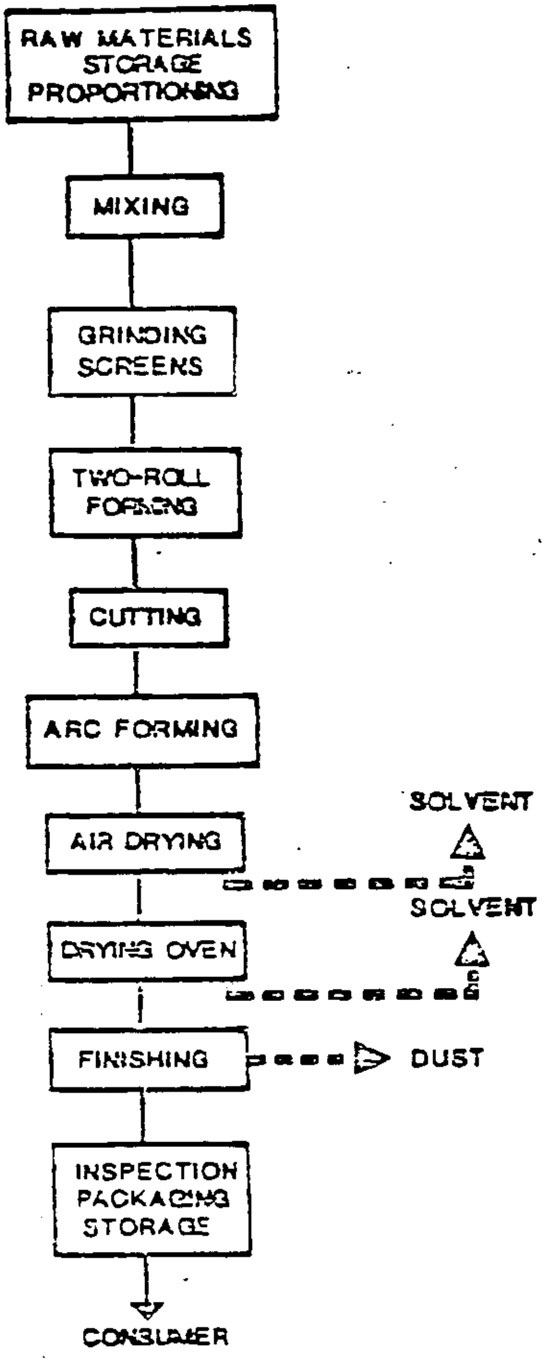

Figure 6.3. Wet-Mixed Molded Brake Lining Manufacturing Operations (Gregg, 1974)

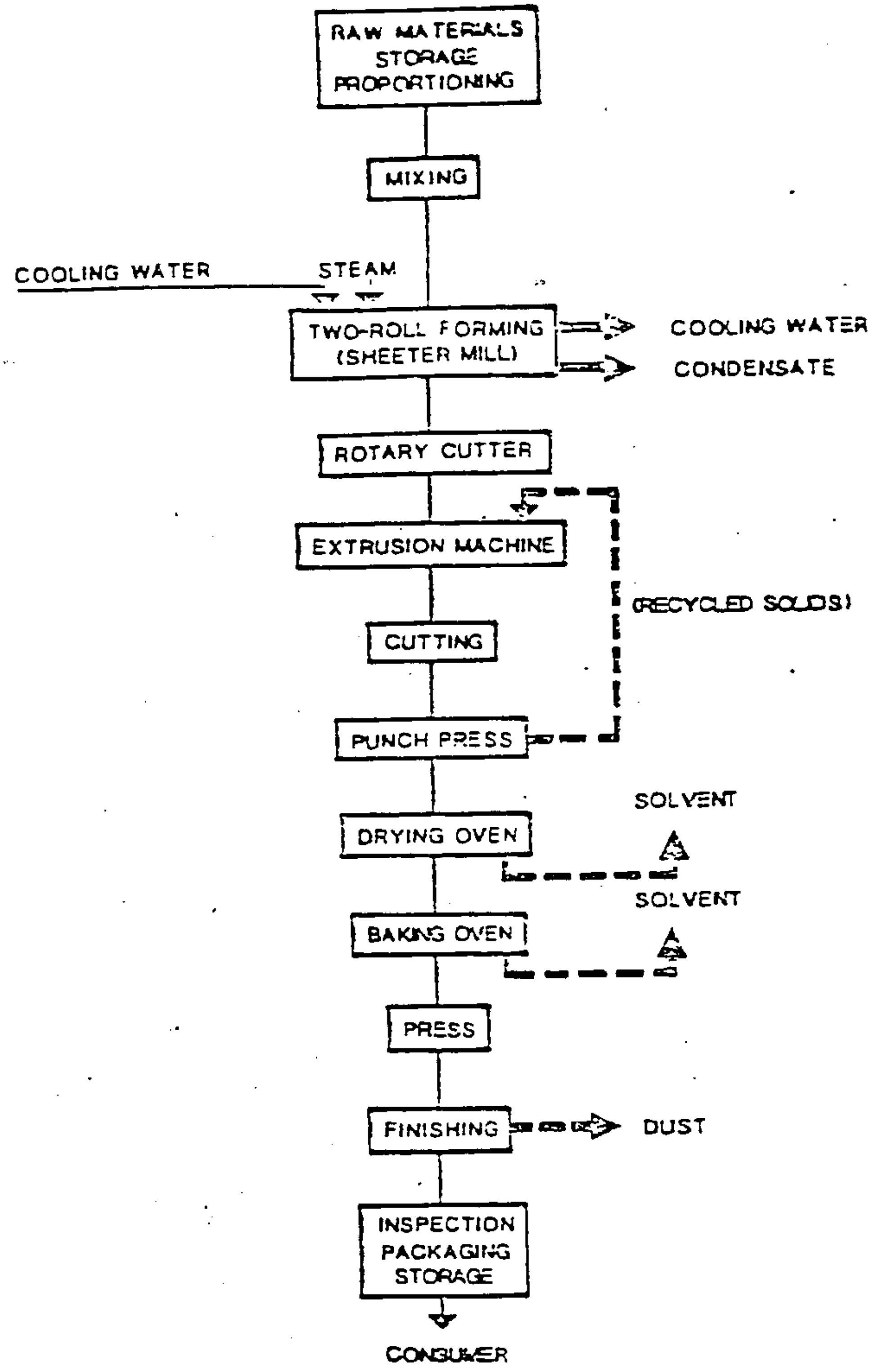

Figure 6.4. Molded Clutch Facings Manufacturing Operations (Gregg, 1974)

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 manufacutre 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 82% of the total (Clifton, 1977). Asbestos is used because of its thermal stability, relatively high friction level, and reinforcing properties.

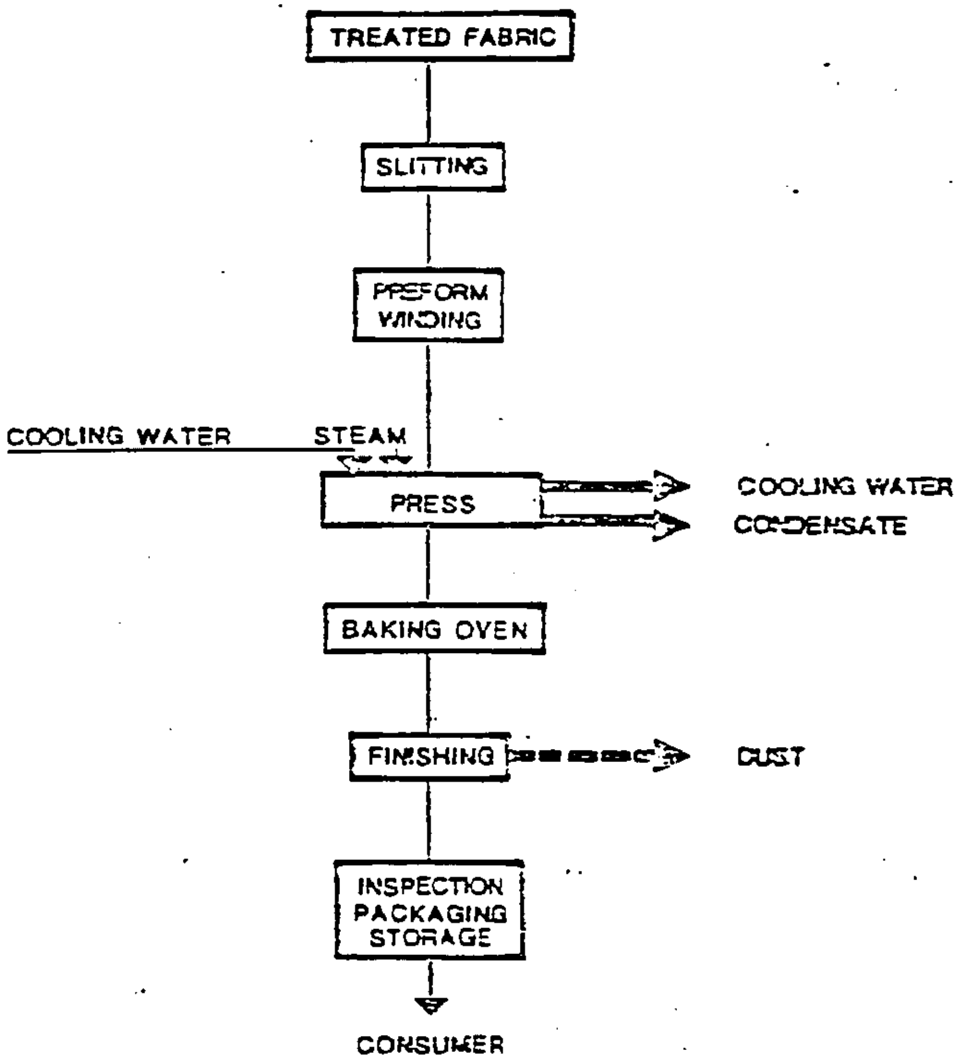

Figure 6.5. Woven Clutch Facings Manufacturing Operations (Gregg, 1974)

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	"
	Sulfur	"
	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)

(wt %)

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

(wt %)

Example No. 1*	
Asbestos	55
Barite	10
Phenolic resin binder	20
Brass	5
Magnesium carbonate	8
Limestone	8
Organic calcium powder	10

Example No. 2**	
Asbestos	60
Phenolic resin	15
Nitrile rubber	3
Cashew dusts	12
Calcium fluoride	7
Copper iodide	3

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

Example No. 4****	
Asbestos	50
Tarry residue	12
Barite	20
Phenolic resin	20
Graphite	2

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* 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 (Bruckman and Rubino, 1977; 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 (Rohl et al., 1976, 1977; Alste 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), Jacko and DuCharme (1973), and Anderson et al. (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, 1977) 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	≤66% (this figure is not accurate; see discussion in Section 6.4.1.1)
Anderson *et al.*, 1973	Laboratory simulations utilizing a disc brake assembly mounted on a dynamometer. Air samples of wear debris collected down wind of disc brake.	Transmission electron microscopy	Test results and procedures precluded a size distribution estimate	<0.02%
Jacko and DuCharme, 1973 (contains same data as Jacko *et al.*, 1973)	Samples were generated by operating a standard American car under typical driving conditions in Detroit, Michigan. More abusive conditions, such as fade tests, were also included. 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	0.25% overall average (an independent check done by Battelle 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 um 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 um 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
Rohl *et al.*, 1977	This is basically a reprint of the Rohl *et al.*, 1976 study with the inclusion of brake wear test samples obtained from Europe and Australia.			The mean weight percentage ranged from 1.4% in Australia to 2.3% in France

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 (~ 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. Rohl et al. (1976) 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, 1977) 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 Partitle Size Distribution

The first major consideration of methodology is the type of samples which were collected. Lynch (1968), Bush *et al*. (1972), and Anderson *et al*. (1973) collected laboratory samples produced by simulations, while other researchers listed in Table 6.5 collected samples from automobiles which were undergoing or had undergone actual driving conditions. Conditions encountered during actual use may not be totally reproducible in the laboratory; hence, the asbestos emission factors may be somewhat different. It would seem probable that samples collected from actual auto use may be more relevant to airborne emission potential than laboratory simulations.

Jacko and DuCharme (1973) used specially designed collectors which enclosed brake and clutch assemblies which allowed wear debris samples to be collected while the test car was being driven on the street. Rohl *et al*. (1976, 1977), Alste *et al*. (1976), Hickish and Knight (1970), and Hatch (1970) collected wear debris samples from automobiles in repair shops which perform brake maintenance.

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 um in length while Jacko and DuCharme (1973) found that 30% of the fibers were from 0.25-0.50 μ 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. Jacko (1978b) attributes the particle size distribution differences to a mechanical degradation technique utilized by Rohl et al. (1976) but not by Jacko and DuCharme (1973). 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 ≤ 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 number of fibers, but a small weight fraction, of 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 (forsterite, olivine, and dehydroxylated serpentine) have similar elemental ratios, and several nonfibrous minerals have similar X-ray diffraction patterns. The only sensitive method which can be used is microscopy. The accuracy of X-ray diffraction to determine the asbestos concentration of brake wear debris is beyond the scope of this report.

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 forsterite (olivine). Jacko and DuCharme (1973) found that 20-40% of the wear debris composition was 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 forsterite;" this result was in agreement with Rohl et al. (1976) who also could not verify the presence of forsterite. Jacko (1976c) did find a reduction of asbestos and the formation of olivine (a form of forsterite) on frictional heat-affected layers using a combination of X-ray diffraction and thermogravimetric analysis. 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, 1977) studies are 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 in New York and 29 samples from Australia and Europe, while Jacko and DuCharme's wear debris samples came only from original auto equipment, a partial relining, and a relining for the car tested. 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. Jacko and DuCharme (1973) did use brake linings manufactured by five different manufacturers, including original and replacement equipment; however, only "class A" friction materials were used. Class A materials refer to the better quality, longer wearing friction materials, as opposed to class B materials, which have inferior wear characteristics. Jacko (1978b) suspects that the wear debris collected by Alste et al. (1976) may have resulted from wear of class B brake linings; however, there is no confirmation of this supposition.

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.

It has been suggested by several industry spokesmen that class A material would contribute a smaller asbestos emission to the environment than class B material. This has not been confirmed experimentally.

Industry spokesmen also believe that a larger percentage of foreign cars imported into the U.S. are equipped with class B brake linings than cars manufactured domestically.

A recent study by Seshan and Smith (1977) has supported the work of Rohl _et al_. (1976) and Alste _et al_. (1976) and contradicts the work of Jacko and DuCharme (1973). Seshan and Smith (1977) examined automobile brake drum dust using transmission electron microscopy. They found unaltered chrysotile fibre fundles with some phenolic binder and deformed chrysotile which were difficult to determine by selected area electron diffraction. However, they were able to study the deformations in detail using high resolution dark-field microscopy and suggested that dark-field microscopy be used to identify the sources of asbestos fibres found in air pollution samples. These investigators also examined the brake drum dust with light optical microscopy (LOM) and X-ray diffraction (XRD) and found little (less than 1%) chrysotile and no forsterite which they concluded was due to the fact that the fibre sizes and concentrations were below the limits of detection for LOM and XRD.

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

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

(3) The combined total of brake and clutch friction material worn away annually is 123.6 million pounds (117 (brakes) + 6.6 (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, 1977; 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 (4.5% 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 (1973) and Anderson et al. (1973).

6.4.2.1 A Hypothetical Calculation

As mentioned earlier in Section 6.4, asbestos fibers have been monitored in ambient air samples by Holt and Young (1973), Alste et al. (1976), and Nicholson et al. (1973). Selikoff et al. (1972) monitored ambient concentrations of asbestos in the New York City area and determined the following concentrations:

Site	Concentrations (ng/m^3)
Manhattan	25-60
Bronx	25-28
Brooklyn	19-22
Queens	18-29
Staten Island	11-21
Philadelphia	45-100
Ridgewood, N.J.	20
Port Allegany, Pa.	10-30

Bruckman and Rubino (1975) reported that asbestos levels in non-urban and remote non-urban air are typically less than 1 ng/m^3, while urban air usually has levels below 30 ng/m^3. From thirty selected monitoring sites in Connecticut, Bruckman and Rubino (1977) found the following concentrations:

1) less than 10 ng/m^3 in areas removed from emission sources
2) above 30 ng/m^3 near each of four industrial users
3) 10 ng/m^3 to 25 ng/m^3 adjacent to toll plazas where autos commonly apply brakes

The above data gives a general idea of the magnitudes of various background levels of ambient air concentrations of asbestos. The following hypothetical case is intended to project a theoretical magnitude of contamination from friction material use.

Hypothetical Case: This calculation attempts to estimate the levels of asbestos which may be added to urban environments as a result of wear from automobile brake linings. As noted in Tables 6.6 and 6.7, the amount of asbestos emitted by brake linings has been estimated to range from 2.5 to 55 tons airborne per year. The calculation below will assume a nationwide emission average of 10 tons per year. New York City will be considered because of available air monitoring data. New York City has a population of approximately 7.9 million people and an area of roughly 300 sq. miles. It is assumed that friction material use follows population; therefore, of the estimated 10 tons of emissions from brake linings, NYC would be responsible for:

$$\frac{7.9 \text{ million (NYC pop.)}}{210 \text{ million (US pop.)}} \text{ X } 10 \text{ tons} = 0.376 \text{ tons} = 3.4 \text{ X } 10^{14} \frac{\text{ng}}{\text{yr}}$$

This value of $3.4 \text{ X } 10^{14}$ ng/yr translates into an emission of roughly $9.34 \text{ X } 10^{11}$ ng/day. The volume of air 1000 ft. above street level over NYC is about $2.5 \text{ X } 10^{11} \text{ m}^3$. It is assumed that the daily emissions of asbestos become equally distributed throughout the air 1000 ft. above street level. Therefore, the ambient air concentration of asbestos which results from daily brake emissions would be:

$$\frac{9.34 \text{ X } 10^{11} \text{ ng/day}}{2.4 \text{ X } 10^{11} \text{ m}^3} = 3.7 \text{ ng/m}^3$$

The resulting estimate is on the same order of magnitude as available monitoring data. It should be remembered that this calculation is totally theoretical and is not intended as proof that brake emissions are responsible for all asbestos emissions monitored in ambient air. Many other factors need consideration in terms of brake emissions to air, such as weather effects upon airborne fibers and actual distribution patterns from emission sources. The potential for the sizes of particles emitted to remain airborne is a major consideration.

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 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 words, 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; limited commercial success has been achieved only with semimetallic friction material. 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.

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 Quantities of Asbestos Released to the Environment from Manufacture

Listed below in Table 6.10 are the estimated quantities of asbestos released to the environment from asbestos friction products manufacture. The estimates in Table 6.10 are not intended to be considered precise quantities. The estimates are based upon available data and engineering assumptions and are intended only to project a general magnitude of release.

Table 6.10. Estimated Annual Environmental Release of Asbestos from Friction Material Manufacture (SRC estimate)

	Quantity (short tons)	Comment
To waste dump or landfill:		
Baghouse fine and product scraps	8,130	Mostly free-fibers*
Wastewater solids from air scrubbers	6.7	Wet free-fibers*
To water:		
Wastewaters from air scrubbers	0.3	Free-fibers*
To air:		
Baghouse emissions	0.61-6.0	Free-fibers*
Air scrubber emissions	0.14	Free-fibers*

* These "free-fibers" may be coated with resin, however, by "free" the intention is to indicate a potentially respirable fiber.

The estimates in Table 6.10 were derived by methods which are explained in the following subsections.

6.6.1 Release from Baghouses and Product Scraps

Jacko and DuCharme (1973) have reported that the amount of asbestos contained in all of the automotive brake friction materials sold each year is about 103 million lbs., which corresponds to about 118 million lbs. prior to grinding and drilling. This indicates that approximately 12.7% of the asbestos is lost to product scraps. The grinding and drilling of brake linings during manufacture can release as much as 30% of the lining material as waste (EPA, 1974). Even with the relatively high price of asbestos fiber, the asbestos contained in product scraps is not recovered for reuse (Gregg, 1974). Once the resin has set up, it is not regarded as economical to break it down to salvage the fiber. These wastes are normally disposed to landfills or waste piles.

In most cases, the emissions from grinding and drilling operations are collected in baghouses (EPA, 1974). These baghouse wastes can amount to as much as 13.5 tons per month for a plant producing 40,000 shoes per day (EPA, 1974). To determine the industry-wide quantity of asbestos disposed from baghouses and product scraps, the following assumptions are made: 1) about 12.7% of the total asbestos consumed in friction materials is lost to scraps and, 2) about three-fourths of this total is collected in baghouses and the remaining one-fourth is collected by vacuum cleaning operations or as damaged product. Based upon a total asbestos consumption of 64,000 tons for all friction materials in 1976 (Clifton, 1977), the amount of asbestos lost to product scraps would be about 8,130 tons. Baghouse collections would roughly amount to 6,100 tons and the other scraps would amount to roughly 2,030 tons. Virtually all of the asbestos collected in baghouses is in a potentially respirable form. Disposal operations of these baghouse wastes can potentially release fibers into the atmosphere (EPA, 1974). It is virtually impossible to quantify the amount of asbestos fibers released during disposal operations without monitoring data, of which there are none.

In most of the plants making friction materials, air emissions are controlled by baghouses; however, in a few plants, wet dust collectors are used and a wastewater results (Gregg, 1974). Asbestos releases from wet dust collection are discussed in the next subsection.

The efficiency of an asbestos baghouse collector, in terms of atmospheric emissions, has been monitored to have an efficiency of nearly 99.99% (Siebert et al., 1976). Applying this efficiency to the estimated quantity of 6,100 tons of asbestos collected by baghouses indicates that the asbestos fiber emissions to the atmosphere would be 0.61 tons annually. However, in Section 7.3.1, a baghouse emission factor has been developed which estimates that 1.34 lbs. of asbestos fibers are emitted per year per each 100 CFM rating. The exhaust air flow of a medium size friction material plant has been estimated to be in the neighborhood of 30,000 CFM (Gregg, 1974). Therefore, using the 1.34 lb. emission factor indicates that a medium size plant would emit about 400 lbs. of asbestos fibers each year. Table 6.2 lists over 30 friction material plants; therefore, this method predicts that roughly 6 tons of fibers would be emitted to the atmosphere industry-wide. As explained in Section 7.3.1, the 1.34 lb. emission factor is a "worst possible" case. The difference in estimates, 0.61 tons and 6.0 tons, is significant. There are not enough monitoring data available to make a precise estimate.

6.6.2 Release from Wet Dust Collection

Process wastewaters containing asbestos fibers are not generated by friction material manufacturing operations. However, waters used to clean fibers and particulates from air do contain asbestos, and these wastewaters are released by some plants. Wet dust collection is rarely used in the asbestos industry. Gregg (1974) identified only four friction material manufacturing plants that discharge wastewaters from wet dust collection. At all of the known plants, the wastewaters are clarified before discharge to surface waters. Currently, the number of plants using wet dust collection is not known; therefore, the estimates projected below are based upon Gregg's (1974) data.

The effluent waste load from wet dust collection for a typical plant is estimated to be 25 lbs. of suspended solids per day (Gregg, 1974). Assuming the suspended solids are about 50% asbestos (because asbestos is roughly 50% of the friction material's raw content) and an average work year of 50 weeks at 5.5 days per week, then about 3,450 lbs. of asbestos are collected by wet collection each year at a typical plant. Four plants would collect about 13,800 lbs. or roughly 7 tons of asbestos fibers. Clarification may remove approximately 95% of the suspended solids. The sludge collected from clarification would therefore contain about 6.7 tons of asbestos fibers; this sludge is disposed of in landfills. The clarifed water released to surface waters would contain about 0.3 ton of asbestos.

Wet-type air scrubbers normally operate in the range of 98% efficiency. Therefore, based upon a collection of 7 tons, these wet dust collectors would emit about 0.14 ton of fibers into the atmosphere.