GCA-TR-79-73-G

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Toxic Substances
Washington, D.C.

Submitted in Partial Fulfillment of
Contract No. 68-02-3168
Technical Service Area 3, Work Assignment No. 18

EPA Project Officer

James Bulman

LIFE CYCLE OF ASBESTOS IN COMMERCIAL AND INDUSTRIAL USE INCLUDING ESTIMATES OF RELEASES TO AIR, WATER AND LAND

Final Inhouse Report

February 1982

Prepared by

David Cogley
Nancy Krusell
Robert McInnes
Peter Anderson
Ronald Bell

GCA CORPORATION
GCA/TECHNOLOGY DIVISION
Bedford, Massachusetts

DISCLAIMER

This Final Inhouse Report was prepared for the Environmental Protection Agency by GCA Corporation, GCA/Technology Division, Burlington Road, Bedford, Massachusetts 01730, in partial fulfillment of Contract No. 68-02-3168, Technical Service Area 3, Work Assignment Nos. 2 and 18 and Contract No. 68-02-2607, Work Assignment No. 36. The opinions, findings, and conclusions expressed are those of the authors and not necessarily those of the Environmental Protection Agency. Mention of company or product name is not to be considered as an endorsement by the Environmental Protection Agency.

CONTENTS

CONTENTS (continued)

CONTENTS (continued)

FIGURES

FIGURE (continued)

TABLES

TABLES (continued)

TABLES (continued)

TABLES (continued)

SECTION 1

INTRODUCTION

OVERVIEW

Asbestos is a generic term for a group of fibrous minerals that are used in many industrial, commercial and household products. Asbestos provides strength, durability, resilience, chemical and thermal stability, and resistance to heat, corrosion, rot, vermin and chemicals. An average United States resident could expect to find asbestos around his home contained in the following products: floor tile, house siding, automobile brakes, appliance insulation, roof flashing compound, municipal water supply pipe, sewer mains, wood stove gaskets and fireproofing for wood stove installations. For every U.S. citizen, approximately 1.6 Kilograms (3.6 lbs) of asbestos is used to manufacture products annually.[1]

Asbestos products reach the consumer after passing through several manufacturing and fabrication steps. These steps are most easily understood by examining the asbestos products industry. This industry has been categorized into the following three groups:[2]

- Primary Industries: those industries which 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 which 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 which 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.

Table 1 presents a classification of the various industries and indicates the interrelationship of the three groups.

TABLE 1. ASBESTOS PRODUCTS INDUSTRY[3]

Primary industry	Secondary industry	Consumer industry
Asbestos paper	Fireproof absorbent papers Table pads and heat protective mats Heat/fire protection components Insulation products Underlayment for sheet flooring Filters for beverages Roofing materials	Acoustical products Oven and stove insulation Electrolytic cell diaphragms Filter media Wallboard Power cable insulation
Friction products	Clutch/transmission, brake components Industrial friction materials	Automobile brakes and transmissions
Asbestos - cement pipe	Chemical process piping Water supply piping Conduits for electric wires	Water supply and sewage piping Corrosive resistant piping and ducts
Asbestos - cement sheet	Hoods, vents for corrosive chemicals Portable construction buildings Molten metal handling equipment Industrial building materials Laboratory furniture Cooling tower components	Arc deflectors Decorative building panels Fire doors Siding Shingles Tanks for chemicals Roofing products
Floor tile	Office, home, commercial floors	Floor tiles
Gaskets and packing	Valve, flange, pump, tank sealing components	Automobile gaskets Pump and value seals
Sealants	Automotive/truck body coatings Roof coatings and patching compounds	Plaster and stucco Caulking Automotive undercoatings
Asbestos-reinforced plastics	Electric motor components Molded product compounds for high strength/weight uses	Molded plastics Motor armatures Furniture Electrical switches
Asbestos textiles	Heat/fire protective clothing Electrical wire and pipe insulation Theater curtains and fireproof draperies Commercial/industrial dryer felts	Drip cloths Fire hoses Garments, gloves Motion picture screens Rugs
Miscellaneous	Wholesalers	Ammunition wadding

REPORT FORMAT

This report describes the life cycle of asbestos from mining and milling the raw mineral through its ultimate use and disposal by the consumer. Following a discussion of mining and milling operations, the remaining sections of the report are organized by primary industry in descending order based on asbestos consumption. The main thrust of the report is identifying releases of asbestos fibers to the air, water and land during manufacture, use and ultimate disposal of the mass-produced product. Estimates are provided of worker exposure levels and ambient asbestos levels in the vicinity of primary industry plants. Each primary industry is discussed in detail. Asbestos products, their composition, uses, substitutes and manufacturing processes are described with special attention given to the handling and disposal of asbestos. The roles of secondary and consumer industries are addressed when specific asbestos-related information is available. The conclusion segments found at the end of each section encompass projections and trends as well as a summary of information on the product discussed.

DATA PRESENTATION

Data presented herein were obtained from published reports. These were augmented by telephone calls and plant visits to obtain further information on manufacturing operations, industrial asbestos consumption, pollution control devices, manufacturing facility asbestos emissions, industry trends, substitute products and exposure data for workers and product users. Some new monitoring data were obtained for presentation in this report.

Asbestos consumption data in metric tons, along with the relative percentage breakdown for each primary industry are presented in Table 2. These data were extracted from the 1980 Bureau of Mines (BOM) survey, which is based on an annual survey of domestic raw-asbestos fiber consumers. The number of manufacturers responding to the BOM survey, approximately 300, account for 60 percent of the total annual domestic asbestos consumption.[4] The values reported represent an extrapolation of the 60 percent figures received by BOM up to 100 percent consumption. Consequently, there is some inherent uncertainty, which U.S. BOM estimates to be ± 40 percent, associated with the reported values. The individual product categories in Table 2 differ slightly from those reported by the BOM. For this report, the paper category includes paper products, thermal and electrical insulation, and roofing products. In addition, that portion of the flooring products asbestos consumption which is attributable to flooring felt (approximately 60 percent),[5] has also been defined here as "paper products." These changes were made to consolidate the presentation and to group together all products that are manufactured by conventional paper making equipment.

There exists a great body of worker exposure data gathered in response to OSHA regulations. These data, when summed over the known labor force, provide a limited estimate of worker exposure in mining, milling, manufacturing, and in some cases product installation. Alternatively, a limited amount of exposure data for products are available. Exposure to persons living or working near mines, mills, manufacturing facilities, and end-use locations was difficult to assess accurately because of the limited amount of ambient monitoring data available. However, nonoccupational exposure has been estimated using air quality dispersion models in conjunction with assumed emissions.

TABLE 2. 1980 ASBESTOS CONSUMPTION BY PRODUCT CATEGORY[a]

Product category	1980 Consumption (metric tons)	Percent of 1980 Consumption
Asbestos cement pipe	144,000	40.2
Asbestos paper	90,020	25.1
Friction products	43,700	12.2
Floor tile	36,080	10.1
Gaskets and packing	12,300	3.4
Coating and sealants	10,900	3.0
Asbestos cement sheet	7,900	2.2
Textile	1,900	0.5
Plastics	1,500	0.4
Miscellaneous	10,400	2.9
Total	358,700	100

[a] GCA product category designations.

There is also a scarcity of data concerning process emissions from primary asbestos industry facilities. Due to OSHA regulations, many primary plants have installed fabric filters at the principal fiber introduction areas. Estimates of how much asbestos fiber is released to the filters at these stations vary depending on the amount of asbestos introduced into the manufacturing process, the conditions of the ventilation system, the method of processing, i.e. wet or dry, and the employment of dust inhibiting materials or operations. Similarly, the amount of product scrap and control device waste that is generated by a facility varies considerably among manufacturers. Finally, asbestos users are generally reluctant or unable to estimate these waste amounts. In addition, published estimates on waste quantities for primary industries vary considerably.[6,7] As a result, the emission estimates cited in this report are, at best, order of magnitude estimates.

TERMINOLOGY

In this report atomspheric asbestos concentrations are reported in terms of:

- Optical-microscope-visible fibers per cubic centimeter (fibers/cc) for fibers longer than 5 μm.
- Optical-microscope-visible fibers per cubic meter (fibers/m^3) for fibers longer than 5 μm.
- Electron-microscope-visible fibers per cubic centimeter (fibers/cc)
- Electron-microscope-visible fibers per cubic meter (fibers/m^3).
- Nanograms of asbestos per cubic meter (ng/m^3).

Table 3 shows conversion factors that can be multiplied by concentrations expressed as optical-microscope-visible fibers/cc to yield a concentration expressed in the units desired. In developing these figures it was assumed that:

- There are 50 electron-microscope-visible fibers for every optical-microscope-visible fiber greater than 5 μm in length.[7]
- There are 1,000 electron-microscope-visible fibers per nanogram although the actual conversion may be from 100 to 10,000 fibers/ng.[7] The conversion factors presented in Table 3 are useful for the preparation of first order estimates only. Asbestos fiber size distribution varies with the grade of fiber used and the extent of processing during manufacture and product use.

TABLE 3. CONVERSION FACTORS[7]

Optical-microscope-visible fibers/cc > 5 μm in length	Optical-microscope-visible fibers/m^3 > 5 μm in length	Electron-microscope-visible fibers/cc	Electron-microscope-visible fibers/m^3	ng/m^3
1[a]	1,000,000	50	50,000,000	50,000

[a] Values shown are all equivalent to 1 optical-microscope-visible fiber/cc > 5 μm in length.

REFERENCES

1. Clifton, R. A., Asbestos. 1980 Minerals Yearbook, U.S. Bureau of Mines, Washington, D.C., 1981.

2. Daly, A. R., A. J. Zupko and J. L. Hebb. Technological Feasibility and Economic Impact of OSHA Proposed Revision to the Asbestos Standard (Construction Excluded), prepared for Asbestos Information Association/North America, Washington, D.C., 29 March 1976.

3. Weston, Roy F., Environmental Consultants. Technological Feasibility and Economic Impact of OSHA Proposed Revision to the Asbestos Standard (Construction Excluded). Asbestos Information Association/North America. March 26, 1976.

4. Telecon. R. A. Clifton. U.S. Bureau of Mines, Washington, D.C., with Peter Anderson, GCA/Technology Division. October 8, 1981.

5. The Resilient Floor Covering Institute. Comments on the Advanced Notice of Proposed Rulemaking on the Commercial and Industrial Use of Asbestos Fibers. Submitted to the U.S. EPA, Washington, D.C. February 18, 1980.

6. Meylan, W. M., P. H. Howard, S. S. Lande and A. Hanchett, Chemical Market Input/Output Analysis of Selected Chemical Substances to Assess Sources of Environmental Contamination: Task III. Asbestos. EPA-560/6-78-005, U.S. Environmental Protection Agency. Washington, D.C., August 1978.

7. Suta, B. E., and R. S. Levine. Non-occupational Asbestos Emissions and Exposure. In: Asbestos, Volume I, Properties, Applications, and Hazards, L. Michaels and S. S. Chissick, eds. John Wiley & Sons, New York, N.Y. 1979. pp 171-205.

SECTION 2

AIR POLLUTION CONTROL PRACTICES, ASBESTOS EMISSIONS, AND ASBESTOS EXPOSURE

INTRODUCTION

The dangers associated with asbestos exposure combined with regulatory policies concerning asbestos have prompted asbestos mining, milling and manufacturing industries to employ a variety of measures to reduce human exposure to asbestos fibers. These measures include such techniques as enclosure of asbestos fiber transfer points, the ducting of airborne asbestos from these enclosures to air pollution control devices and the subsequent disposal of the captured asbestos. This section presents an overview of these control techniques and disposal methods.

In addition, estimates of the amount of asbestos released to the air from process and disposal operations will be reviewed in this section. These estimates are based on studies performed by two independent researchers.[1] Their work will be reviewed in detail and both occupational and nonoccupational exposure levels will be discussed. These studies used air emission estimates in conjunction with mathematical dispersion models to predict ambient asbestos concentrations in the vicinity of primary asbestos manufacturing facilities. These predicted concentrations will also be discussed and compared to actual ambient asbestos concentrations measured by the Connecticut Department of Environmental Protection.[2] Finally, GCA evaluated all asbestos release information and prepared its own estimates on asbestos fiber releases to the environment. These estimates will be summarized in this section.

CONTROL TECHNIQUES

Asbestos Mining and Milling

The mining of asbestos-bearing rock can be a primary source of airborne asbestos fibers, although emission controls exist for each process in this operation. Major sources of asbestos emissions from mining operations include drilling, blasting, road dust and ore dumping, crushing and transportation. Bag filters can be attached to mobile drilling units to control emissions during this process. The need for filtering devices has been eliminated in some instances by using a wet drilling procedure. Emissions during blasting are largely uncontrolled but may be reduced somewhat by wetting the surface around the blast site with water or a chemical wetting agent.[3] Road dust is often controlled by using sprays of water with and without chemical additives or by using a spray of oil. Once mined, ore is dumped into a "dumping pit" which feeds the ore into a crusher to reduce the particle size.[4] To control emissions the pit can be enclosed while the crusher can be hooded and vented to a baghouse. Emissions during loading can be controlled by wetting the ore while loading and unloading trucks, or by loading and unloading in emission-controlled enclosures.[4] Emissions during trucking can be controlled by using closed bodied trucks or flexible impervious covers.[3] At present, however, the extent to which emission controls are applied in the mining of asbestos is largely unknown.

In the milling operation asbestos is separated from the accompanying rock. Sources of emissions include ore stockpiles, ore dryers, hammermills, crushers vibrating screens, belt conveyors and automatic bagging machines. Water is often sprayed onto ore stockpiles to control emissions. Hammermills, crushers, vibrating screens and bagging machines are hooded and vented to a central baghouse. Belt conveyors are usually completely enclosed to prevent emissions. Transfer points where ore, asbestos fiber and asbestos-containing waste products are transferred from conveyor systems to plant operations are hooded and vented to a baghouse.[3] Cyclones are commonly used in ore-drying operations due to their relative insensitivity to process gas changes in temperature and humidity. The major disadvantage of cyclone filters is their poor efficiency, which is about 70 percent for asbestos fibers. By using multiple small cyclones to replace one large cyclone the efficiency can be increased to about 90 percent.[3]

Asbestos Manufacturing Industries

Several potential sources of asbestos emissions in the asbestos manufacturing industries can be identified. In the fiber receiving and storage area, broken bags and spills account for most of the fiber release. Control practices in this area include pelletizing shipments, shrink-wrapping pallets, repairing broken bags, vacuuming spills and receiving asbestos in pelletized or compressed block form. Manufacturing operations which have a high potential for emissions include blending, mixing, forming, rolling, and finishing. In the friction materials industry, finishing operations generate the greatest quantity of emissions with as much as 30 percent of the asbestos in the product being ground away as dust.[5] Hoods and enclosures are used extensively throughout the plants to control emissions. Hoods of either a low-volume, high-velocity or high-volume, low velocity design are used depending on the particular manufacturing process. Low-volume, high-velocity hoods maintain a face velocity of between 3050 and 3650 meters per minute (10,000 and 12,000 feet per minute) while high-volume, low-velocity hoods maintain a face velocity of at least 46 meters per minute (150 feet per minute.)[3] The high-velocity hoods are used with machining equipment, such as saws and drills where the release of particles is localized. High-volume, low-velocity hoods are used to vent equipment such as mixers and bag opening stations where localized capture is not possible. In most cases the hoods and associated ductwork tie into a centralized gas-cleaning device.[5,6]

Baghouses are the most common air pollution control devices used in the asbestos industries. In a monitoring study of 5 different asbestos emission sources removal efficiency was found to exceed 99.99 percent.[7] Although the efficiency was high, measurable quantities of small asbestos fibers were still released. Fiber concentrations of air exiting the baghouses were found to be between 1.1×10^7 and 3.3×10^9 f/m^3 for fibers greater than 0.06 μm in length and between 6.4×10^3 and 8.3×10^5 f/m^3 for fibers greater than 1.5 μm in length, indicating that the vast majority of fibers released were shorter than 1.5 μm. Although actual collection efficiency for fibers shorter than 1.5 μm cannot be determined from the available data, it is evident that efficiency decreases as a function of fiber length below 1.5 μm.[7] Wet scrubbing devices are used by some plants to control asbestos emissions although wet scrubbers are generally being replaced with baghouses. The collection efficiency of wet scrubbers is relatively low, about 90 percent, and unlike baghouse filters they produce wastewater.[3] Cyclones are sometimes used where the emissions gas stream is subject to high temperature and/or humidity. The collection efficiency of cyclones for asbestos fibers is relatively low, about 70 percent. An overall collection efficiency of up to 90 percent can be obtained using multiple cyclones. A survey of asbestos products manufacturing plants by Hardwood, et al.[8] showed that 80 percent of the asbestos products manufacturing plants used baghouse filters while only 6.8 percent used scrubbing devices as is shown in Table 4. The remaining 13.2 percent of the plants were reported to be using either cyclones, filters or some combination of control equipment. Since this survey was conducted in 1974 it is likely that some plants have substituted baghouse filters for scrubbers in order to eliminate wastewater discharges.[6]

TABLE 4. USE OF EMISSION CONTROL IN ASBESTOS PRODUCTS MANUFACTURING PLANTS, 1974[8]

	Plants using device		Total devices used	
Control device	No.	Percent	No.	Percent
Baghouse	72	80.0	335	90.1
Scrubber	6	6.8	8	2.1
Cyclone-baghouse combination	4	4.4	12	3.2
Cyclone	4	4.4	7	1.9
Filter systems	3	3.3	6	1.6
Scrubber-baghouse combination	1	1.1	4	1.1
Total	90	100.0	372	100.0

WASTE DISPOSAL

Asbestos Milling Waste Disposal

Compared to asbestos manufacturing plants, asbestos mills generate vast quantities of waste. Whereas a large manufacturing plant may need a 3-acre site to dispose of its waste, a tailings disposal site for a large mill occupies about 100 acres. In 1974 approximately 67 percent of all asbestos emissions were thought to have originated from mining and milling operations and disposal with the majority of these emissions coming from mill tailing disposal sites.[1] Emissions from mining and milling have probably since decreased due to new regulations although no supporting monitoring data presently exists. The asbestos content of mill tailings varies greatly between different plants with values of 1 to 30 percent asbestos being reported.[1]

Unlike most manufacturing plants, mills use on-site disposal of waste. Extensive conveyor systems, with numerous transfer points are used to transport waste tailings from the mill to a disposal area. EPA regulations require that there be no visible emissions from conveying or disposal of the waste and that tailings be wetted before disposal (40 CFR 61.22(u)). Emissions can be minimized by wetting the waste before transporting it from the mill and by using completely enclosed conveyors. Active disposal sites for mills are subject to the same regulations (40 CFR 61.25) as asbestos manufacturing industries.

Inactive sites, in which mill tailings were disposed, may be covered with 15 cm (6 inches) of nonasbestos containing material and a cover of vegetation (40 CFR 61.22(L)(5)(i), or with at least 61 cm (2 feet) of compacted nonasbestos containing material (40 CFR 61.22(L)(5)(ii)), or with a resinous or petroleum-based dust supression agent which effectively binds dust and controls wind erosion (40 CFR 61.22(L)(5)(iii)). Although a cover of soil and vegetation is the most desirable means of emissions control it is often impractical at mill tailing disposal sites. The large area occupied by these sites makes the cost of soil prohibitive while the high alkalinity of the tailings makes it difficult to grow vegetation. Erosion is generally controlled at these sites by applying chemical dust supression agents. These agents bind the dust and waste together, forming a crust which resists wind and water erosion.[9] Only short to moderate term stabilization is possible using these chemicals with reapplication being necessary every 1 to 3 years.[10]

Asbestos Manufacturing and Fabrication Industries

Asbestos manufacturing operations present potential waste disposal problems. Asbestos-containing waste is often generated in the form of product scraps, and as general housekeeping waste which includes floor sweepings, empty shipping bags and vacuum cleaner bags. In most plants, the majority of waste is in the form of dust collected in baghouse filters.

Handling and disposal procedures vary with the type of waste generated. Figure 1 depicts various asbestos-containing waste disposal treatment options. Asbestos-containing scrap products are generated in both friable and nonfriable form. Nonfriable scraps are not likely to cause atmospheric emissions since the asbestos fibers are encapsulated by a binding agent and may be disposed of as is, without any special handling. Some scraps, such as floor tile and paper scraps can be ground up and fed back into the head end of the production process. Friable asbestos material as defined by EPA regulation (40 CFR 61.21(k)) means any material that contains more than 1 percent asbestos by weight and that can be crumbled, pulverized, or reduced to powder by hand pressure. Before disposal, friable asbestos-containing scraps should be placed in plastic bags, then tied and marked to indicate the asbestos contents. Alternately, friable materials can be wetted and sealed in barrels or drums. All asbestos-containing waste scraps should be isolated from other forms of waste.

Vacuum cleaner dust is the major form of asbestos-containing waste generated by general housekeeping practices. This waste should be placed into plastic bags and be kept separate from nonasbestos containing waste. The bags should be securely sealed and marked to indicate the contents. Empty shipping bags should also be bagged, tied and marked before disposal. In some cases, such as in the floor tile industry, empty shipping bags are fed into the production line and are incorporated into the product.

Baghouse filters are the most common pollution control devices used in the asbestos manufacturing industries and at most plants they generate the greatest quantity of asbestos-containing waste. In some cases baghouse dust is wetted and handled as a slurry. As a slurry, the waste can be pumped into a tank truck and hauled in bulk shipments. Alternatively, the baghouse catch can be wetted and placed in leak-tight containers, such as 55 gallon drums (40 CFR 61.22 (j)(4)(B)). The potential for emissions can be minimized by using lined drums. The baghouse catch can also be mixed with cement to form solidified, nonfriable pellets (40 CFR 61.22 (j)(4)(C)(ii)) which can be hauled in open trucks. In some industries the baghouse dust is recycled to the head end of the process, such as is done in the manufacture of roof coatings. As many as 6 plants are thought to be using wet scrubbers to control emissions.[8] Waste from scrubbers is handled as a slurry. The waste is generally pumped into tank trucks and hauled to disposal sites.

Asbestos-containing wastes are defined under the National Emission Standards for Hazardous Air Pollutant (NESHAPs) Program as being hazardous (40 CFR 61.21). EPA regulations require that no visible emissions be generated during transportation (40 CFR 61.22 (j)) or from disposal (40 CFR 61.25 (a)) of asbestos-containing waste. Regulations also require that asbestos-containing waste be covered with at least 15 cm (6 in.) of compacted nonasbestos containing material (40 CFR 61.25 (e)(1)) or be covered with a resinous or petroleum based dust supressing agent which effectively binds dust and controls wind erosion (40 CFR 61.25 (e)(2)). If the disposal site is in compliance with the above regulation, the disposal site is not required to employ warning signs and fencing (40 CFR 61.25 (d)).

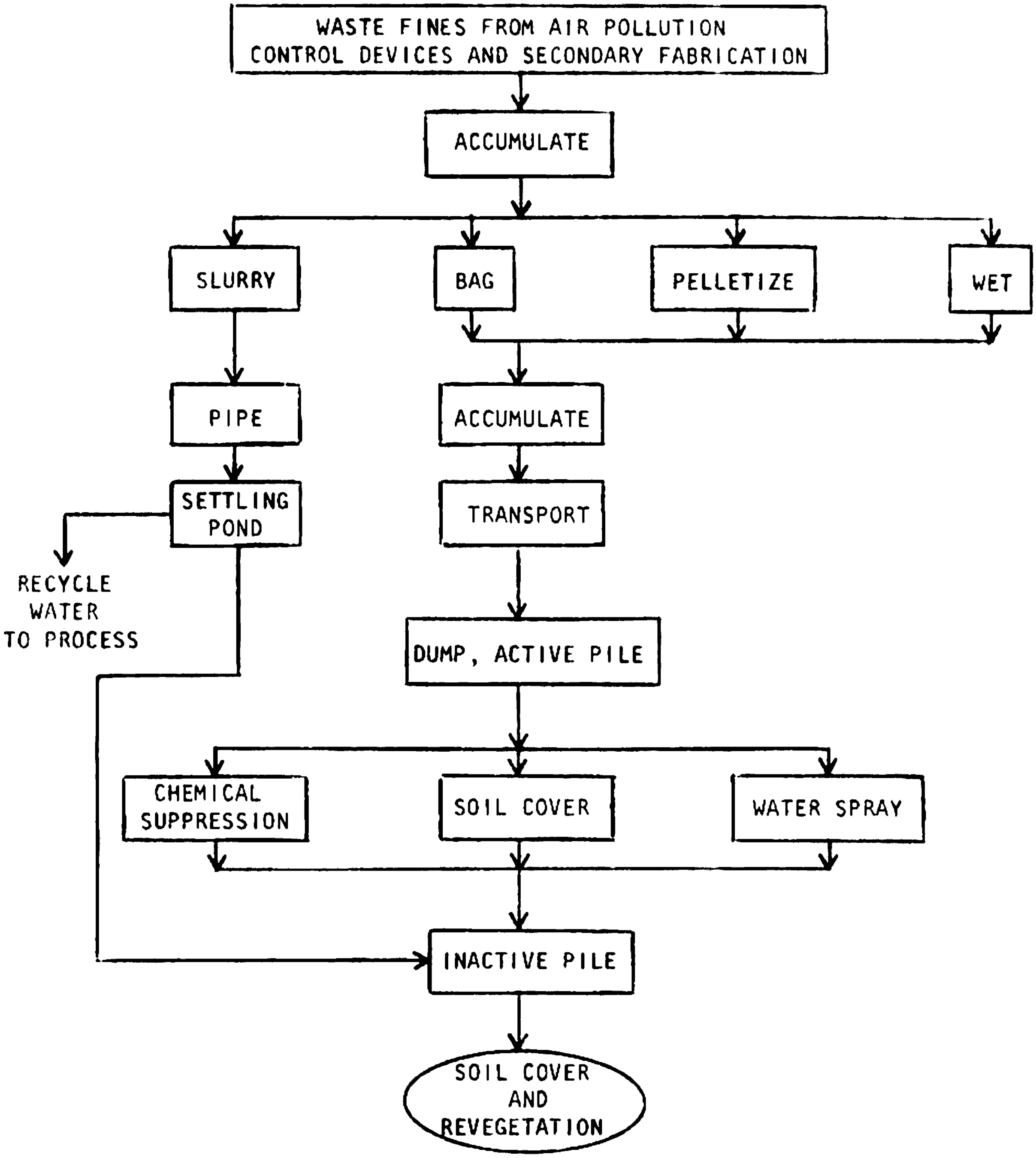


Figure 1. Asbestos-containing waste disposal treatment options.[10]

Asbestos-containing waste should be handled carefully and be kept separate from other waste. The disposal site should be notified before the waste is sent so that a trench can be dug into which the waste will be unloaded. Asbestos-containing wastes are unloaded into trenches either in bags, barrels or as a slurry. The waste should then be immediately covered with soil to prevent reentrainment of the asbestos by the wind. Compaction of the cover should be minimized to prevent bag breakage when waste is disposed of in plastic bags.

Inactive waste disposal sites are those sites in which additional asbestos-containing material will not be deposited and in which the surface will not be disturbed by vehicular traffic (40 CFR 61.17 (t)). Emissions from these sites can be controlled either by covering with at least 15 cm (6 in.) of compacted nonasbestos containing material and a cover for vegetation (40 CFR 61.22 (L)(5)(i)) or by covering with at least 61 cm (2 feet) of compacted nonasbestos containing material and maintained to prevent exposure of the waste (40 CFR 61.22 (L)(5)(ii)). Vegetation is in most cases the most desirable cover since it requires little or no maintenance and serves to reduce both water and wind erosion.

Before the present standards for the disposal of asbestos-containing wastes were adopted in 1975, waste dumps were a common means of disposal. A study in 1974[1] showed that 37 percent of all asbestos product manufacturers disposed of asbestos-containing waste in dumps while only 13.4 percent used sites which would be acceptable under present standards. Several studies made prior to 1975 have shown atmospheric asbestos emissions from dumps to be very high, approaching occupational levels in the worst cases.[1] Although no studies have been conducted since 1975 it should be safe to assume that emissions from disposal have decreased as more stringent asbestos control regulations have been adopted.

HUMAN EXPOSURE TO ASBESTOS

Introduction

In this section available data on asbestos exposure in the working and ambient environments is summarized. Elevated levels of asbestos fibers in the working environment have long been recognized as a serious problem. Workplace fiber concentrations of between 0 and 30 optical-microscope-visible fibers per cubic centimeter (f/cc) have been documented in numerous studies. As a result, worker exposure can be quantified with a fair degree of accuracy. On the other hand, nonoccupational exposure from manufacturing and disposal sources has received much less attention. Exposure estimates presented in this section are based on dispersion models using assumed emission factors with questionable accuracy. In addition, little ambient monitoring data is available to validate such models. Studies are further compounded by natural background fiber concentrations.

Asbestos Consumption Data

As discussed in Section 1, the asbestos consumption data used in this report are those developed by the Bureau of Mines for 1980. Asbestos consumption varies from year to year due to several factors, including the introduction of new products, the deletion of old ones, the increased use of asbestos substitutes and natural fluctuations in business activity which affect the production and delivery of all goods and services. In this report, asbestos emissions estimates for each product category are related to asbestos consumption data using emission factors developed by Suta and Levine.[1] To understand the accuracy and validity of these emissions estimates, it is therefore important to have a historical perspective on changes in asbestos consumption. Such an overview will insure that the asbestos emissions estimates developed will not underestimate or overestimate the extent of asbestos release.

Table 5 presents biannual consumption data, by product category, for the years 1976-1980. Two facts are evident from an examination of this table. First, and most important in terms of emissions, is that overall use of asbestos fibers decreased by 42 percent between 1978 and 1980. This decreased consumption occurred in every product category and must primarily be attributed to a general decline in business activity, especially in the automobile and building construction sectors. Asbestos product categories such as friction products and gaskets and packing, which reflect automobile-related asbestos use, and those of asbestos-cement sheet and floor tile, which are associated with building construction activities, declined significantly from 1978 to 1980. The net impact of this business slowdown is that the asbestos emission estimates presented in this report, which are based on 1980 asbestos consumption data, may not be representative of long term trends in asbestos consumption and emissions. Nonetheless, the 1980 asbestos data is the most recent available and will provide the basis for our emission estimates.

An examination of Table 5 also points out changes in asbestos consumption for specific product categories and in so doing provides a commentary on the quality of the data itself. With two notable exceptions, the percent of total asbestos consumption consumed by any product category remained relatively constant from 1976 to 1980. The two exceptions are the paper products group, which in this report includes paper, roofing products, thermal and electrical insulation and flooring felt, and asbestos cement pipe. The paper products category has lost a significant share of total asbestos consumption from 1976 to 1980, both in tons of asbestos consumed and percent of overall annual consumption. A large part of this dramatic decrease, however, can be attributed to an abnormally high consumption rate cited by the Bureau of Mines for roofing products in 1976. Had this roofing consumption rate been closer to the previous five-year average, 1976 paper asbestos use would have amounted to roughly 33 percent of total industry consumption and the decrease for this product category from 1976 to 1980 would have been far less dramatic. The reason for the abnormally high 1976 roofing products consumption figure has not been explained by the Bureau of Mines. Users of this data must therefore recognize that while it is the official government estimate for raw asbestos consumption, its accuracy may be somewhat questionable.

TABLE 5. BUREAU OF MINES ASBESTOS CONSUMPTION DATA, BY PRODUCT CATEGORY, 1976-1978-1980

Product category	1976		1978		1980	
	Consumption (metric tons)	Percent of annual consumption	Consumption (metric tons)	Percent of annual consumption	Consumption (metric tons)	Percent of annual consumption
Paper[a]	328,000	50.0	154,100	24.9	90,020	25.1
Friction products	58,000	8.8	73,700	11.9	43,700	12.2
Asbestos-cement pipe	127,000	19.3	217,400	35.1	144,000	40.2
Asbestos-cement sheet	21,000	3.2	36,100	5.8	7,900	2.2
Floor tile	41,000	6.3	50,400	8.1	36,080	10.1
Gaskets and packing	18,000	2.7	31,100	5.0	12,300	3.4
Sealants	18,000	2.7	19,100	3.1	10,900	3.0
Plastics	20,000	3.0	4,900	0.8	1,500	0.4
Textiles	7,000	1.1	2,900	0.5	1,900	0.5
Miscellaneous	19,000	2.9	29,700	4.8	10,400	2.9
TOTALS	656,000	100.0	619,400	100.0	358,700	100.0

[a] Includes roofing, thermal and electrical insulation and flooring felt.

The asbestos cement pipe category displayed an increasingly larger share of the total asbestos consumption from 1976 to 1980. However, this percentage increase is due more to the more rapid decrease in asbestos use by the other product categories than it is to the increased use of asbestos in the manufacture of asbestos concrete pipe. This is clearly shown by an examination of the 1978 and 1980 data. Between these two surveys, use of asbestos in pipe production decreased by roughly one third while the percentage of asbestos consumption attributed to this category increased by five percent. These data strengthen the argument that asbestos consumption data and the emissions estimates that are derived from them must be clearly understood and not taken out of context in order to accurately present the extent of asbestos release in the environment today.

Exposure Estimates of Suta and Levine

Suta and Levine[1] present detailed estimates on occupational and nonoccupational exposure to asbestos. Their study presents this data in terms of the number of asbestos fibers inhaled per person per year. To do this, they extrapolate asbestos concentration estimates to total annual asbestos inhalation quantities using the following assumptions:

- The average person inhales 15 m^3 of air/day
- For every optical-microscope visible fiber, there are 50 electron microscope visible fibers
- There are 1000 electron-microscope visible fibers per nanogram of asbestos

Occupational Exposure--

Based on Suta and Levine's assumptions, a maximum occupational exposure level can be calculated. This level assumes that the worker is exposed to the maximum permissible workplace asbestos level of 2 optical-microscope visible fibers per cc over a 40 hour work-week. This 2 fiber per cc level can also be expressed as an asbestos concentration of 100,000 ng/m^3. Using this maximum permissible concentration, a worker in the asbestos industry would inhale 125 billion electron microscope visible fibers or 125,000 μg of asbestos annually. This estimate assumes that the average worker is employed for 50 weeks per year and inhales 5 m^3 of air per day while in the asbestos laden atmosphere. This estimate is roughly one-half that calculated by Suta and Levine. While the rationale for their higher estimate is not clearly explained, they apparently assumed a higher work-time inhalation rate. Typically, asbestos workers are exposed to an average concentration of 1 f/cc and can therefore be expected to inhale about 63 billion fibers per year. While the occupational exposure discussion by Suta and Levine does not give an estimate of the number of workers exposed, it does provide a rationale for calculating occupational and nonoccupational exposure levels.

Nonoccupational Exposure--

Nonoccupational exposure to asbestos for persons living near asbestos industrial facilites was determined by Suta and Levine[1] by applying assumed plant emissions to a mathematical dispersion model (Binormal Continuous Plume Dispersion Model developed by D. Bruce Turner). Suta and Levine based their nonoccupational exposure estimates on emission estimates from the primary asbestos industry only, excluding the secondary asbestos industry and consumer use related emissions sources. The determination of plant emissions was based on 1974 production data and took into account improved air pollution controls. The following assumptions were first made in order to calculate nonoccupational asbestos exposure:

- A radius of 30 km is used to define a population living near asbestos mines and mills as they are located in rural areas.
- A radius of 5 km is used to define a population near an asbestos industrial facility which are generally located in urban area.
- Plant emissions are those shown by Suta and Levine.[1]

Estimates of atmospheric concentrations and the annual amounts of asbestos inhaled for persons living near asbestos industrial facilities are given in Table 6. For this report, the roofing products segment along with 60 percent of the flooring products segment were regrouped under paper products to conform to CCA designations. Ambient background concentrations are included in these estimates. Average atmospheric asbestos concentrations range from 21 to 33 ng/m^3 for the various production categories in urban areas with the annual amount of asbestos inhaled ranging from 115 million to 180 million electron microscope visible fibers. As a point of reference, the median ambient urban atmospheric asbestos fiber concentration as reported by Suta and Levine[1] is 20 ng/m^3 with 108.6 million electron-microscope visible fibers being inhaled by the average person.[1] In contrast, the average asbestos worker can be expected to inhale 63 billion electron-microscope visible fibers. Persons living near mines and mills are shown by Suta and Levine[1] to be exposed to much higher concentrations of asbestos than are persons living near asbestos production facilities. Tailing piles are thought to be the major source of emissions from mining and milling operations. As shown in Table 6, the average asbestos concentrations near these operations is 400 ng/m^3 with 2.2 billion electron microscope visible fibers being inhaled by the average person residing near these operations. This still amounts to only about one-half of one percent of the maximum allowable worker exposure and only about 94,000 persons are affected since mines and mills are located in rural areas.[1] It was, however, reported in this study[1] that the upper 1 percentile of the persons residing in the vicinity of asbestos mines and mills might inhale occupational levels of asbestos.

For rural areas it has been estimated that 10 percent of the population which experiences maximum asbestos contact (upper tenth percentile) is exposed to asbestos concentrations ranging from 8 to 100 ng/m^3 for the various production categories. In urban areas, the upper tenth percentile of the population is exposed to concentrations ranging from 28 ng/m^3 to 120 ng/m^3. Persons exposed to 120 ng/m^3 are expected to inhale 660 million electron-microscope-visible fibers/year.[1] Both average and upper tenth percentile exposure levels are presented in Table 6.

TABLE 6. ATMOSPHERIC EXPOSURE TO ASBESTOS IN THE VICINITY OF ASBESTOS INDUSTRIAL FACILITIES[1]

Type of facility	Plants analyzed		Background	Atmospheric asbestos concentration[a] (ng/m^3 or thousands of fibers/m^3)[b]	Annual amount of asbestos inhaled[a] (μg or millions of fibers)[c]
	Number	Estimated portion of total plants (%)			
Mines and mills	5	100	Rural	400.0 (6000)[d]	2,190 (32,900)[d]
Friction products	51	90	Urban	23.0 (44)	125 (240)
			Rural	3.4 (24)	19 (130)
Gaskets, packing, or insulation	39	65	Urban	24.0 (40)	130 (220)
			Rural	4.4 (20)	24 (110)
Textiles	24	95	Urban	21.0 (28)	115 (155)
			Rural	1.3 (8)	7 (45)
Cement	35	50	Urban	27.0 (120)	148 (660)
			Rural	7.2 (100)	39 (550)
Floor tile	9	90	Urban	21.0 (32)	115 (175)
			Rural	1.0 (12)	5 (66)
Paper[e]	58	80	Urban	33.0 (84)	180 (460)
			Rural	13.0 (64)	71 (350)

[a] Includes nominal atmospheric concentration background.

[b] Electron-microscope-visible fiber data were calculated from mass data assuming 1000 fibers/ng. Actual conversion may be 100-10,000 fibers/ng; hence, reported figures may be one order of magnitude high or low.

[c] Consumption assumes a daily inhalation of 15 m^3.

[d] Median population exposure for indicated "at risk" population followed by upper 10 percent population exposure in parentheses.

[e] Paper includes roofing products and 60 percent of flooring industry.

Suta and Levine[1] determined process waste disposal sites to be a major source of atmospheric asbestos emissions with an estimated 383 metric tons being emitted during 1974. Relying on several previous studies made prior to 1975, they determined the atmospheric concentration around disposal sites to be on the order of 10 to 1000 times higher than typical background concentrations, possibly approaching occupational concentrations in some cases. However, these estimates were based on emissions measurement made prior to 1975 at which time stricter disposal regulations went into effect (40 CFR 62.15). Suta and Levine estimated emissions from consumer waste in 1974 to be 91 metric tons. Although much less than the emissions from process waste disposal, consumer waste is more likely to be disposed in uncontrolled waste dumps and be handled by persons unaware of the hazards.[8]

Ambient Monitoring Studies--

There is very little actual ambient monitoring data available to support the human exposure estimates by Suta and Levine.[1] Their ambient data was based on estimates of plant emission rates which were subsequently used with atmospheric dispersion modeling calculations. However, Bruckman and Rubino of the Connecticut Department of Environmental Protection[2] measured ambient asbestos levels both adjacent to and removed from several different users of asbestos. Approximately 40 monitoring sites were selected; ambient locations including "typical" urban sites removed from known stationary sources of asbestos emissions, rural-background sites, and stations contiguous to 4 industrial users of asbestos (i.e., manufacturers of friction products, insulated wire and cable, ammunition and molding compounds). Ambient chrysotile asbestos levels removed from asbestos emission sources in both urban and rural locations were below 10 ng/m^3. However, asbestos concentrations near the industrial users of asbestos exceeded Connecticut's proposed asbestos air quality standard of 30 ng/m^3, 30 day average. These measured levels included 32 ng/m^3 for a manufacturer of friction products; 33 ng/m^3 for a manufacturer of insulated wire and cable and a manufacturer of ammunition, located approximately 1/2 mile apart; and 33 ng/m^3 for a manufacturer of molding compounds. These elevated levels occurred in spite of the fact that each source was in compliance with NESHAPS and other current applicable state and federal air quality regulations.

Connecticut's actual atmospheric asbestos concentration measurement, in the vicinity of industrial facilities, closely resembles atmospheric concentration estimates which Suta and Levine[1] developed based on dispersion modeling (see Table 6). Suta and Levine estimated that average atmospheric concentrations, within 1.6 km of an industrial user, range from 28 to 120 ng/m^3 for urban sources and 8 to 100 ng/m^3 for rural sources. The range of fiber concentrations presented is due to varying emission rates from different industrial sources. Connecticut's measurements fall in Suta and Levine's range, but it is important to note that Connecticut's samples, which exceeded 30 ng/m^3, were measured within 1 km of the industrial user. Connecticut's spot sampling data are too limited to estimate an average atmospheric concentration over a given area, as provided by Suta and Levine. Nonetheless, the actual atmospheric measurements obtained by Connecticut, support Suta and Levine's atmospheric concentration estimates.

Atmospheric asbestos concentration estimates, based on dispersion modeling, were also determined by GCA/Technology Division.[11] The dispersion modeling conducted by GCA differs from Suta and Levine in that actual emission rates were measured, rather than relying on gross emission estimates. Samples were taken in the exhaust vents of an asbestos paper plant to determine the averages asbestos concentration of the exhaust gases. The exhaust gas fiber concentration data was combined with process aspiration rates to determine total plant asbestos emission rates. Employing this data in a Gaussian Plume dispersion model, it was estimated that plant-related asbestos concentrations above 50 ng/m^3 may be encountered within 500 meters of the plant, depending on the meteorological conditions present. GCA/Technology Division Dispersion Model estimates were made with actual emission measurement data, and like the Connecticut data, support Suta and Levine's atmospheric asbestos concentration estimates.

Emission Estimates

Suta and Levine made detailed estimates of air-borne asbestos emissions resulting from the manufacture and disposal of asbestos containing materials. These data have been upgraded to account for 1980 asbestos consumption figures, and are presented in Table 7. As can be seen in this table, disposal emissions from manufacturing are estimated to be 179 metric tons, compared to 86.8 metric tons of process emissions. These estimates may be high as they fail to take into consideration new regulations regarding the disposal of asbestos-containing waste (40 CFR 61.25). However, no current data exist on the degree to which disposal sites are in compliance with the new disposal standard. In addition, no measurements of emissions from disposal sites which are in compliance have been made.

TABLE 7. AIRBORNE ASBESTOS EMISSIONS FROM PROCESS AND DISPOSAL - PRIMARY INDUSTRY[1]

Industry segment	1980 annual asbestos consumption (Mt/yr)	Asbestos emissions to air/ Mt/yr from Process	from Disposal	Total
Paper	90,020	45.0	45.01	90.01
Friction material	43,700	10.86	21.73	32.59
A.C. pipe	144,000	14.24	71.92	86.16
A.C. sheet	7,900	0.83	3.95	4.78
Floor tile	36,080	3.63	18.13	21.76
Gaskets and packing	12,300	6.12	6.12	12.24
Sealants	10,900	0.63	5.39	6.02
Plastics	1,500	a	0.74	0.74
Textiles	1,900	0.31	0.92	1.23
Miscellaneous	10,400	5.22	5.22	10.44
TOTAL	358,700	86.84	179.13	265.97

[a] Minimal amounts

After reviewing the Suta and Levine data, GCA has developed its own estimates on asbestos releases from process and disposal operations. Visual observations by GCA personnel at asbestos-containing waste disposal sites have indicated that the majority of sites exhibit no visible emissions, and therefore appear to be in compliance with Federal asbestos disposal regulations. By assuming compliance to be at least 90 percent, GCA has estimated disposal emissions to be reduced by at least ten times from Suta and Levine's estimate of 179 metric tons for uncontrolled disposal practices. This places disposal emissions from manufacturing processes, updated to 1980 U.S. Bureau of Mines consumption data, at approximately 18 metric tons. However, a tenfold reduction may be a conservative estimate and a 100-fold reduction may more accurately represent emissions using present day disposal techniques. GCA can therefore state with reasonable confidence that emissions from disposal of manufacturing wastes containing asbestos fall between 2 and 18 metric tons per year.

A summary of GCA's fiber release estimates is presented in Table 8. This information is based on Suta and Levine's[1] fiber release estimates for process operations proportioned to reflect 1980 U.S. Bureau of Mines consumption data for each industry segment. However, as stated above, GCA has estimated emissions from disposal to be one order of magnitude lower than that reported by Suta and Levine due to the recent regulations enacted to limit emissions from disposal sites. Suta and Levine's emission estimates were used as a basis for estimating fiber release from process operations since it is believed that their assumptions closely depict actual conditions.

TABLE 8. GCA ESTIMATES OF FIBER RELEASE FROM MANUFACTURING AND DISPOSAL - 1980

	Annual asbestos consumption Mt/yr	Asbestos Emissions to air, Mt/yr		
		From process	From disposal	Total
Paper	90,020	45.0	4.5	49.5
Friction	43,700	10.9	2.2	13.1
A.C. pipe	144,000	14.2	7.2	21.4
A.C. sheet	7,900	0.8	0.4	1.2
Floor tile	36,080	3.6	1.8	5.4
Gaskets and packing	12,300	6.1	0.6	6.7
Sealants	10,900	0.6	0.5	1.1
Plastics	1,500	[a]	0.1	0.1
Textiles	1,900	0.3	0.1	0.4
Miscellaneous	10,400	5.2	0.5	5.7
TOTAL	358,700	86.7	17.9	104.6

[a] Minimal amounts

Atmospheric emissions from consumer disposal are estimated to be 28.5 metric tons by Suta and Levine.[1] Due to limitations in available data, this study made no attempt to quantify human exposure from this source.

CONCLUSION

Baghouses are without question the most common type of air pollution control devices used in asbestos milling and manufacturing. Baghouse collectors have been determined to be highly efficient for removing long fibers although there is a paucity of data concerning the collection efficiency for short fibers. The use of wet scrubbers has greatly diminished, having been replaced by baghouse collectors. Substituting baghouse filters for wet collectors has the advantage of eliminating wastewater discharges, in addition to providing higher collection efficiencies. Cyclone collectors are primarily used only as precleaning devices prior to a baghouse filter due to their poor performance at removing small particles. However, cyclones are employed in ore drying operations, where the combination of high temperature and humidity, in addition to the relatively large particle size of the ore bound asbestos fibers, makes cyclone collectors the most suitable type of control.

Recognition of the dangers associated with asbestos exposure has lead to regulations eliminating the past practice of open dumping of asbestos wastes. Recent EPA regulations require disposal sites handling asbestos wastes to take measures to eliminate visible emissions. In addition, asbestos-containing wastes must be covered with at least 15 cm (6 inches) of compacted nonasbestos-containing material or be covered with a resinous or petroleum based-dust supression agent which effectively binds dust and controls erosion. Such currently employed dust control techniques have significantly reduced the amount of asbestos fibers released to the ambient air from a disposal site.

Emission estimates by Suta and Levine[1] place disposal emissions from manufacturing at a higher level than manufacturing process emissions. However, as previously stated, recent EPA regulations have resulted in a significant reduction in the amount of emissions generated at waste disposal sites. It is estimated that disposal emissions have been reduced by one order of magnitude relative to past practices.

GCA analyzed the assumptions made by Suta and Levine in estimating asbestos emissions to the air from manufacturing and disposal. Suta and Levine's estimate for asbestos emissions from process operations totals 86.8 Mt/yr, when their original 1974 estimates are upgraded to account for 1980 asbestos consumption. GCA's process emission estimate is 86.7 Mt/yr and essentially agrees with Suta and Levine's assumptions. GCA's estimate also takes into account 1980 asbestos consumption.

With regard to disposal emissions, GCA again used the Suta and Levine data as a starting point. However, GCA estimates that Suta and Levine have not taken into account the widespread compliance of industry disposal sites with applicable EPA regulations governing the ultimate deposition of asbestos-bearing waste. Based on its belief that compliance with these regulations is from 90 to 99 percent complete, GCA has reduced Suta and Levine's estimates by 10 to 100 times, or to approximately 2 to 18 metric tons per year. The later figure, 18 metric tons per year will be used in this report as GCA's estimate for disposal emissions from primary manufacturing.

There is a vast difference in population exposure estimates due primarily to insufficient data on process emissions and ambient asbestos concentrations. However, recent monitoring studies and atmospheric dispersion modeling programs conducted by the Connecticut Department of Environmental Protection and by GCA, show that elevated asbestos fiber levels are likely to be present in the ambient air in the vicinity of asbestos manufacturing facilities. This evidence supports the need for further monitoring of manufacturing emissions and ambient levels of asbestos.

REFERENCES

1. Suta, B. E., and R. S. Levine. Nonoccupational Asbestos Emissions and Exposures. In: Asbestos, Volume I Properties, Applications, and Hazards. L. Michaels and S. S. Chissick, eds., John Wiley & Sons, New York, NY, 1979, pp. 171-205.

2. Bruckman, L., and R. A. Rubino. Monitored Asbestos Concentrations in Connecticut. J. Air Pollution Control Assoc. 28(12), pp. 1221-1226. December 1978.

3. Control Techniques for Asbestos Air Pollutants. AP-117. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, February 1973.

4. Harwood, C. F., and T. P. Blaszak. Characterization and Control of Asbestos Emissions from Open Sources. IIT Research Institute, U.S. National Technical Information Service. PB-238-925. September 1974.

5. Jacko, M. G., and R. T. DuCharme. Brake Emission: Emission Measurements from Brake and Clutch Linings from Selected Mobile Sources. U.S. National Technical Information Service, PB-222-372. 1973.

6. Sittig, M. Pollution Control in the Asbestos, Cement, Glass, and Allied Mineral Industries. Noyes Data Corporation, Park Ridge, New Jersey, 1975.

7. Harwood, C. F., D. K. Ostreich, P. Siebert, and J. D. Stockham. Asbestos Emissions from Baghouse Controlled Sources. American Industrial Hygiene Association Journal, August 1975, pp. 515-603.

8. Harwood, C. F., P. Siebert, and T. P. Blaszak. Assessment of Particle Control Technology for Enclosed Asbestos Sources. EPA-650/2-74-098, U.S. Environmental Protection Agency, Washington, D.C., October 1974.

9. Background Information on National Emission Standards for Hazardous Air Pollutants. EPA-450/2-74-009, U.S Environmental Protection Agency, Research Triangle Park, N.C., October 1974.

10. Manufacturing Waste Disposal and Utilization, In: Proceedings of the Fifth Mineral Waste Utilization Symposium, Chicago, Illinois, April 13-14, 1976, pp. 308-318.

11. Cogley, D. Modeling Atmospheric Asbestos Concentrations in the Vicinity of an Asbestos Paper Plant. Unpublished. GCA/Technology Division, Bedford, Massachusetts, September 1979.

12. Clifton, R. A. Asbestos, 1980 Bureau of Mines Mineral Yearbook, Washington, D.C. August 22, 1979.

13. Levine, R., ed. Asbestos: An Information Resource. May 1978.

SECTION 3

MINING AND MILLING OF ASBESTOS

INTRODUCTION

Asbestos is a generic term encompassing a number of impure, naturally occurring hydrated mineral silicates separable into filaments. Six commercial varieties of asbestiform minerals have been identified and are presented below according to the rock forming minerals group from which they originated.

Group	Variety	Formula
Amphibole	Anthophyllite	$Mg_7Si_8O_{22}(OH)_2$
	Amosite	$(Fe^{2+}Mg)_7Si_8O_{22}(OH)_2$
	Crocidolite (blue asbestos)	$Na_2Fe_2^{3+}(Fe^{2+}Mg)_3Si_8O_{22}(OH)_2$
	Tremolite	$Ca_2Mg_5Si_8O_{22}(OH)_2$
	Actinolite	$Ca_2(MgFe^{2+})_5Si_8O_{22}(OH)_2$
Serpentine	Chrysotile (white asbestos)	$Mg_3[Si_2O_5](OH)_4$

Chrysotile, which accounts for 85 percent of the world's production and use, is graded and grouped according to fiber length. The fibers are distinguished by separation into eight groups numbered 1 through 8. Grade 8 is not used in this country.[1] The remaining seven grades and their product uses are discussed below:

- Grades 1, 2, and 3--Fiber lengths for these three grades are greater than 19 mm, 10 to 19 mm, and 6 to 10 mm. respectively. The major end-use products made from these fiber grades include textiles, clothing, theater curtains, different types of packings, fireproof textile products, woven brake linings, clutch facings, electrical insulation material, and high-pressure and marine insulation.

- Grade 4--Grade 4 fibers range from 3 mm to 6 mm in length. Their major use is in asbestos-cement pipe.

- Grade 5--Grade 5 fiber lengths overlap with Grade 4, ranging from 3 to 6 mm. Fibers within this grade are used in asbestos-cement sheets, flat and corrugated sheets, low-pressure asbestos-cement pipes and molded products. They are also used in some paper products, such as pipe, insulation, wrappings and other products including brake linings and gaskets.

- Grade 6--Fibers within this grouping are less than 3 mm long. Primary use is in asbestos-cement products, gaskets, brake linings, vinyl sheet backings and millboard.

- Grade 7--Grade 7 fibers are also less than 3 mm long. Fibers within this group are used in molded brake linings and clutch facings, asphalt compounds, joint and insulation cements, roof coatings, plastics, and caulking compounds.

ASBESTOS MINING

The fiber is mined and milled primarily outside the United States. Of the estimated 1980 worldwide asbestos production (approximately 4.8 million metric tons) only 80,000 m.t. or less than 2 percent was mined in the United States.[1] Currently, four asbestos mining and milling operations are active in this country: two in California and one each in Vermont and Arizona. Details on American asbestos mines are presented in Table 9. According to Table 9, 542 persons were employed in asbestos milling and mining in 1973. More recent data indicate that current total employment in these operations is approximately 480 persons.[1]

Three of the four active asbestos mines are open pits; underground mining is practiced only in Arizona. In open pit mining, ore is removed from shallow deposits with earth-moving equipment. Generally a shallow overburden containing a low percentage of asbestos fiber must be removed to obtain access to more concentrated asbestos veins below. Blasting may be required to reach deeper fiber veins or to reduce boulders to a size acceptable to the mill. Asbestos fibers can be emitted from overburden dumps and exposed ore; from drilling and blasting; and from overburden and ore removal, loading and transport.

Underground mines follow asbestos ore veins with shafts, galleries and drifts using blasting and earth-moving equipment. Overburden removal is not required and ore deposits are not exposed to weathering, thus reducing asbestos fiber emissions. Significant amounts of dust may be generated during transfer operations, but many of the dirtier processes occur underground.[2]

At the mines, coarse ore is typically crushed by a jaw or gyratory crusher to an acceptable size. Oversize rock is separated by rotating cylindrical trommel screens and is crushed in a secondary crusher. Ore is conveyed to driers, or in larger installations, rotary kilns, where moisture in the ore (up to 30 percent by weight) is removed. Dried ore is then placed in storage, with large amounts being held to allow for any variation in fiber demand and mine production which may occur over time. Prior to milling, the dried ore may undergo an additional crushing step.

TABLE 9. AMERICAN ASBESTOS MINES AND MILLS[1,3]

Operating company	Mine location	Employees[a]	Mill location	Employees[a]	Estimated production (metric ton/yr)
Calaveras Asbestos Corp.	Calaveras County, Calif.	36	Copperopolis, Calif.	135	49,900[b]
Union Carbide Corp.	San Benito County, Calif.	36	King City, Calif.	50	25,000[b]
Vermont Asbestos Group	Hyde Park, Vt.	58	Hyde Park, Vt.	143	49,900[b]
Jacquays Mining Corp.	Gila County, Ariz.	8	Globe, Ariz.	5	2,700[b]
Total		159		383	

[a] 1973 figures. A more up-to-date breakdown is unavailable. According to a U.S. Bureau of Mines estimate, current total employment in United States mining and milling operations is 480 persons.[1]

[b] Annual figures based on daily production rate for 250 days/yr.

At almost any step in the mining process, asbestos fibers can be released. Weather clearly influences the extent of emissions. Rain and snow will cover exposed ore and overburden, while simultaneously cleaning the air and reducing ambient asbestos levels. Wind has an opposite effect, distributing existing emissions, entraining exposed fibers and reentraining settled fibers.

Blasting at the mine produces large quantities of dust which may contain asbestos fibers. If rock drilling at open pit mines is required to properly place explosives, air-swept rotary and percussion drills are commonly used, adding to dust emissions. Water-swept drills are more often utilized to reduce dust in underground mines, but are not used in large-scale field operations due to problems of water supply and the possibility of freeze up in winter.

All stages of ore handling (shoveling, screening, loading and unloading) can generate emissions. Underground ore handling activities contribute to ambient levels of asbestos as well as above ground activities since ventilation air is generally exhausted to the atmosphere without any pollution control. The most recent in-depth study of the types and effectiveness of pollution control equipment used in asbestos mining operations was conducted by Harwood[4] in 1973. At four major U.S. mines, dust control was found to be either limited or else nonexistent. Cyclones were used in conjunction with drilling equipment, in some cases, but emissions were still significant. Water sprays were used to a limited extent to control dust during ore handling and blasting operations. Ore was found to be transported from mines to mills in large open trucks, covered only by loose-fitting tarpaulins, which could result in asbestos being blown into the atmosphere. A high potential for fiber release was also found to exist during the loading and unloading of ore. In addition, private roadways in the mine vicinity were paved with asbestos-containing tailings from which fibers were released due to vehicular traffic.

Worker Exposure from Asbestos Mining

Recent data on the exposure to asbestos of persons employed in asbestos mining operations are generally lacking. During 1971, employees at six active asbestos mines were monitored to determine their time weighted average exposure to asbestos fibers. Results are summarized in Table 10. A total of 140 samples were collected in the workers' breathing zones, with results ranging from less than 0.1* fibers per cc to 7.8* fibers per cc as measured using the NIOSH phase contrast (optical) procedure.[5] The average mine worker exposure was 1.2* fibers per cc. Drillers were exposed to the highest levels of asbestos, with concentrations averaging 2.8* fibers per cc.

The asbestos mining and milling industry in the U.S. is regulated by the Mine Safety and Health Administration (MSHA). Under MSHA standards, which became effective in December of 1978, mine workers may be exposed to a maximum

---

*Optical microscope visible fibers.

TABLE 10. ASBESTOS FIBER EXPOSURES IN MINES (TIME-WEIGHTED AVERAGE)[5]

Occupation	Total samples	Asbestos fibers/m^3 (>5 μm in length) Highest exposure	Lowest exposure	Average exposure[a]
Driller	31	7.8 x 10^6	1.0 x 10^6	2.8 x 10^6
Explosives man	6	0.6 x 10^6	0.1 x 10^6	0.3 x 10^6
Heavy equipment operator	55	1.7 x 10^6	0.5 x 10^6	1.1 x 10^6
Maintenance man	7	0.5 x 10^6	0.1 x 10^6	0.3 x 10^6
Truck driver	20	0.8 x 10^6	0.2 x 10^6	0.5 x 10^6
Other	21	0.8 x 10^6	0.04 x 10^6	0.5 x 10^6

[a] Arithmetic mean.

Note: Data are based on samples taken during 1971 at six mines with 118 employees. All samples were collected in employee breathing zones, and analyzed by optical phase contrast microscopy.

of 2,000,000* f/m^3 (2 f/cc) for an 8-hour work day. Under the same standard, an exposure level of 10,000,000* f/m^3 (10 f/cc) is allowed for periods of up to 15 minutes per day. However, recent mine inspection data are lacking as are data regarding the extent to which dust control equipment and practices are being utilized.

Best Available Pollution Control Technology

Spraying--

Water sprays have been used extensively in mining operations to control dust emissions. Increased effectiveness has been achieved by mixing chemical additives with the water. Salts, such as sodium, calcium and magnesium chloride can be added to restrict the evaporation of water from the dust while oils and polymers have been added to give a more permanent binding action. Foam dust suppressing agents can be used in place of water sprays. Foams cover more completely than water sprays and are therefore more efficient.[4]

Drilling--

Air swept drills, designed to carry broken fragments and dust away from the cutting face while reducing the temperature of the drill bit, are responsible for high fiber levels. Emissions can be reduced on large rotary drills by drilling through a platform. The platform itself serves as a hood while rubber aprons attached to the platform with hinges provide a settling chamber for dust raised during drilling. Mobile primary drilling units which have attached compact bag filters currently offer the best method of dust control for open-pit drilling. Air emissions can be reduced without the need for filters by using water swept drills. The use of these drills is often limited by the water supply and the potential for water pollution.[4]

Blasting--

Blasting should be done in such a way that efficient rock removal is achieved while reducing emissions at the same time. Emissions can be reduced by using multiple detonations in place of one larger charge. Spraying water around the blast site has been found to reduce emissions in this area but does not control emissions from blast fragments. After changes have been set, bags of water can be placed in the blast holes to reduce emissions due to blast fragments.[4]

Road Dust Control--

In May of 1974, federal regulations[†] were adopted prohibiting the surfacing of roads with asbestos-containing tailings. However, temporary roadways in the areas of asbestos ore deposits are exempt. Emissions on roadways are generally created by traffic. Dust can be blown from trucks transporting asbestos ore while all vehicles can cause the release of asbestos from roads surfaced with

---

[*] Optical microscope visible fibers.

[†] 40 CFR Part 61 Subpart B - National Emission Standards for Hazardous Air Pollutants.

tailings due to the reentrainment of settled particles. In most cases, spraying is the most practical method of dust control. Water can be used, but must be reapplied often since it dries relatively fast. Better results have been obtained using polymers and lignin sulfate or bitumen compounds. Heavy oil controls dust successfully, but its use can cause problems with odors and seepage. On paved roads vacuum sweepers may be preferable to sprays since the dust is actually removed and emissions will not become a problem once the road dries.[4]

Ore Dumping, Crushing and Transporting--

Once mined the ore is dumped into a large "dumping pit" from which it is fed into a jaw crusher to reduce particle size. The ore is then loaded on trucks and hauled a short distance to an ore pile at a local mill. To control emissions, the dumping pit can be enclosed and the crusher can be hooded and exhausted to a baghouse. Loading and unloading can be carried out in ventilated, emission-controlled enclosures. A fine water spray can also be used during loading and unloading to reduce emissions. Emissions during transporting can be controlled by using closed bodied trucks or by using open trucks with flexible impervious covers.[4]

ASBESTOS MILLING

Each asbestos mine has an associated mill where asbestos fibers are separated from the ore, graded and packaged. Table 9, which lists active asbestos mines in the United States, also lists active mills affiliated with each mine.

Two milling techniques are used: air aspiration and wet separation. Air aspiration involves frequent handling of the asbestos ore, fibers and tailings creating numerous possible sources of emissions. The milling process itself takes place in hammermills, known as fiberizers, or in crushers which separate asbestos fibers from the ore rock and from each other. Milled particles are then shaken on progressively finer screens. Small rocks and fiber clumps pass through the screens to the next level, larger rocks are conveyed to tailing dumps or to crushing, and free fibers are removed from the sequence by airflow.

Separated fibers are conveyed to grading screens, classified according to length, then sent to storage bins by grade. Different grades are blended to obtain any desired final grade, which is then bagged for shipment.

Exposure from Asbestos Milling

During 1971, employees at six asbestos mills were monitored to determine their time-weighted average exposure to asbestos fibers. Results are summarized in Table 11. A total of 436 samples were collected in workers' breathing zones, with results ranging from a low of 1.2 fibers per cc to a high of 24.8 fibers per cc measured using the NIOSH phase contrast (optical) procedure.[5] The average mill worker was exposed to 9.1 fibers per cc; it is assumed that, stimulated by more stringent MSHA regulations, the average exposure has dropped since 1971. For example, the laborer classification had the highest average

TABLE 11. ASBESTOS FIBER EXPOSURE IN MILLS (TIME-WEIGHTED AVERAGE)[5]

Occupation	Total samples	Asbestos fibers/m^3 (> 5 μm in length)		
		Highest exposure	Lowest exposure	Average exposure[a]
Blender, bagger and packer	132	24.8×10^6	2.7×10^6	11.3×10^6
Palletizer and car loader	31	18.1×10^6	1.2×10^6	10.0×10^6
Crusher and dryer operator	32	20.3×10^6	7.1×10^6	11.0×10^6
Foreman	32	15.8×10^6	4.3×10^6	8.3×10^6
Laboratory technician	33	17.4×10^6	4.5×10^6	8.8×10^6
Laborer	37	17.3×10^6	8.2×10^6	12.1×10^6
Maintenance man	50	16.9×10^6	3.8×10^6	8.4×10^6
Mill operator	50	17.9×10^6	4.7×10^6	11.5×10^6
Other	39	10.5×10^6	2.3×10^6	6.0×10^6

[a] Arithmetic mean.

Note: Data are based on samples taken during 1971 at six mills with 370 employees. All samples were collected in employee breathing zones, and analyzed by optical phase contrast microscopy.

exposure, 12.1 fibers per cc, due in part to sweeping, but vacuuming may have superseded sweeping as the dangers of asbestos exposure have become known and as regulations have tightened.

Best Available Pollution Control Technology

All processes described in the air aspiration milling method result in fiber release. When first received from the mine, asbestos ore is stored in large open ore stock piles. Windbreaks and sprays can be used to minimize emissions from these piles. Since the air aspiration method of milling requires that the ore be dry, wetting adds to the process cost. Before the actual milling operations, ore is fed to an ore dryer where moisture is removed by heating. Cyclones and multiple cyclones have been used extensively to control emissions from this operation due to the relative insensitivity to high temperature and humidity of cyclones. However, the removal efficiency is relatively low (about 70 percent)[6] and visible emissions are often generated. Conventional baghouse filters cannot be used due to the high temperatures generated by the process. Baghouses using orlon cloth bags are installed on ore dryers in a Canadian mill operated by the Johns-Manville Corporation.[7] The orlon material can withstand greater temperatures than can conventional baghouse cloth while providing a much greater removal efficiency than cyclone devices. In one mill in the U.S. the ore dryer is vented to a baghouse which uses a heat resistant filter material trade named Nomex.[4] Hammermills, crushers, vibrating screens and automatic bagging machines can be hooded and vented to a central baghouse filter. Central vacuuming systems can be used to remove dust from the work areas. Ore is transported between different unit operations by a belt conveyor. To control emissions, conveyors can be completely enclosed while transfer points can be hooded and vented to a baghouse. Extensive conveyor systems are generally used to transfer mill tailings to an onsite disposal pile. Numerous transfer points as well as the point at which the tailings are dumped are potential sources of emissions. Emissions can best be controlled by wetting the tailings before they are placed on the conveyor and by using completely enclosed conveyor systems. After the tailings have been dumped and graded, chemical stabilizers can be applied to limit landfill emissions.[6]

Since the wet separation method is a proprietary process used only in one U.S. plant operating details are not available, but some factors influencing emissions are known. Perhaps most important, because of the loosely bound asbestos fibers in the ore at the source of this plant's asbestos, little or no crushing is required. In addition, use of a wet separation technique reduces in-process asbestos emissions to the atmosphere while presenting a high potential for water pollution.[2]

ENVIRONMENTAL REGULATIONS AND COMPLIANCE

In addition to MSHA's occupational exposure regulations, the U.S. Environmental Protection Agency (EPA) has promulgated regulations* that require no

---

*National Emission Standards for Hazardous Air Pollutants (NESHAPs) 40 CFR Part 61 Subpart B - National Emission Standard for Asbestos.

visible emissions to be produced from milling or disposal operations, that tailings be wetted before disposal, and that waste be covered with at least 15 cm (6 in.) of soil or with a resinous or petroleum-based dust suppressing agent at least once in a 24-hour period. Inactive sites must be covered with either at least 15 cm (6 in.) of soil and vegetation, or 61 centimeters (2 ft) of soil, or be covered with a resinous or petroleum-based dust suppressing agent. These regulations should greatly reduce the emissions from waste piles which are believed to be the major source of airborne asbestos emissions. However, recent data regarding compliance with the new regulations is currently lacking.

In order to comply with the existing regulations most mills will have had to have applied the best available technology. However, no current information exists regarding the extent to which emission controls are applied or whether the mills are in compliance with the current regulations. The most recent study of the control technology which is used in the mining and milling of asbestos was presented by Harwood[4] in 1974. In his study, Harwood visited five mills, noting emission sources and types of control equipment used. There was only one mill described in his report that could possibly meet the present MSHA and EPA standards. In this mill the ore stockpile was sprayed extensively. All of the milling operations, as well as ore drying and bagging were enclosed and vented to a baghouse filter. Vacuum cleaning was used extensively throughout the work area and dust was visible only in the bagging room. Mill tailings were wetted before being conveyed to the disposal site. In the other mills visited, Harwood found that baghouse filters were used only with hammermills, crushers and screening devices while cyclones were used to control emissions from ore dryers. Spraying of the ore pile and vacuuming were practiced to a limited extent. Ore tailings were transported dry to disposal sites using either enclosed or semienclosed conveyors. Generally no effort was made to control emissions at the disposal site. Visible emissions from the ore drying and the tailing disposal operations were observed. Dust was observed in almost all work areas and was particularly heavy in the bagging room. The extent to which dust control practices and equipment are applied in asbestos mills may have changed significantly since Harwood's study. However, no recent inspection data is available and it is not known to what extent the asbestos mills are in compliance with current MSHA and EPA regulations.

ATMOSPHERIC EMISSIONS FROM MINING AND MILLING

Estimates of atmospheric emissions from the asbestos mining and milling industry for 1974 are given in Table 12. The emission factors shown were estimated using recent emissions data and took into account the air pollution controls used in 1974. The atmospheric emissions for each mill and mine were calculated by multiplying the emission factor by the annual production. The total emissions were estimated to be 373 metric tons from mining and 1039 metric tons from milling. The combined emissions from mining and milling were estimated to be 1,412 metric tons or 67 percent of all atmospheric asbestos emissions generated in 1974. The majority of these emissions are thought to have originated from wind erosion of tailing piles.[8]

TABLE 12. ASBESTOS EMISSIONS TO AIR FROM MINING AND MILLING (1974)[8]

Mine	Annual production (metric tons)	Emission factors (Kg/metric tons)			Total atmospheric emissions (metric tons)		
		Mining	Milling	Total	Mining	Milling	Total
Vermont	36,138	4	9	13	145	325	470
Coalinga[a]	27,104	4	18	22	108	488	596
Union Carbide	31,621	3	5	8	95	158	253
Copperopolis	4,517	4	9	13	18	41	59
Jacquay	2,710	2.5	10	12.5	7	27	54
Total	102,090				373	1039	1412

[a] Atlas Minerals Company has since closed its California Asbestos Mine and Mill.

AMBIENT ASBESTOS FIBER CONCENTRATIONS

Background levels of asbestos vary according to location. Levels of 40 to 100 electron microscope visible fibers per cubic meter were found in a remote area of California.[9] Concentrations of asbestos in urban air have been reported in one study to range from 0 to 2,400 electron microscope visible fibers per cubic meter.[9]

A 1974 field survey of ambient asbestos levels in the vicinity of the Atlas Asbestos Company mill in Coalinga, California, which is now closed, showed 100 million electron microscope visible fibers per cubic meter within 500 meters of the mill tailings pile. Atmospheric concentrations of asbestos 100 meters downwind of an asbestos mill near King City, California were reported to be on the order of 100 million fibers per cubic meter while, perhaps due to unusual wind conditions. Concentrations on the order of 10 million fibers per cubic meter were reported 500 meters upwind from the source. The King City mill is unique in its use of a wet process; it is believed that most of the fibers in the ambient sample originated in the mill's ore pile and tailings dump.[10]

NONOCCUPATIONAL ATMOSPHERIC EXPOSURE

In estimating nonoccupational exposure, Suta and Levine[8] chose radii of 5 km and 30 km to define a population living in an urban environment surrounding asbestos-product manufacturing plants and rural settings around asbestos mines and mills, respectively. Atmospheric asbestos concentration for the rural areas surrounding asbestos mines and mills has been measured at 400,000 fibers* per cubic meter. The average value for urban settings is 25,600 fibers* per cubic meter or only 6 percent of the rural concentration. By assuming that each person inhales 15 cubic meters of air per day,[8] it can be calculated that the average persons living near asbestos mines and mills and those located near asbestos-product manufacturing plants will inhale 2,190 million fibers* and 140 million fibers* annually, respectively.

The rural concentration for mining and milling operations presented by Suta and Levine[8] are based on studies conducted prior to promulgation of the 1975 amendments to the Asbestos NESHAPs regulation. If the mines and mills are in compliance then the current actual nonoccupational exposure may be much less than that reported by Suta and Levine. Disposal problems could presently exist due to the large amounts of tailings disposed and the large area which the disposal site occupies (about 100 acres for a large mill). Chemical dust suppression may be the desired method of erosion control due to the cost and environmental problems associated with covering such a large area with soil.[11] The tailings are generally highly alkaline, making vegetation as a final cover impractical.[11] Maintenance is relatively high on inactive landfills where erosion is controlled by chemical dust-suppressing agents, with reapplication necessary every 1 to 3 years.[12]

---

*Electron microscope visible fibers.

REFERENCES

1. Clifton, R.A. Asbestos. 1980 Minerals Yearbook. U.S. Bureau of Mines, Washington, D.C.

2. Sittig, M. Pollution Control in the Asbestos, Cement, Glass, and Allied Mineral Industries, Noyes Data Corporation, Park Ridge, New Jersey, 1975.

3. Meylan, W.M., P.H. Howard, S.S. Lande, A. Hanchett. Chemical Market Input/Output Analysis of Selected Chemical Substances to Assess Sources of Environmental Contamination: Task III. Asbestos EPA 560/6-78-005. U.S. Environmental Protection Agency. Washington, D.C. August 1978.

4. Harwood, C.F. and T.P. Blaszak. Characterization and Control of Asbestos Emissions From Open Sources, IIT Research Institute, U.S. National Technical Information Service, PB-238-925, September 1974.

5. Schutz, L.A., W. Bang and G. Weeks. Airborne Asbestos Fiber Concentrations in Asbestos Mines and Mills in the United States, U.S. Bureau of Mines Health and Safety Program, Technical Progress Report 72, Denver, Colorado, June 1973.

6. Control Techniques for Asbestos Air Pollutants, AP-117, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, February 1973.

7. Goldfield, J. Fabric Filters in Asbestos Mining and Asbestos Manufacturing, Paper 74-275, Presented at the 67th Annual APCA Meeting, Denver, Colorado, June 9-13, 1974. p. 31.

8. Suta, B.E., and R.J. Levine. Nonoccupational Asbestos Emissions and Exposures, In: Asbestos, Volume 1 Properties, Applications, and Hazards, L. Michaels and S. S. Chissick, eds., John Wiley & Sons, New York, N.Y. 1979, pp. 171-205.

9. Murchio, J.C., W.C. Cooper, and A. DeLeon. Asbestos Fibers in Ambient Air of California. California Air Resources Board, March 1973.

10. Asbestos: An Information Resource, R.J. Levine, ed., DHEW Publication Number (NIH) 79-1681, National Cancer Institute, U.S. Department of Health, Education and Welfare, Public Health Service, National Institutes of Health, Bethesda, Maryland, May 1978, p. 105.

11. Background Information on National Emission Standards for Hazardous Air Pollutants, EPA 450/2-74-009, U.S. Environmental Protection Agency, Research Triangle Park, N.C. October 1974.

12. Ase, P., J. Huff, L. Huff, C.F. Harwood, and D. Destreich. Asbestos Manufacturing Waste Disposal and Utilization, In: Proceedings of the Fifth Mineral Waste Utilization Symposium, Chicago, Illinois, April 13-14, 1976, pp. 308-318.

SECTION 4

ASBESTOS PAPER PRODUCTS

INTRODUCTION

Asbestos paper products are defined in this report to include any product manufactured on a fourdrinier or cylinder papermaking machine. This definition serves to group together products with similar asbestos handling, production and emission control equipment. Such a grouping minimizes the number of product categories and avoids repetition. Asbestos paper products include nine general categories. Listed in their order of descending annual consumption level they are:

- Flooring felt
- Roofing felt
- Beater-add gaskets
- Pipeline wrap
- Millboard and rollboard
- Specialty papers
- Commercial papers
- Electrical insulation
- Beverage and pharmaceutical filters

The U.S. Bureau of Mines estimated the 1980 consumption of asbestos fiber in these paper products to be 90,020* metric tons or 25 percent of all asbestos consumed in the United States.[1] Table 13 shows the approximate percentage use of asbestos fiber in asbestos paper products by subcategories.

---

*This figure was arrived at by rearrangement of Bureau of Mines Data such that paper products could now include roofing and flooring felt figures, which were extrapolated from roofing and flooring product categories respectively.

TABLE 13. ESTIMATED USE OF ASBESTOS FIBER IN PAPER PRODUCTS[2] - 1979

Category	Percent of consumption
Flooring felt	45
Roofing felt	33
Beater-add gaskets	9
Pipeline wrap	5.6
Millboard	3.0
Electrical insulation	0.4
Commercial paper	
General insulation	1.3
Muffler paper	NA
Corrugated paper	NA
Specialty papers	
Cooling tower fill	0.9
Transmission paper	0.4
Chlorine electrolytic diaphragms	1.1
Decorative laminates	NA
Beverage and pharmaceutical filters	0.03

NA = Not available but considered small.

PRODUCT DESCRIPTIONS

Flooring Felt

Composition--

Asbestos flooring felts are composed of about 85 percent asbestos and 15 percent latex binder.[2] The latex binder is normally a styrene-butadiene type, although acrylic latexes have been used in the past.[2] Chrysotile asbestos is used with the shorter fibers, grades 5 through 7 predominating. These grades are normally obtained from Canada although limited quantities are available domestically. The domestic grades are mostly used, however, to make vinyl-asbestos floor tiles in which the asbestos fibers are used as a reinforcing agent for the vinyl and not as a backing (see Floor Tile section).

Uses and Applications--

Most asbestos flooring felt is sold commercially and is used in residential applications. Due to its special qualities, asbestos felt backing is used with vinyl sheet flooring as a general floor surfacing medium. Asbestos backing is particularly useful in prolonging floor life when moisture from below the surface is a problem.

Special Qualities--

Asbestos is used in flooring felts to add dimensional stability and other important properties necessary in flooring such as high moisture, rot, and heat resistance. These qualities have allowed asbestos to successfully compete with previously successful flooring felt materials--organic and jute felt--such that asbestos has now largely replaced them as a backing material.

Roofing Felt

Composition--

Asbestos roofing felts are composed principally of asbestos fibers (85 to 87 percent).[2] Other materials, such as wet and dry strength polymers, kraft fibers, fiberglass, and mineral wool, are also often used as filters. Sheets are saturated with coal tar or asphalt. The paper is made in either single or multilayered grades and may have fiberglass filaments or wire strands embedded between paper layers for reinforcement. Usually grade 6 or 7 chrysotile fiber imported from Canada is used in roofing felt.

Uses and Applications--

Asbestos roofing felt is primarily used for built-up roofing and as an under layer for other roofing products. Built-up roofing is attached to the roof deck by adhesive tars or by nailing if the roof deck can accept nails. There are three basic types of built-up roofing; gravel surface, smooth-surface, and mineral surface.[3] As an underlayer for other roofing products, asbestos roofing paper is attached to the roof deck, again by tar adhesives or by nailing. It is then covered by shingles, cement sheets or other forms of common roofing.

Special Qualities--

Asbestos is used in roofing felts because of its dimensional stability and resistance to rot, fire, and heat. Rot resistance is particularly important due to roofing felt's use on flat or nearly flat roofing with poor drainage. Given the rapid heating and cooling of roof surfaces, felt cracking is a prime concern, particularly in damper climates or in areas where snow, subject to periodic melting, has accumulated on the rooftop. Asbestos felt resists cracking, perhaps better than any competing product.

Beater-add Gaskets

Beater-add gaskets are so named because of the process used in their manufacture: Asbestos fibers and binders are added in the beaters of the papermaking process. Other types of asbestos gaskets, such as compressed sheet gaskets, are not paper products and are discussed elsewhere.

Composition--

Beater-add gasket papers are composed of 60 to 80 percent asbestos fibers and 20 to 40 percent binders, usually latex.[2] The latex polymer used determines the material's suitability for use in water, aqueous solutions, oils, fuels, or chemical environments. Polymers used as binders in addition to latex include natural rubber, various synthetic rubbers, neoprene, nitrile, and other elastomers.

Nearly all domestic beater-add gaskets are formulated with various grades of chrysotile asbestos although in the past, small amounts of crocidolite asbestos were used on customer request since crocidolite is preferable to chrysotile in applications involving strong mineral acids and alkalis. At present, no domestic manufacturers report using crocidolite asbestos in gasket paper.

Uses and Applications--

Gaskets are installed to obtain tight, nonleaking connections in piping and other joints. Asbestos gaskets are used mainly by the automotive industry in a variety of applications, including heat gaskets, carburetor gaskets, manifold gaskets, and oil and transmission gaskets. In addition, asbestos gaskets are widely used in other transportation applications, such as trains, airplanes, and ships. Further, they are used in industrial and commercial equipment of all varieties, including heat exchangers, boilers, furnaces and pipe connections. The chemical industry uses asbestos gaskets extensively for piping, reactor and equipment connections because of the high chemical inertness of asbestos.

Special Qualities--

Asbestos is used in beater-add gaskets because it is not only heat resistant, resilient, and strong, but is also chemically inert which is important for many chemical applications. No other material currently available possesses all of these characteristics for beater-add gasket applications.

Pipeline Wrap

Composition--

Asbestos pipe wrapping papers contain a minimum of 85 percent asbestos, are commonly reinforced with parallel strands of fiberglass for strength, and are saturated with either coal tar or asphalt.[2] They also may contain cellulose and starch binders.

Uses and Applications--

Asbestos pipe wrap protects underground pipelines from corrosion. The wrapping paper is normally attached to the outside circumference of the pipe by machine winding. On occasion, it is attached via hand winding during special field fabrication or damage repairs. The wrap can be attached or bonded to the pipe surface by special adhesive coatings or by hot enamels that are coated onto one side of the paper. The coatings or enamels also aid in the corrosion protection of the pipe.

Special Qualities--

Asbestos paper has been successful as pipeline wrap due to the ability of asbestos to resist soil chemicals, rotting, and decay, while maintaining dimensional stability throughout its lifetime. These qualities are very important for underground pipeline wrap, as well as for the few times that asbestos pipe wrap may be applied above ground.

Millboard and Rollboard

Composition--

Asbestos millboard is composed primarily of asbestos fibers; asbestos content ranges from 68 to 95 percent by weight, with 70 percent considered typical.[4] Group 5 chrysotile fibers are preferred. Binders, which may be starches, elastomers or silicates or, less frequently, glue, cement and gypsum, usually account for 3 to 25 percent by weight. Mineral wool, fiberglass, and cellulose are commonly used as filler.

Insulating board is a specific subcategory of millboard consisting of asbestos with a calcium silicate (lime/silica) binder. In this product, amosite is used instead of chrysotile because it provides a higher degree of reinforcement at low board densities and has favorable drainage properties.

Uses and Applications--

Asbestos millboard is rot-resistant, will stand up to many corrosive gases and liquids, and is fire and temperature resistant. This makes millboard particularly important as a lining in floors, partitions, ceilings and fire doors, and as an insulating barrier in stoves, ovens, and heated appliances. It has important uses in metal and chemical industries as well. Table 14 illustrates industry applications.

TABLE 14. INDUSTRIES USING ASBESTOS MILLBOARD AND INDIVIDUAL APPLICATIONS[5]

Industry	Application
Electrical	Thermal protection in large circuit breakers
Appliance	Fireproofing agent for commercial and home security boxes, safes, and files
Aluminum	Pouring trough cover and trough liner
Marine, shipyard, aircraft	Liner for container that catches hot metal from cutting operations
Foundry	Trough liner and iron trough cover
Steel	Backup insulation for furnace lining
Metallurgical	Used between the hot mandrel and the bearing shell in molten babbit operation
Ceramic	Low mass kiln cars
Glass	As insulation in glass tank crowns, melter, refiner, sidewalls, etc.

Special Qualities--

Millboard varieties differ in their ability to withstand elevated temperatures: standard millboard is good to 427°C and high quality millboard is rated to 538°C. Above 566°C even high quality millboard becomes brittle.

Rollboard differs from millboard in that it is thin enough to permit flexibility. Consequently, rollboard cannot survive elevated temperatures. Rollboard is also relatively thin which contributes to its low upper temperature limit, 177°C.

Electrical Insulation

Composition--

The composition of asbestos electrical insulation paper varies with the intended application but generally contains chrysotile asbestos fibers and cellulose bound with latex polymers. Small amounts of amosite and tremolite are also used occasionally.

Electrical insulation is frequently impregnated with solid resins to increase dielectric strength, improve mechanical properties and provide moisture-proofing characteristics offsetting the hygroscopic property of asbestos fiber. Depending upon the expected temperature of service, resin-bonded papers or boards may use phenol, formaldehyde, polyvinyl acetal, epoxy, or silicone resins. Glass or other fibers may also be present.[6]

Uses and Applications--

Asbestos is used in the electrical industry in the form of paper, tape, cloth and board. It may be applied as a felted material or as a filler for natural and synthetic insulating resins. The largest use of asbestos electrical paper is as insulation for dry transformers, for layer insulation, layer barriers, core barrier tubes, general conductor wraps, lead insulation, and cross-over insulation.[7,8]

Appliances that use asbestos papers for wire insulation include stoves and toasters. The extent to which asbestos paper is currently used for these applications is not clear, but use has dropped significantly due to manufacturer concern and the increased availability of substitutes.

Special Qualities--

Asbestos is used in electrical paper insulation because of its high thermal and electrical resistance, which permits the paper to act effectively as an insulator and protects the conductor from fire.[9]

Commercial Paper

Composition--

The commercial asbestos paper category encompasses a broad range of papers that differ primarily in weight and thickness. The product is normally composed of 95 to 98 weight percent asbestos fiber and 2 to 5 weight percent starch binder.[2] Short and medium grades of chrysotile are used.

Muffler paper contains a very high percentage of asbestos fiber and only a small percentage of starch binder. The surface of the product is waffled or indented.

Corrugated asbestos paper is a commercial paper product corrugated and cemented to a flat paper backing, sometimes laminated with aluminum foil. Corrugated paper is manufactured with a high chryotile asbestos content and a starch binder.

Uses and Applications--

General asbestos insulation papers are used in steel and aluminum factories for thermal insulation in annealing furnaces, trough lining for smelting process, and refractory lining.

Muffler paper is used by the automotive industry primarily in the construction of catalytic converters for exhaust emissions control systems. The paper is applied as a wrap between the inner and outer skins of the converter or muffler.

Corrugated asbestos paper is used as a thermal insulator for pipe covering, block insulation, and specialty panelings. Applications of corrugated asbestos paper include appliance insulation up to 150°C, hot-water and low-pressure steam pipe insulation, process line insulation, and panel insulation, such as paneling in elevators.

It should be noted that a large portion of the commercial paper produced is sold to distributors and/or converters who, in turn, sell to their customers. Thus, due to the large number of people involved in the production and conversion process, it is nearly impossible to identify all of the specific end uses which might arise in the production and conversion process.

Special Qualities--

Asbestos is used in commercial papers because of its resistance to fire and corrosion. It provides commercial papers with the strength and durability needed for numerous applications.

Specialty Papers

There are six major classes of asbestos specialty papers:

- Cooling tower fill
- Transmission papers
- Beverage and pharmaceutical filters
- Electrolytic diaphragms
- Decorative laminates
- Metal linings

Composition--

The base for cooling tower fill consists of a blend of two grades of chrysotile asbestos bound with DuPont neoprene latex; the content is 90 to 91 percent asbestos and 9 to 10 percent binder.[10] Asbestos transmission paper is a latex-bound product currently made with chrysotile asbestos. Electrolytic diaphragms are made from mixing asbestos fibers and water to form a slurry. Decorative laminates are produced by impregnating asbestos electrical paper with thermosetting resins and then fusing multiple layers together at high temperature and pressure. They are asbestos paper that is formed in thin, rigid sheets and then colored or patterned accordingly. They contain asbestos and a phenolic or melamine resin. Industrial laminates consist basically of asbestos fibers, combined to make electric paper with thermosetting resins added.

Metal lining paper is manufactured like commercial asbestos paper except that the metal lining paper contains a higher percentage of binder and a small percentage of clay.

Uses and Applications--

The major use of asbestos fill in cooling towers is in applications where high heat resistance is necessary. One such application is in gaseous diffusion as performed at the governmental facilities in Oak Ridge. The Munters Corporation produces a fill, "Asbedek," used mainly in mechanical draft towers.

Automobiles equipped with automatic transmissions get their drive from metal transmission disks covered with a super-tough asbestos paper.[11] Four-, six-, and eight-cylinder autos with power shift contain from 8 to 12 of these paper-lined disks.

Asbestos beverage filter paper is used by beer, wine and liquor distilling industries to remove microorganisms and fine solids from the liquid medium. Pharmaceutical and cosmetic industries use the paper as well.

Asbestos is used as a diaphragm in production of chlorine via brine electrolysis. Asbestos paper sheets were used in diaphragm cells through the 1930s and 1940s but now almost all diaphragm cells made with asbestos use a slurry[12] of water mixed with asbestos, rather than as a paper. The slurry is vacuum-deposited onto a cathode pole, and the diaphragm is built-up inside the electrolysis cell.

Decorative laminates can be bonded to plywood, fiberboard, or metals and can be sawed, drilled, or sanded with conventional woodworking equipment. Decorative laminates appear generally in wall or ceiling paneling, desk tops, counter tops, and worktable tops. Asbestos is only one of many materials from which decorative laminates can be made; the bulk of decorative laminates are made with kraft papers. Industrial laminates are used for telephone switchboard construction, television circuit boards, and other electronic applications. Tube and rod laminate can also be used as core or winding barriers for such equipment. The sheets can also be stamped or fabricated into specialty spacers or washers.

Metal lining paper is used as a corrosion-resistant liner for both metal sidings and culvert pipe. Culvert pipe is in turn used for landfill drainage and water treatment applications.

Special Qualities--

Asbestos is used in specialty papers primarily due to its chemical and heat resistant properties.

Asbestos is used in cooling tower fill for its heat and chemical resistance. In applications where high heat resistance is necessary, asbestos paper will continue to be used, because of its proven durability and heat resistant qualities. Extensive government testing at governmental facilities at Oak Ridge[13] found asbestos fill (Asbesdek) superior in performance to alternatives.

Asbestos is used in transmission papers for its excellent friction characteristics and oil resistance as, during use, the paper-lined disks are normally coated with transmission oil. Asbestos has been found to be durable in this application.

For beverage and pharmaceutical filters, asbestos represents a mineral medium that does not degrade or otherwise affect liquid quality while acting as a suitable filter. In the electrolytic diaphragm, it provides strength and the appropriate properties needed for manufacturing this product. In the electrolytic process, cathode surfaces are generally lined with a layer of asbestos either in the form of paper or as vacuum-deposited fibers.[14] The asbestos maintains the caustic strength and minimizes the diffusional migration of hydroxyl ions. All diaphragms gradually clog with residual impuritioes in the brine and particles of graphite from the anode, and therefore must be renewed at regular intervals (approximately every 100 days).[15]

High-pressure industrial laminates are a significantly more durable form of the decorative product. Asbestos is no longer being used in any significant quantity in making decorative laminates.[16] Asbestos paper was used to produce a special fire-retardant decorative laminate; fire retardant laminates are used for interior surfacing and paneling public buildings, buses, railcars, and ships requiring a Class 1 fire-resistant rating.[17] Decorative laminates are thin, rigid sheet materials that have been resin-saturated to press the layers together. They are faced with decorative colors or patterns and characterized by showing resistance to damage from scuffing or scratching.[16] Industrial laminates are sheets produced from asbestos electrical paper fused at high temperatures. Asbestos electrical paper is used here to allow for effective insulation and to protect the conductor from fire.

Asbestos is used in metal lining paper to provide corrosion-resistance and strength.

Beverage and Pharmaceutical Filters

Composition--

The major difference between asbestos beverage filters and other asbestos paper products is the formula.

Asbestos beverage filters may contain, in addition to asbestos, cellulose fibers, various types of latex resins and, occasionally, diatomaceous earth. The asbestos content varies from a high of 50 percent for pharmaceutical filters to as low as 5 percent for rough filtering applications. In general, the higher the asbestos content, the better the filtering qualities. The grade of asbestos used is a very high-purity grade (longer fiber; thus in the lower grade numbers) obtained, when available, from Arizona mines; a usable grade is also available from Canada. This particular high-purity grade of crystotile must be free of trace minerals such as iron and calcium.

Uses and Applications--

Asbestos filter sheets are primarily used by the beer, wine, and liquor distilling industries to filter (remove) microorganisms, fine, or very fine solids from liquids. In the beverage industry, there are several filtration steps; asbestos filter papers have most commonly been applied for "sterile" filtration, the complete removal of all yeast cells and microorganisms, both aerobic and anaerobic, that might have survived previous filtration.[18] Asbestos filters are also used for haze clarification, removing cloudiness from the liquid product and giving it a sparkling clarity.

At present, about 30 percent of the wine industry, 10 percent of the beer industry, and 25 percent of the distilling industry use some form of asbestos filtration.[19] Asbestos filter paper is also used for specialty applications in the cosmetics and pharmaceuticals industries and for the filtration of various fruit juices, such as apple juice.

Special Qualities--

Asbestos is used in filters because it has an exceptionally large surface area per unit of weight and a very unusual natural positive electrical charge. This positive charge is very desirable for removing particles from beverages as the particles are usually negatively charged. Although other substances may be used as filter materials, asbestos appears to provide one property required by some beverage manufacturers which its competitors lack--that of the removal of haze from liquid beverages. The filtering efficiency of non-asbestos sheets is considered about equal to that of asbestos, aside from haze removal capabilities. Substitutes for asbestos filters are readily available and will likely undergo further improvements as they are developed. As far as is known, substitutes seem to equal asbestos in durability and service life.

SUBSTITUTES

Asbestos is used in paper products for the variety of qualities it imparts to the product. Qualities such as dimensional stability, resilience, thermal and electrical resistance, strength, and overall resistance to moisture, fire, decay, rot and chemicals make asbestos a unique yet vital raw ingredient to the paper product categories previously described. Individual paper products use some or all of these qualities and the ability of a substitute to replace asbestos depends on the degree to which it can replace one or more of these specific qualities. Substitutes may occur in two forms: as a fiber substitute in which the asbestos fiber is replaced in the manufacture of the paper product, or as a completely different asbestos-free material which attempts to duplicate some or all of the characteristics of the original asbestos product. The commercial availability of either or both substitute forms for each paper product category will be subsequently discussed.

Potential fiber substitutes in asbestos flooring felt that have been studied include fiberglass, cellulose, Nomex, and other polymeric fibers. However, at present none of these have been found to be an acceptable substitute for asbestos. Material substitutes however are available which replace the need for asbestos felt backing in vinyl floors, either by providing a complete covering in and of itself as in carpeting, wood floors and "place and press" vinyl tile squares, or by providing another type of backing as in foam-cushioned backings, and even backless sheet vinyl. The choice between carpeting, wood floors and vinyl tile squares is usually made by customer preference. Foam cushioned backings are formed by attaching a cellulose foam layer to sheet vinyl surfacing. "Backless" sheet vinyl is actually a sheet flooring with a special vinyl backing which allows the floor to stretch and contract. Both of these products are actively competing with asbestos backing today. In addition, a flooring system "sandwich" consisting of a vinyl surface, a foam cushion midsection, and an elastic vinyl backing is also being produced, and it is expected to provide increased competition for asbestos flooring felt in the future.

Alternates to asbestos roofing felt include organic felt, fiberglass felt and a rubberized single-ply membrane roofing system. Organic felts and fiberglass felts, like asbestos roofing felts, are saturated with coal tar or asphalt before use. Organic felts, though the least durable are the most widely used as they are the lowest in cost. Fiberglass is stronger, more durable, longer wearing and more heat resistant than organic felt, but according to some, because the material is so new, conversion will require both manufacturing experience and applicator training.[20] Single-ply membrane roofing is applied to the roof deck cold, an important attribute when city ordinances or other considerations prohibit hot tar. Single-ply membrane systems are roughly 5 to 10 percent more expensive than asbestos, however they are relatively new and their durability is yet to be proven. Finally, Johns-Manville produces the GlasPly built-up roofing system which utilizes asphalt-impregnated fiberglass ply felts. This system requires less mopping asphalt than other systems because more asphalt is impregnated during manufacturing.[21]

Three basic alternatives to asbestos beater-add gaskets exist: ceramic paper, Teflon, and all-metal products. Silicone rubber is also a potential substitute, as it is serviceable to 316°C; however, its applications are limited because it cannot be used in the presence of certain oils and fluids. Ceramic paper has the heat resistance of asbestos, but is not particularly resilient and is deteriorated by oil,[5] effectively eliminating it from possible use in automobile gaskets. Ceramic paper does have good resistance to some chemicals and in some high temperature applications has been shown to outlast asbestos. For example, ceramics have been used in place of crocidolite asbestos paper as a layering paper in sulfuric acid production.[22] Fiberfrax paper, composed of ceramic fibers, inert fillers, and organic bonding agents can be used as a direct substitute for some asbestos gaskets.[23]

Teflon is not a resilient, rubbery material as is asbestos; rather it is plastic, tending to deform and flow under loads. Due to its nonsticking properties, Teflon is difficult to retain in joints so it is commonly used with an asbestos paper filler.

As with Teflon, all-metal gaskets are not resilient but are useable in limited applications. Because of the lack of resilience, all-metal gaskets cannot be substituted directly in most automotive applications.

Saturated fiberglass is becoming more and more competitive with asbestos in pipe protection because it has many of the characteristic advantages of asbestos. A comparison of the pipeline protection of fiberglass versus asbestos is very similar to the discussion of fiberglass roofing felt versus asbestos roofing felt. Fiberglass is more dimensionally stable, rot resistant, and stronger than organic materials, yet asbestos still enjoys slight advantages in these qualities. Asbestos also has a better fire rating than fiberglass. Fiberglass has the advantage of requiring less asphalt saturation than asbestos and, given the escalating cost of petroleum products, this may mean a lower cost.

In addition to fiber replacement in pipeline wrap, there are a variety of asbestos-free coating materials which are potential substitutes. These include enamels, extruded plastics (polythylene and polypropylene), fusion bonded thermosetting powder resins, liquid epoxy and phenolics, tapes, wax coatings, polyurethane foam insulations and concrete.

Several of these materials have been available for years while others have been introduced fairly recently. Although wax coatings, polyurethane foam insulations and concrete may be used in only special situations, other coatings, such as extruded plastics, provide excellent moisture, rot, and chemical resistance as well as strength and therefore can be used in most general applications.

Plastic tapes, although not adapted for use as pipeline wrap to date, display excellent moisture resistance. However, some can be attacked by various soil chemicals (depending upon application). Research in this area may be applicable in the future if the use of plastic in pipe wraps looks viable as an alternative, as plastic has been used in this area in the past.

The principal substitutes for asbestos millboard and rollboard are fiberglass, mineral wool, and alumina silicate (ceramic) boards, although vermiculite compositions have also been successfully employed. These product substitutes are manufactured by several companies, including Carborundum, Johns-Manville, Babcock and Wilcox, and Pars Manufacturing Company. These substitutes generally have equal or superior insulating qualities relative to asbestos but most have significantly higher prices.

Substitute products currently available for electrical and thermal insulation include DuPont's Nomex Paper, Carborundum Corporation's Ceramic Fiberfrax® Paper, Manning Paper's Manninglass, and Masonite's Benelex 402. Nomex is an aramid paper composed mostly (85 percent) of a highly aromatic polyamide synthetic material.[24] Polyamides as well as polyethersulphone are high temperature polymeric materials which have insulating qualities similar to asbestos. Fiberfrax® is a homogeneous product composed primarily of silica and alumina held together with an organic binder.[25] It is a paper that exhibits good dielectric strength, is somewhat stiff and can be cut and handled easily. Manninglass is a glass fabric. Like most glass fabrics, when wrapped tightly onto wire and treated with resins, it is more vulnerable to abrasion than most other wire coverings and is not suited for applications requiring severe flexing. Benelex 402 is a dense lignin-resin cellulose laminate. It is able to withstand abrasive action, acidic conditions and steam cleaning.[26]

Substitutes which may be used in place of asbestos commercial paper include ceramic, cellulose and fiberglass products. Applications vary, and those products demonstrating high temperature resistance appear to lack the ability to couple this with sustained strength. Ceramic paper can be used at higher temperatures than asbestos; however it has not been proven to be as strong or as resilient as asbestos paper. Cellulose and fiberglass papers generally lack the heat resistance and dimensional stability required for heat and flame resistance.

Substitutes for specialty papers include:

Specialty paper	Substitute product
cooling tower fill	polyvinyl and polypropylene plastics cellulose aluminum steel
transmission paper	none, but research and development currently underway in this area
beverage and pharmaceutical filters	cellulose and glass fibers
electrolytic diaphragms	Nafion membrane cell PTFE
laminates	chemically treated papers glass and ceramic papers kraft papers
metal linings paper	versicore

Asbestos-cement sheet use as cooling tower fill is rapidly decreasing due to its potential for wear and fiber release under extreme conditions. A wide variety of substitute materials are currently available for cooling tower fill including polyvinyl and polypropylene plastics, cellulose, aluminum, and steel.[10,13] Metal substitutes are more durable; fire resistant metal laminates are economical and are now on the marketplace. Fill substitutes must be chemical resistant as well as flame resistant.

No substitutes for asbestos transmission-paper appear to be available. For most applications any of the materials mentioned for cooling tower fill substitutes are adequate. An alternative to asbestos electrolytic diaphragms is DuPont's Nafion membrane mentioned previously. It consists of a film of perfluorosulfonic acid resin (copolymer of tetrafluoroethylene) and another monomer to which negative sulfonic acid groups are attached. Promising results have also been obtained with a two-layer diaphragm polypropylene-(PTFE). This cell has a resistance inside the electrolysis cell which is comparable to that of asbestos. Tests carried out over a period of 1100 hours did not show significant deterioration.

Economical, fire-resistant laminates that use chemically treated papers as a laminated substrate and/or laminating resins containing flame-resistant chemicals are available. Also, glass and ceramic paper substrates are used when the extra cost is acceptable. For decorative laminates, asbestos papers have been replaced by Kraft papers.

As for metal linings, H. H. Robertson Co. has produced "Versicore," which is manufactured in the same manner as their Galbestos sheetsiding which contains asbestos paper, except that the asbestos paper lining is replaced with a 3 mil thick layer of epoxy resin. Various types of specially painted sheets can also be used as a siding substitute for Galbestos.

Substitute fibers which may be used in place of asbestos fibers in filters include cellulose and glass. According to industry sources, these nonasbestos substitutes have the durability of asbestos filters, but above grade 70 (an indication of filter porosity), asbestos filters are more efficient.[27,28]

MANUFACTURING

Paper products are all made in similar processes, which can be represented by the schematic diagram in Figure 2. Individual products may be the result of additional manufacturing steps, as with roofing felt; the consequence of different forming, as with millboard; or the outcome of varying raw materials, as with specialty paper. By adjusting the percentages and types of asbestos fibers, binders, and fillers, different semifinished products are formed. Secondary processing, molding, cutting, or bonding is usually required to attain the final product.

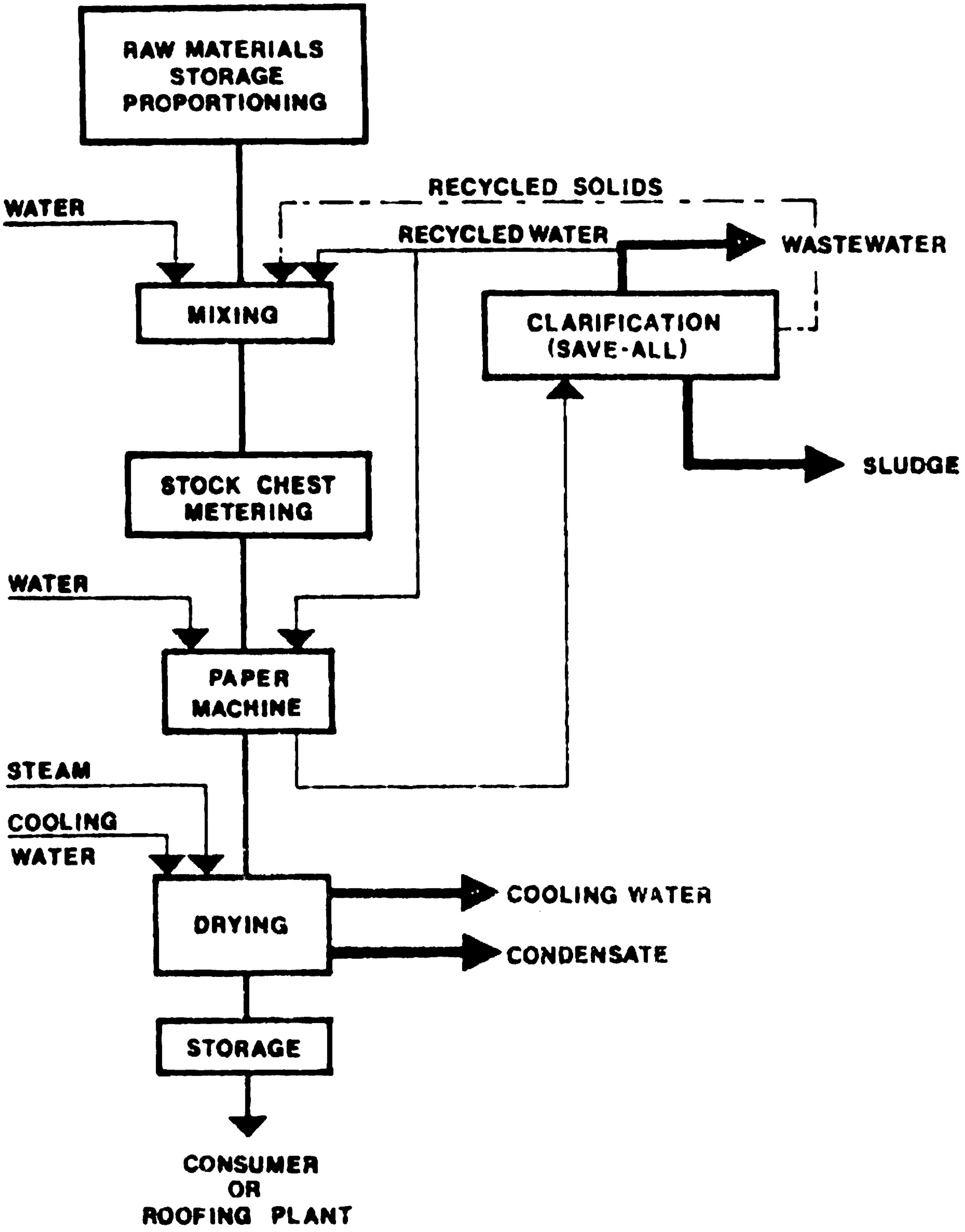


Figure 2. Asbestos paper manufacturing operations.[4]

Primary Manufacture

The sequence of manufacturing steps is described for all products except millboard/rollboard and beverage filters. This description is then followed by a description of the unique features of millboard/rollboard and beverage filter manufacture.

Raw Materials--

Asbestos paper generally contains from 70 to 95 percent asbestos by weight with binders adding from 3 to 15 percent weight, and fillers making up the remainder. A mixture of short chrysotile fibers, predominantly grades 5 through 7, forms the basis for the sheet. Starches, latex, corn gum, glue, and cement are typical binders while cellulose fibers, rubber, clay, and rock wool may be used as filler.

The exact formula of any product is frequently specified by the purchaser to ensure that desired product qualities are obtained. In addition to varying the percentage of asbestos in the final product, fillers and binders such as mineral wool and fiberglass can be included to provide specific properties in the final sheet.

Material Receiving--

Most manufacturers receive asbestos by rail in bundles of 25 or 50 100-pound bags, bound together by a small amount of glue to minimize shifting during shipping and slippage during handling. Bundles may be plastic stretch-wrapped or shrink-wrapped to minimize fiber release and bag breakage. This concept is relatively new and has only come into common use in the last 2 years. At this time wrapping is a customer option.

Forklift trucks are used to unload the asbestos bundles into storage. Other materials, such as wood pulp, rags, paper, and broke are commonly stored in the same area.

Mixing--

In the mixing step, asbestos fibers are combined with water, binders and fillers in a hydrapulper or beater. Depending on the product to be manufactured, the asbestos may be dumped into the mixer in its original triple-wall Kraft paper bag. For other products incapable of accepting organic material, the bags are opened, emptied into the mixer, and disposed of in a sanitary landfill.

After mixing, the slurry may be pumped through Jordan refiners, turbine-like pieces of equipment that break down fibers and fiber clumps. At this stage in the process, the stock typically contains about 3 percent fiber. The stock will be further diluted to nearly 1/2 percent solids before being applied to the machine.

Paper Machines--

Two types of paper machines are used to manufacture asbestos paper: Fourdrinier machines and cylinder machines. The difference occurs at the machine's wet end, when the dilute slurry is formed into a paper sheet.

A Fourdrinier machine feeds a thin layer of refined stock onto an endless moving wire screen. As the stock is carried away from the point of application, water in the stock passes through the wire mesh, leaving a moist paper sheet behind. In a cyclinder machine, stock is pumped into a vat containing a screen-surfaced cylinder. As the cylinder rotates, a thin coating of fibers collects on its surface while water drains through the screen. The fiber coating is then transferred to a carrier felt moving across the top of the cylinder. Depending on the desired thickness of the end product, one or more cylinders may be required. The moving felt presses the damp layers together as it passes over each successive cylinder, forming one damp sheet.

After the formulation stage, the two machine types are similar. Vacuum boxes pull water out, and nip rolls squeeze out moisture until the sheet is strong enough to leave the supporting felt and pass over a series of steam-heated dryer rolls. As a final step, the sheet is "calendered" by passing between two pressure rollers, producing a smooth surface.

Some paper products require no further processing other than trimming, additional calendering or cutting to size. Of the nine product categories, five fall into this category: commercial paper, flooring carrier, electrical insulation paper, beater-add gasketing paper, and specialty paper.

Saturation--

Two product categories undergo a second processing step, asphalt saturation. Both roofing felt and pipeline wrap are made as described above, but pipeline wrap has glass fiber strands running lengthwise for strength. Hundreds of bobbins feed a string-like glass into the wrap at some point in the forming stage such that they are placed in the center of the product's thickness.

In the saturation step, diagrammed schematically in Figure 3, the paper roll is unwound and passed through a bath of hot asphalt or coal tar until it is thoroughly saturated. It may then pass over hot rollers to seal the asphalt into the paper, followed by cold rollers to smooth the surface. Cooling water may be sprayed directly onto the paper surface or a coating may be added to keep layers from sticking when the material is rolled and packaged. In some plants saturation is not a separate process but instead is the last step on the paper machine.

Millboard and Rollboard--

Millboard production is in general similar to papermaking, but has a number of important differences. Asbestos, binders and fillers, which vary between manufacturers, are mixed with water to form a slurry. Millboard may contain from 5 to 40 percent portland cement and starch. As binders, clay, lime and mineral wool are used as fillers, particularly in applications not exposed to high temperatures. The final product may contain from 70 to 95 percent asbestos by weight.

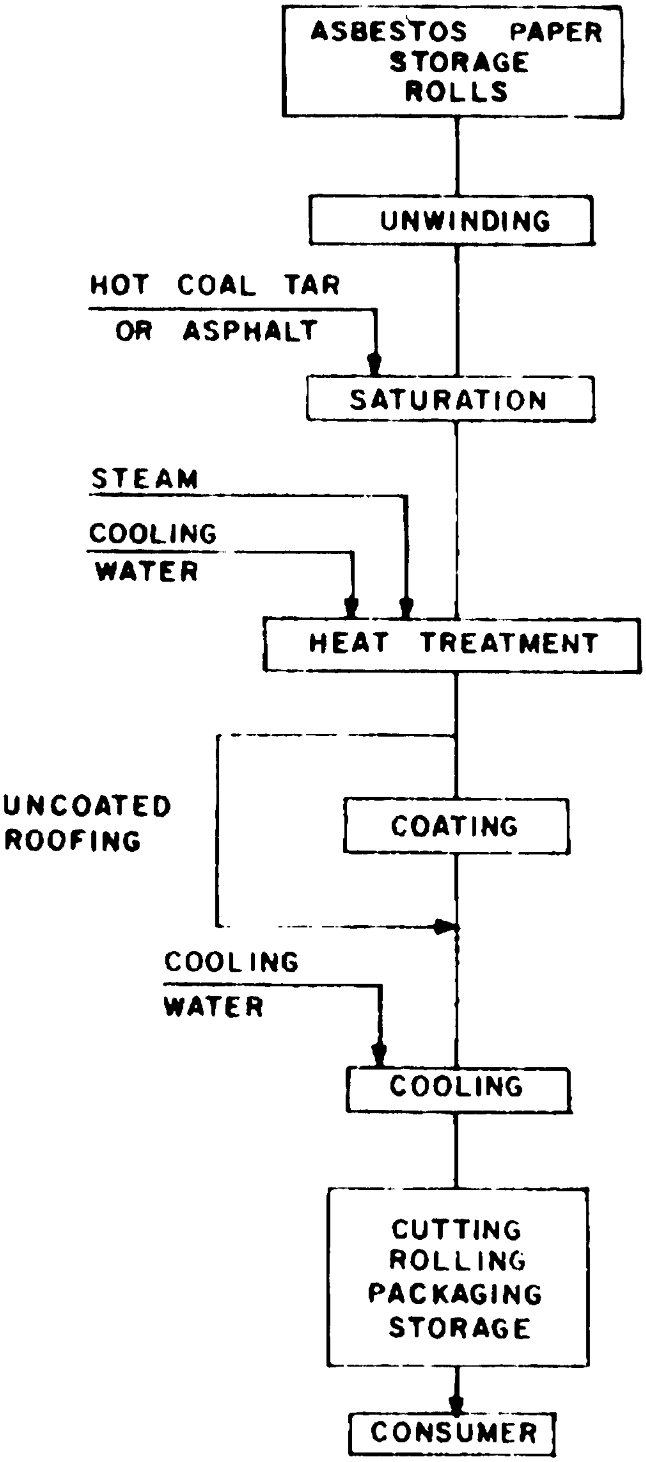


Figure 3. Asbestos paper saturation.[4]

The slurry is pumped to a vat where a rotating cylinder picks up a thin coating of the mixture, in the same way that a cylinder paper machine picks up paper stock. The thin sheet is drawn through a press for partial dewatering, then wound continuously on a roller until the desired thickness is obtained. The machine stops as workers cut the material built up on the roller lengthwise, removing one thick sheet of damp millboard. Since the material is still moist, individual layers adhere to each other in one thick sheet instead of separating into thin, distinct sheets like those formed on a paper machine. The forming process takes about 1 minute per sheet. Wet sheets go through a heat curing step before being trimmed to standard sizes. The process is schematically diagrammed in Figure 4.

Rollboard is a special type of asbestos paper with many of the same applications as millboard. Rolls of 1.59 mm (1/16-inch) thick paper are bonded together with sodium silicate to form a two-ply sheet, 3.18 mm (1/8-inch) thick. Rollboard gets its name because it is sold in rolls, like roofing felt.

Beverage Filters--

Asbestos beverage filters are made on a conventional cylinder or Fourdrinier paper machine. Because demand for this product is low, the machine is only used to produce beverage filters infrequently; for the most part, the machine is employed to produce more popular products.

The major difference between asbestos beverage filters and other asbestos paper products is the formula. Asbestos beverage filters may contain from 5 to 50 percent asbestos by weight, with diatomaceous earth, organic fiber, and resins making up the remainder of the filter.

Manufacturing Plants

At present in the United States there are a limited number of manufacturers of asbestos paper products. The major companies have generally broad product lines, producing several types of paper products. A plant will usually produce a given product continuously for a period of time until demand for that product is satisfied, then switch to the production of another product. With the top five manufacturers accounting for more than 80 percent of total production, the market can be characterized as highly concentrated.[2]

In Table 15 the principal manufacturers of asbestos paper products are shown. The table also includes most plants, locations, capacities in tons/day, type of papermaking machines, and paper products made.

There are two major producers of flooring felt: Armstrong Cork and Congoleum Industries. Nicolet Industries of Ambler, Pennsylvania, and Brown Company of Berlin, New Hampshire, made asbestos flooring felt in the past, but terminated their production in 1980 and the mid-1970s, respectively.[46,47] GAF Corporation formerly manufactured asbestos flooring felt in Erie, Pennsylvania, but announced a commitment to end sales of asbestos paper products effective April 1, 1980.[48]

There are two major domestic manufacturers of asbestos roofing felt: Nicolet Industries and Celotex Corporation. The plants listed make base

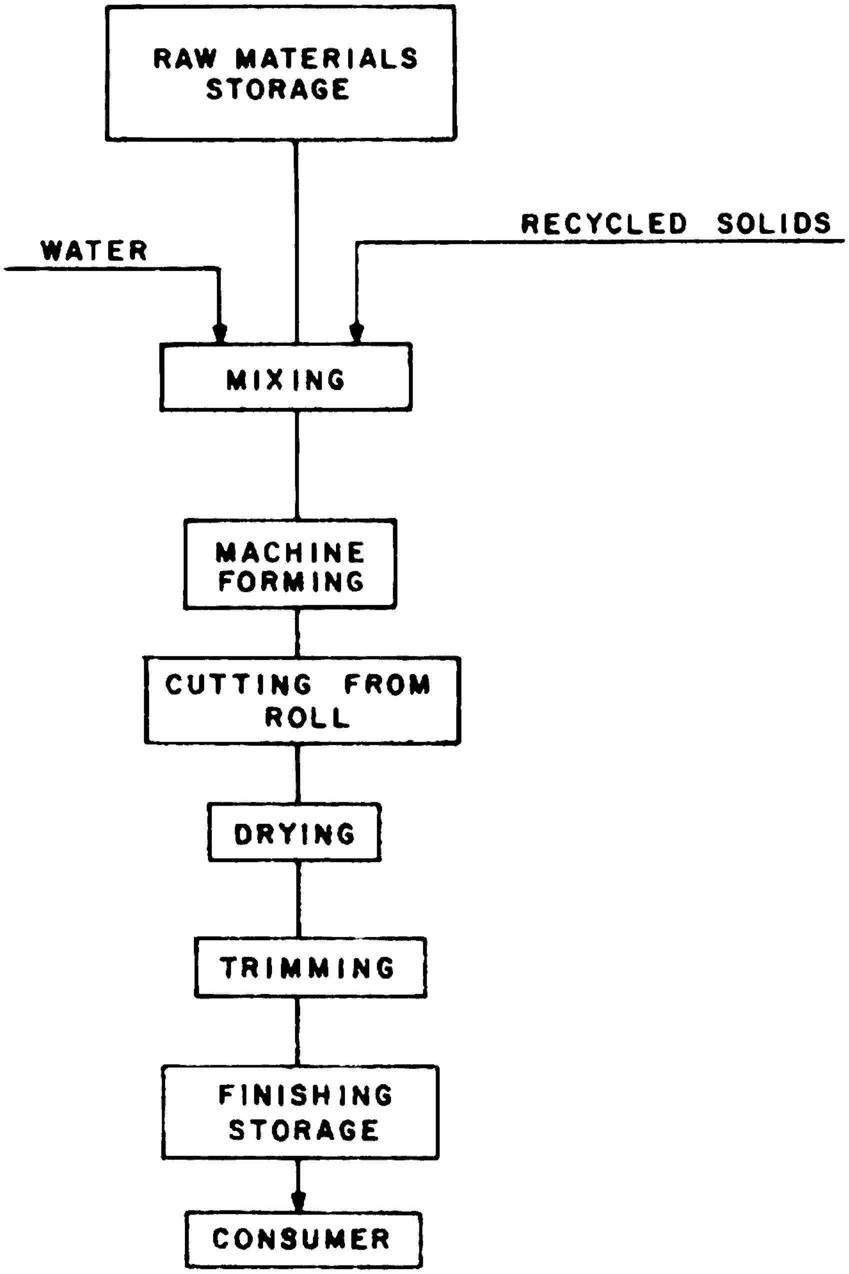


Figure 4. Asbestos millboard manufacture.[4]

TABLE 15. PRINCIPAL MANUFACTURERS OF ASBESTOS PAPER[4,29-46]

Company	Plant location	Plant capacity (ton/day)	Machinery	Paper product mix
Alsop Engineering	Milldale, CT	-	-	Beverage and pharmaceutical filters
Armstrong Cork	Fulton, NY	260	1 single cylinder, width 146 in. 2 fourdrinier, width 88 and 162 in.	Flooring felt, gaskets
Boise Cascade	Beaver Falls, NY	-	-	Gasket papers
Celotex Corporation, a Subsidiary of Jim Walter Co.	Lockland, OH	200	3 single cylinder and 1 six cylinder - width varies from 72 to 114 in., 1 millboard	Roofing felt, pipeline wrap millboard, rollboard, commercial paper specialty paper
	Linden, NJ	100	1 single cylinder, width 136 in.	Roofing felt, commercial paper
Cellulo	Fresno, CA Sandusky, OH	- -	- -	Beverage and pharmaceutical filters
Colonial Fiber Company	Covington, TN Rochester, NH			Gasket papers, specialty paper Specialty paper
Congoleum Industries	Cedarhurst, MD	260	2 single cylinder, width 120 and 168 in., 2 fourdrinier, width 120 and 204 in.	Flooring felt
Ertel Engineering	Kingston, NY	-	-	Beverage and pharmaceutical filters
Filter Products Co. (H&K Filters)	Richmond, CA	-	-	Beverage and pharmaceutical filters
Hollingsworth & Vose	East Walpole, MA	45	1 six cylinder, width 120 in. 1 fourdrinier, width 94 in.	Gasket papers
Johns-Manville	Manville, NJ	150	2 five cylinder, width 80 in. 1 single cylinder	Gasket papers, pipeline wrap, specialty paper
	Waukegan, IL	-	1 six cylinder, width 72 in.	millboard, rollboard, specialty paper
Nicolet Industries	Ambler, PA	50	1 four cylinder, width 80 in. 2 double cylinder, width 50 and 52 in.	Roofing felt, pipeline wrap commercial paper, specialty paper
Quin-T-Corp.	Tilton, NH	-	-	Millboard, rollboard, electrical insulation
Rogers, Corp.	Rogers, CT	-	-	Gaskets

felt which is later saturated with asphalt. Saturation plants are not necessarily located at the sites where the base felts are made; manufacturers of base felts may have a number of saturation plants.

Domestic manufacturers of beater-add gaskets include Armstrong Cork, Hollingsworth & Vose, Boise Cascade, Colonial Fiber Company, Johns-Manville, and the Rogers Corporation.[39-41] Most gasket paper produced is sold to fabricators who make the final consumer product. The 1978 edition of the Thomas Register lists almost 200 fabricators of asbestos gaskets, but this includes fabricators working with compressed sheet gaskets in addition to those working with beater-add gaskets.

Manufacturers of asbestos pipe wrap include Nicolet Industries, Johns-Manville and Celotex.[40,42] Nicolet is reported to be a much larger producer of this product than is Celotex.[30]

Celotex, Johns-Manville and Quin-T Corp. manufacture asbestos millboard.[40,44,45] GAF discontinued production of asbestos paper and rollboard as of April 1, 1980.[43,48] Nicolet has closed their Morristown, Pa., plant but may still manufacture millboard elsewhere.[44,46]

Asbestos paper for electrical insulation is currently manufactured by the Quin-T Corporation, formerly owned and operated by Johns-Manville. Manning Paper and Nicolet Industries, which made insulation paper in the past, no longer produce asbestos paper.[44,49]

Commercial paper is manufactured in the United States by Nicolet Industries and Celotex. Johns-Manville discontinued the manufacture of commercial paper in April 1980.[50] Commercial asbestos paper is normally sold by the manufacturer to independent distributors, converters and some original equipment manufacturers. There are about 300 distributors and/or converter companies in the U.S.[29]

The principal specialty paper manufacturers are Johns-Manville, Nicolet Industries, Celotex Corporation and Colonial Fiber Company. They, in turn, sell it to a wide variety of secondary manufacturers which use it to produce consumer and industrial products.

ASBESTOS RELEASE

This section briefly summarizes the papermaking process, discusses the asbestos content of asbestos paper products and reports estimates of workplace fiber levels. Estimates of ambient fiber concentrations near manufacturing plants are also reported.

Emissions of asbestos fibers during production of the nine product categories may differ based on product friability, volumes produced, and plant size. The nature of the actual production processes are very similar. Variations in emissions among plants manufacturing the same or similar products may be a result of the type of control equipment, control practices, and general cleanliness within the plant.

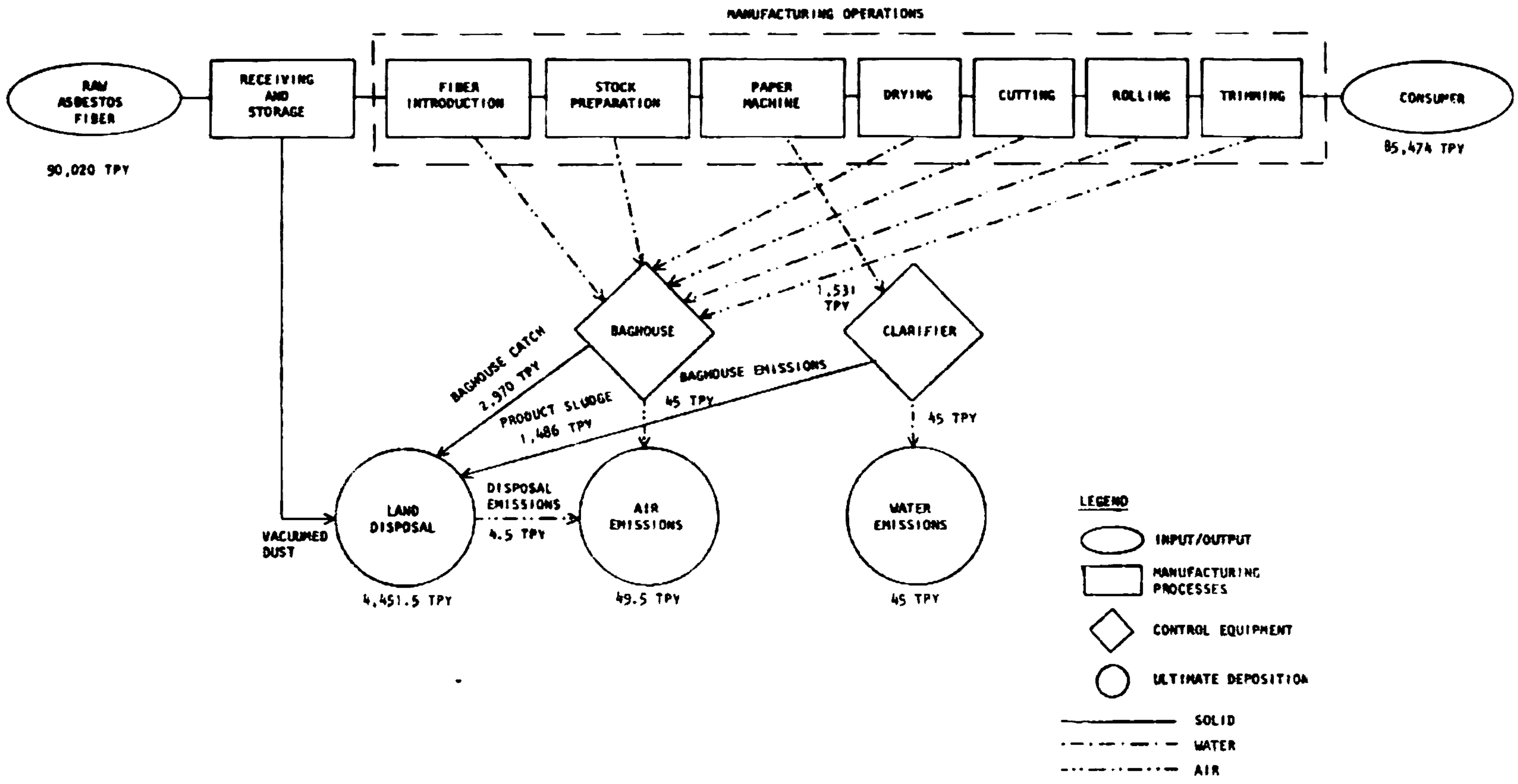
Asbestos paper is essentially made by the same process used for organic paper. Briefly, papermaking involves mixing or pulping the asbestos fiber with water into a 1 to 3 percent slurry although dry mixing of the fiber and additives may precede the wet pulping. The wet stock slurry is then fed onto either a Fourdrinier or a cylinder paper machine. In both machines, paper forms on screen surfaces that draw the water away as the pulp is carried forward, forming a wet mat. This wet mat is conveyed through steam-heated dryer rolls. After drying, the paper may be cut into sheets or collected in rolls. This basic process is the same for nearly all paper products.

In addition to the product use or method of manufacture, asbestos products differ according to the amount of asbestos and other substances in the product. The asbestos content of the finished paper may vary from 5 to essentially 100 percent, although 70 to 95 percent is most common. The binder content in paper usually consists of 3 to 15 percent of its weight. Starches and elastomers are the two major binder groups. Less frequently used binders may include glue, cement, and gypsum. The specification of the amount of asbestos and the type of binders plus other special substances depends on the desired properties and intended uses of the final product. Constituents such as mineral wool, fiberglass, cellulose, and latex may be used to impart special properties.

Clearly, workplace fiber levels at any stage in the manufacturing process will be affected by the asbestos content of the final product. The higher the asbestos content, the higher the potential exposure. Thus a plant producing gasket paper that is 90 percent asbestos by weight will have much higher exposure levels than a plant producing beverage filters containing 10 percent asbestos by weight, given that both facilities use the same process and controls.

Input/Output

Figure 5 shows estimates of process and disposal emissions for the asbestos paper manufacturing industry. These figures are based on Levine's[51] 1974 estimates of air emissions and solid waste generated by the manufacturing process. Estimates by Meylan[52] were used to determine water emissions. All data were projected to 1980 U.S. Bureau of Mines[1] consumption figures. Potential sources of air emissions include fiber introduction, stock operation, drying, cutting, rolling and trimming while water emissions originate at the paper machine. Of the estimated 90,020 metric tons of raw asbestos fiber entering the process, approximately 85,474 metric tons are incorporated into the product. Of the remaining 4,546 metric tons, 4,451.5 m.t. are sent to disposal as sludge, product scraps and as vacuum cleaner and baghouse dust. Approximately 45 metric tons escape through an air emissions control device (typically a baghouse) while another 45 m.t. escape in wastewater discharged from a clarifier. Levine's[51] atmospheric emissions estimates are based on gross assumptions with a reported uncertainty of at least an order of magnitude. Meylan's[52] estimates of atmospheric emissions are generally 1 to 3 orders of magnitude lower. Meylan's estimate of asbestos in paper product wastewater is based on a clarifier efficiency of 96 percent. Atmospheric emissions from disposal, based on GCA estimates, are shown to total 4.5 metric tons per year for the paper products industry. This estimation is loosely based on Levine's data and takes into account new regulations adopted in 1974 regarding the disposal of asbestos.



Note: TPY = metric tons per year.

Figure 5. Input/output estimates for the asbestos paper industry (metric tons).

During Manufacture

Workplace Exposure--

Fiber concentrations in a papermaking facility vary from work station to work station, depending on whether or not the asbestos is wet or dry, whether or not it has been in contact with binder, and also depending upon the ongoing physical process. Table 16 shows time-weighted average fiber counts at different stages in the papermaking process. This table was extracted from asbestos industry figures and includes their engineering estimates on typical fiber counts. These fiber counts are discussed individually in the remainder of this section.

TABLE 16. TIME-WEIGHTED AVERAGE FIBER COUNTS - ASBESTOS PAPER PRODUCTS[a,53]

	Fiber count[b]	
Process step	Range (fibers/cc)	Typical (fibers/cc)
Receiving and storage	0.25 - 2.5	1.0
Fiber introduction	0.3 - 2.8	1.9
Stock preparation	0.1 - 2.7	1.2
Papermaking	0.25 - 1.0	0.8
Drying	0.5 - 1.5	0.8
Slitting and calendering	0.1 - 1.6	1.0
Rewinding	0.5 - 1.5	1.0

[a] Based on plants representing 53 percent of asbestos paper industry production.

[b] Optical-microscope visible fibers.

Receiving and storage--Asbestos fiber is transported to manufacturing plants predominantly by railcars, although some plants receive deliveries by truck. The asbestos, packed in 100-pound bags, is unloaded by forklift trucks and placed in storage until needed. Since receiving and storage activities are the same for all asbestos products, it is valid to use data from all primary asbestos industry segments in estimating fiber levels.

A survey of all primary asbestos industry segments showed a range of exposures in receiving and storage from 0.25 to 2.5 fibers/cc TWA, with 1.0 fibers/cc TWA considered typical.[53] High fiber counts are a result of bag breakage during shipping, careless unloading, and ineffective cleaning. The use of plastic shrink-wrap for bundles of 25 bags can reduce emissions due to breakage, but may increase fiber levels at a later stage, when the plastic wrap must be removed.

Fiber introduction--Another processing step common to all primary asbestos industries, the introduction of raw fiber into the process, can result in high fiber levels. Individual bags may be opened either manually or semiautomatically and the contents dumped into a stock preparation tank of some type or the entire bag may be dumped into stock preparation unopened. In the manual system a worker lifts the bag and slits it open with a knife; in the semiautomatic system a conveyor may be used to move the bags and/or a blade mechanism may be used to open the bags. The empty bags, although generally handled carefully prior to disposal, can be a source of significant fiber amounts.

An industry survey indicated that a typical exposure at this stage of the production process would be 1.9 fibers/cc TWA, with actual values ranging from 0.3 to 2.8 fibers/cc TWA.[53] Almost all fiber introduction stations are equipped with exhaust hoods that collect any dust generated and duct it to an emission control device such as a Ducon system or a baghouse, to the atmosphere, or to another part of the process.

Stock preparation--After the asbestos fiber has been dumped into a hydrapulper or beater, the asbestos along with cellulose material, binders and fillers, is wet mixed to achieve a specified concentration and consistency. In most plants, fiber introduction and stock preparation take place in the same piece of process equipment; in some plants a separate step is required.

For plants with separate fiber introduction and stock preparation steps, fiber counts ranged from 0.1 to 2.7 fibers/cc TWA, with 1.2 fibers/cc TWA reported to be a typical value.[53]

Papermaking--Stock slurry from the preparation step is pumped into a holding tank prior to use. From the holding tank, the slurry flows to the paper machine where it is formed into a sheet, either on a Fourdrinier or a cylinder-type machine. In either case, the high moisture content causes low fiber release during this stage. Exposure levels of 0.25 to 1.0 fibers/cc TWA are reported. Typically, 0.8 fibers/cc TWA can be expected.[53]

Drying--After the paper is formed, the wet pulp is press rolled to remove excess water and routed through steam-heated dryer rolls to attain the desired final moisture content. Although the high moisture content at the wet end of the drying process (75 to 99 percent) minimizes emissions at the dry end of the product, moisture level is reduced (5 percent) and some dust exposure may result.

Exposure levels during drying have ranged from 0.5 to 1.5 fibers/cc TWA with 0.8 fibers/cc TWA considered typical.[53]

Slitting and Calendering--After drying, the wide paper sheet formed by the machine passes to a cutting and slitting area where it is cut into narrower rolls according to customer specifications. The paper may also pass through some pressured rolls, called calender rolls, to achieve a smoother surface finish.

Asbestos fiber levels at this stage have been measured ranging from 0.1 to 1.6 fibers/cc TWA. A typical value would be 1.0 fibers/cc TWA.[53]

Rewinding--The rewinding step involves bulk packaging of paper products on spools or rolls in preparation for shipping. Usually, very little cutting is required at this stage but the winding process can generate fiber release. Exposure levels measured in rewinding are typically 1.0 fibers/cc TWA, but have ranged from 0.5 to 1.5 fibers/cc TWA.[53]

Secondary fabricator industries--Secondary processors or fabricators are firms that purchase products from one or more segments of the primary industry and either fabricate these materials or process them together with other materials into an end product. While some products undergo further processing beyond a secondary stage, the amount of additional activity is minimal. For the most part asbestos paper products go from either primary manufacture or secondary processing to an end use such as a construction company or the automotive aftermarket and repair industry. In general, operations involved in secondary fabrication are quite similar to the finishing operations in primary manufacturing segments. They may utilize such operations as grinding, sawing, sanding, punching, pressing, or splitting, depending on the fabricated product desired.

It is estimated that 60 percent of asbestos paper goes through some form of secondary fabrication before reaching the end user.[53] Typical finishings operations include slitting, sawing, punch pressing, converting, and laminating and typical asbestos exposure ranges have been estimated at 1.0 to 3.5 fibers/cc.[53]

Primary manufacturers of sheet packing sell a pressed gasket material to secondary manufacturers or gasket cutters. Secondary fabricators cut, split, or punch the material to specific shapes for each end use. During these secondary fabrication processes, the packing or gasket materials may be impregnated with polymers, latex, or other chemicals to impart certain properties to the materials. Gasket cutters may use asbestos paper when strength and pressure sensitivity are not critical, whereas asbestos yarns may be used for packing materials for pumps and other applications which require high strength materials. Exposure ranges for packings and gaskets have been reported at 0.2 to 5.0 fibers/cc TWA.[53]

Worker exposure--Using assumptions put forth by Suta and Levine,[54] we can estimate that a person exposed to the maximum permissible asbestos concentration of two optical-microscope-visible fibers/cc greater than 5 μm over a 40-hour week will inhale 125 billion electron-microscope-visible fibers annually. As demonstrated in Table 16, production workers in the asbestos paper manufacturing industry are typically exposed to 1 fibers/cc >5 μm[53] and can be expected to inhale approximately 62.5 billion electron-microscope-visible fibers per year, compared to 6.25 million fibers inhaled for persons exposed to the median ambient urban concentration of 1×10^{-4} fibers/cc >5 μm.

Emissions to Air--

Johns-Manville Corporation sampled ambient fiber levels near seven plants during the period 1969 through 1971. Results of this study are summarized in Table 17. While neither the test method nor the type of asbestos fibers measured were noted in this data summary, it does provide a relative measure of ambient fiber concentrations near asbestos product manufacturing facilities. It is important to note that these plants do not produce asbestos paper products solely. The Waukegan and Manville plants manufactured asbestos-cement pipe, sheeting, and other products, in addition to paper produced during the sampling interval. Overall, reported ambient fiber levels are low, approaching the lower detection limit of the sampling equipment. With one exception, the asbestos fiber levels measured are less than or equal to the median ambient air urban exposure of 20 ng/m^3. These data would also appear to indicate that asbestos emissions from industrial facilities do not significantly increase ambient levels of asbestos fibers.

Emission measurements and subsequent modeling of an asbestos paper plant by GCA/Technology Division in 1979[55] contradicted the Johns-Manville results. Samples taken from general vents between paper machines and hydropulper vents showed typical fiber concentrations of 25 and 90 f/cc, respectively. By combining this fiber concentration data with process aspiration rates, fiber emission rates were estimated and employed in EPA's PTMTP Point Source Dispersion Program. This Gaussian plume model was used to model the dispersion of airborne asbestos emanating from the facility. Six modeling runs were performed for various stability classes and wind directions. The results of the dispersion modeling showed that, in general, plant related concentrations above 0.05 f/cc, as measured by an electron microscope, may be encountered within 500 meters of the plant, depending on the meteorological conditions present. This plant-related exposure is more than twice the median urban exposure of 20 ng/m^3 and exceeds the State of Connecticut's proposed ambient standard of 30 ng/m^3. These ambient levels, as estimated by the dispersion model, are close to values actually measured by a low volume sampler near four industrial users of asbestos in the State of Connecticut (values greater than 30 ng/m^3 were measured).[56]

GCA/Technology Division employed personal sampling pumps with 0.4 μm size Nuclepore filters of 37 mm diameter housed in an open-faced holder to take the samples at a rate of 1.5 l/min. The sampling was not done isokinetically, and therefore, the validity of the data is questionable. Nonetheless, it is felt that the accuracy of the data is sufficient to provide approximate emissions of asbestos fibers into the ambient air. Table 18 details the location and corresponding fiber concentration for each sample taken at the asbestos paper plant.

Suta and Levine[54] have estimated the average atmospheric asbestos concentration within 5 km of asbestos paper manufacturing plants to be 33 thousand electron-microscope-visible fibers per cubic meter with an estimated 180 million fibers being inhaled by the average person annually. This compares to their estimates of 27.4 million electron-microscope-visible fibers being inhaled by persons exposed to the average ambient urban fiber concentration of 5,000 $fibers/m^3$ and 125 billion fibers being inhaled by workers exposed to the maximum allowable concentration of 2 million $fibers/m^3$ >5 μm.

TABLE 17. AMBIENT ASBESTOS FIBER LEVELS REPORTED BY JOHNS-MANVILLE FOR SAMPLING DONE IN 1969-1971[57]

Sample location		Ambient asbestos level[a] (fibers/cc)	
		Total	>5μ
Lompoc, CA	Employee backyard	0.05	0.02
North Plainfield, NJ	Employee backyard	0.02	0.02
Nashua, NH	Plant yard	0.02	0.02
	Plant yard	<0.01	<0.01
	Employee backyard	<0.01	<0.01
	Employee backyard	<0.01	<0.01
Waukegan, IL	South property line	0.02	<0.01
Somerville, NJ	Employee backyard	0.02	0.01
Scotch Plains, NJ	Employee backyard	—	0.02
Manville, NJ	1,000 ft south east	0.02	<0.01
	1,000 ft south east	0.02	<0.01

[a] Test method not reported; data should only be used for relative fiber concentrations.

TABLE 18. SAMPLING RESULTS OF AN ASBESTOS PAPER PLANT (1979)[a],55

Filter number	Location	Sample duration (min)	Pump flow (lpm)	Asbestos fiber concentration (f/cc)[b]
C-6	Below #4 pulper vent (two batches made)	60	1.5	144
C-3	Below #3 pulper vent (one batch made)	60	1.5	10
C-2	Below #1 pulper vent (two batches made)	60	1.5	48
C-5	In exhaust vent, #3 pulper (one batch made)	55	a	49
C-4	In exhaust vent, #1 pulper (two batches made)	55	a	84
C-1	In exhaust vent #4 pulper (two batches made)	50	a	91
C-11	Vent between #1 and #2 paper machines - wet end vent	60	1.5	25
C-12	Vent between #1 and #2 paper machines - second vent from wet end	60	1.5	22
C-8	Topmost catwalk, heat exchanger on wet end of #2 paper machine	60	1.5	1.0
C-9	Same as C-8	60	1.5	1.8
C-14	South end of paper machine building roof, on ridge between machines	60	1.5	0.31
C-13	40 feet west of C-14	60	1.5	0.54
C-15	40 feet east of C-14	60	1.5	0.38
C-16	2 feet west of vacuum pump exhaust, wet end of #1 paper machine	65	1.5	0.15

[a] Samples in vents were clogging due to high moisture content. Pumps were shut off after approximately 30 minutes of sampling although the open-face samples were kept in the vents for the remainder of the sampling period.

[b] Scanning electron microscope analysis.

Release to Water--

As paper products manufacturing is a wet process, substantial amounts of asbestos fibers are discharged in the plant process effluent streams. It has been estimated[4] that the raw water discharge from a typical asbestos paper manufacturing process contains about 19 pounds of suspended solids per ton of product produced (9.5 kg/m.t.). Furthermore, Meylan[52] estimates that approximately 80 percent of paper products suspended solids are asbestos fibers, since this is the average asbestos content of the paper produced. This raw wastewater stream is directed to onsite clarifiers for solids removal. The efficiency of industrial clarifiers with respect to asbestos particles is not available. Meylan[52] estimates that this efficiency may range from 94 to 96 percent. If the 94 percent clarifier efficiency is used in conjunction with the other factors, and they in turn are applied to the 1980 paper products asbestos consumption rate of 90,020 m.t. per year, we can estimate an asbestos release to water of approximately 39 m.t. per year.

Suta and Levine[54] use different factors to arrive at similar waterborne asbestos emission estimates. They assume that approximately 34 pounds of asbestos suspended solids are discharged to clarifiers per ton of asbestos consumed (17.0 kg/m.t.). To this value, they apply a clarifier removal efficiency of approximately 97 percent. Using these factors and 1980 asbestos consumptions, we can calculate an asbestos release to public waters of approximately 45 m.t. per year. While this emission rate is only slightly higher than that calculated using Meylan's rationale, the amount of asbestos removed in the clarifiers and subsequently disposed of on land is more than two times as great.

To maintain a consistency of approach in this report with regards to emission estimates for each product category, GCA has utilized the Suta and Levine estimates. As demonstrated in Figure 5, these translate into an asbestos water emission of 45 m.t. per year.

Releases to Land--

Solid waste from paper products manufacturing is essentially all in the form of baghouse catch and clarifier sludge. Rejected papers, scraps, and trimmings are apparently not wasted in significant amounts, as this waste paper can usually be returned to the beater and repulped for recycling.[52] The quantity of sludge collected in the clarifiers has been estimated using rationale developed by Suta and Levine[54] and upgraded to 1980 asbestos consumption figures. This estimated totals 1486 m.t. of sludge per year. In general, most of the suspended solids (sludge) collected from clarifying units or ponds are disposed of in landfills. To this quantity is added the asbestos captured in baghouses. These baghouses control the principal asbestos fiber introduction and transfer stations. Their asbestos fiber control efficiency is estimated to be 99.9 percent. The baghouse catch adds an additional 2970 m.t. per year of asbestos which is ultimately landfilled, for a total of 4451.5 m.t. per year. Of this amount, approximately 0.1 percent or 4.5 m.t. will escape to the atmosphere due to reentrainment of asbestos during landfilling. This estimate was also derived from Suta and Levine projections, upgraded to account for 1980 asbestos fiber consumption. The actual degree or reentrainment will largely depend on the care with which the dry asbestos fibers captured in the baghouses are properly landfilled and covered.

During Use

Asbestos fibers are encased in all asbestos paper products by some type of binder. They will be released to the atmosphere only when this binder is disturbed, as during product installation and removal, or in the course of natural wear due to the effects of use and age. While no monitoring data exist to support the concentration estimates of asbestos released during installation of an asbestos paper product, these quantities are thought to be mimimal.[51] As is the case for most asbestos products, the predominant amount of asbestos fiber content is wasted to landfills when product replacement is done. The effect of "wear and tear" on asbestos fiber release varies with the individual paper product. The two principal asbestos paper product categories, flooring felt and roofing felt, have a double protection. The asbestos fiber is first encapsulated in a strong binder, and then the asbestos paper is covered with an additional product (vinyl flooring or asphalt roofing) which screens it from direct wear. Both of these products have extended lifetimes (10 to 25 years), and the annual asbestos release would be minimal. The other paper products, including pipeline wrap, gaskets, insulation, specialty and commercial papers and beverage and pharmaceutical papers, have a more direct contact with ambient conditions. In these applications, asbestos fibers can be either released to the air or leached into the ground due to extreme environmental exposure. No ambient monitoring data exists to verify this supposition; however, Suta and Levine[54] have made overall estimates on the amount of asbestos released to the air due to the use of asbestos paper products. When upgraded to account for 1980 paper products asbestos consumption, this estimate totals 9.7 m.t. per year. Neither the rationale nor the calculations used in this estimate was presented.

During Disposal

Maintenance and replacement of asbestos paper products account for approximately 72 percent of annual production and annual asbestos use.[54] Using 1980 consumption figures, this amounts to approximately 61,200 m.t. of asbestos. This asbestos is bound in a matrix by a binder and is unlikely to be released to the environment. In some cases, as in roofing felt, the used asbestos product may be left in place and covered with its replacement. In most applications, however, the discarded asbestos is collected and deposited in a landfill or sent to an incinerator. Certain paper categories, including pipeline wrap and muffler paper, may be exposed to extreme conditions. The binder in these papers may breakdown from long-term use, thereby causing the material to be friable. This possibility has not been substantiated by ambient monitoring, however. Airborne asbestos release that can be attributed to the disposal of used paper products is estimated to total 11.3 m.t. per year, based on 1980 asbestos fiber consumption.[51]

CONCLUSIONS

The asbestos paper products sector is a diversified collection of goods which share a common production technology. Each product category is unique in its historical trends, availability of substitutes and projections for future growth. Collectively, this sector is in a static growth mode, with some categories showing modest annual increases, while most exhibit level or slightly decreasing asbestos consumption. An examination of each paper category will serve to review the current situation on a case-by-case basis.

Flooring Felt

Although asbestos flooring felt is in a high consumption category, future growth is expected to diminish[29] due to a stabilization of the product mix because the changeover (which has been occurring in the recent past) from jute backing to the newer asbestos backing is nearly complete. This means that the asbestos product has now replaced the jute in most every application. From 1971 through 1975, growth of the asbestos backing was estimated at 14.8 percent annually, whereas the same source projects that the annual growth through 1980 will be 5 percent and only 2.9 percent from 1980 to 1985. The market currently backs this up with a small positive growth rate. In addition, new substitutes to the asbestos product, particularly foam cushion backings and backless sheet flooring, are providing increasing competition for the asbestos flooring felt market, indicating that there may well be yet another transitional growth stage at some time in the future, with the development of suitable alternatives.

Roofing Felt

Industry sources believe that the asbestos roofing felt market is currently stable, but a decline is expected in the near future for two major reasons. First, asbestos roofing is beginning to feel competitive market pressures from fiberglass roofing and, second, labor unions and the construction industry are becoming more apprehensive about using asbestos products. Fiberglass has many of the same technical advantages and characteristics as asbestos and is less expensive for initial installation. Furthermore, fiberglass requires less saturation than asbestos and as petroleum and asbestos prices climb the cost differential between fiberglass and asbestos roofing will shift more and more in favor of fiberglass. However, asbestos roofing is considered more durable than fiberglass, possibly making asbestos more cost effective in the long run.

Arthur D. Little[29] expected demand for asbestos roofing to decline at an average rate of 2.8 percent through 1980 and by about 5 percent from 1980 to 1985. Industry sources feel the actual decline will be slightly less.

Beater-Add Gasket

A marginal increase is projected for asbestos gasket substitutes. Other asbestos paper categories seem more prone to substitution than gaskets. However, this may be subject to change as substitute products are developed. Industry contacts[58] pointed to the fact that substitutes are often not used by industries due to their expense, but if concern over the use of asbestos products grows, this attitude could change. Currently, this paper category is enjoying perhaps the least competition from substitute products.

Pipeline Wrap

Saturated asbestos pipe wraps are presently the preferred corrosion protection system for oil and gas pipelines due to their time-tested durability and relatively low cost. However, the market for pipeline corrosion protection is competitive and alternatives to asbestos felt are available.

As might be expected, potential growth in demand for asbestos pipe wrap (or substitutes for it) is a function principally of new pipeline construction and availability of competitive materials.[29] New pipeline construction has historically experienced rapid growth and this is expected to continue. Competitive alternatives to asbestos wrap, which are becoming more available, will most likely exert some downward pressure on the growth of the asbestos wrap market.

At present, most industry sources view the asbestos pipeline wrap market as stable; however, in the near term, a slight downward shift of the market can be expected, primarily due to the competitive pressures of the relatively new fiberglass pipe wraps and new epoxy resins and extruded coatings that are just becoming commercially available. Cost effectiveness still favors asbestos pipe wraps; however, with the rapidly rising costs of asbestos fiber and petroleum products (asphalt and coal tar), the advantage may shift away from asbestos.

Millboard

Substitute millboard products have been developed to meet the variety of temperature, corrosion, and other environmental conditions imposed on the asbestos product. Thus, asbestos millboard production is not expected to increase significantly in the future. The annual growth rate for asbestos millboard and commercial papers is projected to be only 0.9 to 1.0 percent through 1985,[29] but it is anticipated that U.S. firms producing millboard will cease production of the product as acceptable, economical substitutes are developed.[59] Industry is likely to maintain minimal production capacity for specific applications where alternatives are not available. Because alternatives, particularly in heat and flame protection applications, are becoming available, asbestos millboard production may decline in the future. Substitutes for millboard gasket applications are not presently available; therefore, this market segment is presently very stable.

Electrical Insulation

Transformer manufacturers are constantly using more substitutes for asbestos electrical insulation papers. Nomex papers are already extensively used by electrical and transformer manufacturers,[7] while Fiberfrax and other replacement industrial laminates are already on the market. Therefore, the market for asbestos electrical paper is declining, although the rate of decline is not known at present. The market for substitute products such as Nomex paper has been steadily growing since it came on the market in 1965.[60]

Commercial Papers

The overall growth rate for asbestos commercial paper is slightly negative and is not expected to change, indicating that substitute products will have an opportunity to establish themselves in this area. Asbestos muffler paper has already been replaced by ceramic and glass papers in the United States, apparently due to concern exhibited by automotive muffler and converter producers about using asbestos-containing materials. As for corrugated paper, the current outlook indicates that it may not be made in the future. Substitute products like ceramic paper can replace asbestos commercial paper in the future if the greater cost of such products is accepted.

Specialty Papers

Saturated asbestos paper is becoming too expensive compared to the readily available plastic substitutes for cooling tower fill;[13] thus the market should favor replacement of asbestos fill presently in use with substitute products. However, in specialty applications, such as cooling for gaseous diffusions, asbestos fill is used rather than other materials because of its superior heat and chemical resistant characteristics. The use of asbestos-cement sheet as a cooling tower fill is rapidly decreasing due to its potential for wear under extreme pH conditions creating a potential health risk. Nonmetal fills are generally lighter than metal fills and, therefore, have advantages in transport costs and handling ease. Asbestos paper is considered the best fill material in terms of chemical and heat resistance, but for most applications, the extra chemical and heat resistance is not critical. As indicated, plastic fills are becoming the most popular for general applications.

Many of the products developed to replace the other asbestos specialty papers seem to be readily available. The only exception is transmission paper where there are currently no nonasbestos alternatives available, although research and development is underway in this field. In electrolytic diaphragms, substitutes exist, but are not equal to asbestos in properties and quality. Nonasbestos products have already replaced asbestos in many filter papers and industrial laminates, and comparably priced nonasbestos metal lining paper is increasing in market share. There remain some deficiencies to correct; research in such areas as disposal and handling of spent paper generated in electrolytic chlorine production may also be desirable. Some asbestos specialty papers are already being produced in lower volumes. With the many alternative products available, this category appears to have the potential for rapid reductions in asbestos consumption.

Beverage Filters

Asbestos beverage and pharmaceutical filters are not only produced and consumed in very small amounts, but also will likely be totally replaced with available substitutes in the not-too-distant future. However, as this is only a small segment of the asbestos paper products industry, it is unlikely to have any great effect. It has been concluded[18,61] that nonasbestos filter sheets have reached the stage where they can be considered a full substitute for asbestos filters. Further,[18] the comparative economics may favor the nonasbestos filters since the filtering efficiency of the nonasbestos sheets in some applications is considered equal to that of asbestos. However, for haze removal from beverages, asbestos appears superior at present and some beverage manufacturers still require this quality.[19]

The major advantage of asbestos use in the past was its high positive charge which attracts negatively charged ions. In pharmaceuticals, bacteria must be removed from products, and since most bacteria have negatively charged ions, only asbestos filters were able to attract such ions. However, newly developed products can receive such a charge and consequently act similarly.

Overall, the trend for asbestos paper products is in a state of flux. Almost all categories show a stable or marginal decrease in the amount of asbestos to be used. Only in those instances, such as gaskets and some specialty papers, where the specific qualities of asbestos are absolutely essential, is there a slight increase in asbestos consumption predicted. This "leveling off" of asbestos use is generally attributed to the availability of an acceptable, if not completely identical, alternative. Changes in substitute quality and availability will directly affect asbestos use in the paper products sector.

REFERENCES

1. Clifton, R. A. Asbestos. 1980 Minerals Yearbokk. U.S. Bureau of Mines, Washington, D.C., 1981.

2. Meylan, W. M., P. H. Howard, and A. Hanchett. U.S. Asbestos Paper Industry and Substitutes for Asbestos Paper and Asbestos Brake Linings. U.S. Environmental Protection Agency, Washington, D.C., September 1979.

3. Johns-Manville Corporation, Manual for Built-up Roofs, 1978.

4. Carton, R. J. Development Document for Effluent Limitation Guidelines, Building, Construction, and Paper Segment of the Asbestos Manufacturing Point Source Category. EPA-440/1-74-017-a, U.S. Environmental Protection Agency, Washington, D.C., February 1974.

5. Telecon. Sales Personnel, Carborundum Corporation, Niagara Falls, N.Y., with D. Ramsay, GCA Corporation, August 1979.

6. Pye, A. M. A Review of Asbestos Substitute Materials in Industrial Applications. Journal of Hazardous Materials (Netherlands) 3:137-138.

7. Telecon. Hayman, J. Technical Service Representative, DuPont, Wilmington, DE, with Syracuse Research Corporation, July 1979.

8. Telecon. Hughes, N., Quin-T Corp., Tilton, N.H., with Syracuse Research Corporation, July 1979.

9. Telecon. Wilmore, R., National Electrical Manufacturing Association (NEMA), Washington, D.C., with Syracuse Research Corporation, August 1979.

10. Lewis, B. G. Asbestos in Cooling Tower Waters. Argonne National Laboratory, Argonne, Ill., NTIS No. ANL/ES-63, December 1977.

11. Clifton, R. A. Asbestos. Preprint from Bulletin 667, Mineral Facts and Problems. 1975 ed. U.S. Department of Interior, Bureau of Mines, 1975; and Personal Communication with SRC, 1979.

12. Telecon. Lai, M., Hooker Chemical Company, Niagara Falls, N.Y., with SRC, August 1979.

13. Telecon. Skold, J., Munters Corporation, Fort Myers, Fla., with SRC, August 1979.

14. Deutsch, Z. C., C. C. Brumbaugh, and F. H. Rockwell. Alkali and Chlorine. Kirk-Othmer Encycl. Chem. Tech. (2nd ed.), 1, 681-699, 1963.

15. Dahl, S. A. Chlor-Alkali Cell Features, New Ion-Exchange Membrane. Chemical Engineering. August 18, 1975. p. 60-61.

16. Telecon. Cannady, D., Westinghouse Corp., Hampton, S.C., with SRC, August 1979.

17. Cannady, D. Decorative Laminates. Modern Plastics Encyclopedia, 77-78; pp. 124-125. Published in conjunction with Modern Plastics, Vol. 54. No. 10A, NcGraw-Hill Publication. October 1977.

18. Held, R. Nonasbestos Filter Sheets. The Brewers Digest, December 1978, pp. 38-42.

19. Telecon. Varleriote, S., Cellulo Co., Fresno, CA, with SRC (Syracuse Research Corporation), July 1979.

20. Belcher, Louis, GAR Corporation, letter of Joni Repasch, EPA OTS, February 7, 1980.

21. Johns-Manville, Fact Sheet for GlasPly Builtup Roofing Systems, 1979.

22. Telecon. Reznic, B. Applications Engineer, Cotromics Corporation, 3379 Shore Parkway, Brooklyn, N.Y., (212) 646-7996, with M. Shah, GCA Corporation, September 1979.

23. (PWC) Carborundum Corporation. Fiberfrax 110 Paper Product Specifications. March 1979.

24. Anonymous. Nomex Aramid. Bulletin NX-7, published by DuPont, Wilmington, Del. November 1977.

25. Carborundum Corporation. Fiberfrax Ceramic Fiber.

26. Masonite Corp. Benelex 402 Physical Properties.

27. Telecon. Lavery, F., Sales Manager, Ertel Engineering Company, Kingston, N.Y., (212) 226-6023, with M. Shah, GCA Corporation, September 1979.

28. Telecon. Gusmer, J., President, Cellulo Company, Waupaca, Wisconsin, with M. Shah, GCA Corporation, (715) 258-5526, September 1979.

29. Arthur D. Little, Inc. Characterization of the U.S. Asbestos Paper Markets. Prepared for the Ministry of Industry and Commerce - Government of Quebec, Canada, Report C-79231, 1976.

30. Wright, M. D., et al. Asbestos Dust Technological Feasibility Assessment and Economic Impact Analysis of the Proposed Federal Occupational Standard: Part I. U.S. Department of Labor, Occupational Safety and Health Administration, Washington, D.C., September 1978.

31. Gregg, R. T. Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Textile, Friction Materials and Sealing Devices Segment of the Asbestos Manufacturing Point Source Category. EPA-440/1-74/035a, Group I, Phase II, U.S. Environmental Protection Agency, Washington, D.C., December 1974.

32. Chapman, J. H., D. E. Matzzie, and R. G. Hillman. Asbestos Dust - Technological Feasibility Assessment and Economic Impact Analysis of the Proposed Federal Occupational Standard, Part III, Technical Appendices, Asbestos and Health Administration, Washington, D.C., September 1978.

33 Telecon. Don Wheaton, Cellulo Co., Fresno, CA, (209) 485-2692, with Anne Duffy, GCA Corporation, GCA/Technology Division, April 17, 1981, Call No. 27.

34. Telecon. Mr. Hallet, Ertel Engineering, Kingston, N.Y., (212) 226-6023, with Anne Duffy, GCA Corporation, GCA/Technology Division, April 17, 1981, Call No. 28.

35. Telecon. Company Representative. Alsop Engineering, Milldale, Conn., (203) 628-9661, with Anne Duffy, GCA Corporation, GCA/Technology Division, April 17, 1981, Call No. 30.

36. Anonymous. World Wide Directory of Products and Operations 1979. Published by Johns-Manville Corp., 1979.

37. Telecon. Davies, H., Nicolet Industries, Norristown, Pa., with Syracuse Research Corporation, July 1979.

38. Syracuse Research Corporation. Communications to GCA/Technology Division. August-September 1979.

39. Telecon. Pat Thurber. Colonial Fiber Company, Division of Lydall Corp., Manchester, Conn., (203) 646-1233, with Anne Duffy, GCA Corporation/Technology Division. April 14, 1981. Call #9.

40. Telecon. Mrs. Loretta Ferguson. Johns-Manville Corp., Denver, Colo., (303) 979-1000, with Anne Duffy, GCA Corporation/Technology Division. April 13, 1981, Call #2.

41. Telecon. Dot Hebert. Rogers Corp., Rogers, Conn., (203) 774-9605, with Anne Duffy, GCA Corporation/Technology Division. April 14, 1981. Call #4. Some lines have been discontinued. They plan to convert to non-asbestos in the near future.

42. Production verified by Telecon. Company Representative. Celotex Corp., Tamp, Fla., (813) 871-4811, with Anne Duffy, GCA Corporation/Technology Division, April 13, 1981. Call #3.

43. GAF no longer manufactures asbestos-containing products. Telecon. Harvey Loud's office, GAF Corp., New York, N.Y., (212) 621-5000, with Anne Duffy, GCA Corporation/Technology Division, April 13, 1981. Call #1.

44. Telecon. Pat Yoder. Nicolet Inc., Norristown, Pa., (215) 646-4000, with Anne Duffy, GCA Corporation/Technology Division, April 14, 1981. Call #6.

45. Telecon. Company Representative, Quin-T Corp., Tilton, N.H., (603) 286-4362, with Nancy Krusell, GCA Corporation/Technology Division, April 23, 1981.

46. Asbestos Magazine. March 1981.

47. Telecon. Morse, E., Brown Co., Berlin, N.H., with Syracuse Research Corporation, July 1979.

48. Anonymous. CPSC Moves to Ban Asbestos Paper. Asbestos, 61(11), p. 14, May 1980.

49. Telecon. Wong, G., Manning, Paper Co., Green Island, N.Y., with Syracuse Research Corporation, July 1979.

50. Telecon. Johns-Manville, with Lester Y. Pilcher, GCA Corporation, March 1980.

51. Asbestos: An Information Resource. R. J. Levine, ed. U.S. Department of Health, Education, and Welfare, Public Health Service, National Institutes of Health, DHEW Publication No. (NIH) 79-1681, Bethesda, N.Y., May 1978.

52. Meylan, W. M., P. H. Howard, S. S. Lande, and A. Hanchett. Chemical Market Input/Output Analysis of Selected Chemical Substances to Assess Sources of Environmental Contamination: Task III. Asbestos. EPA-560/6-78-005, U.S. Environmental Protection Agency, Washington, D.C., August 1978.

53. Daly, A. R., A. J. Zupko, and J. L. Hebb. Technological Feasibility and Economic Impact of OSHA Proposed Revision to the Asbestos Standard/ (Construction Excluded), Asbestos Information Association/North America, Washington, D.C., 29 march 1976.

54. Suta, B. E., and R. S. Levine. Non-Occupational Asbestos Emissions and Exposures. In: Asbestos, Volume 1. Properties, Applications, and Hazards, L. Michaels and S. S. Chissick, eds., John Wiley & Sons, New York, N.Y., pp. 171-205, 1979.

55. Cogley, D. Modeling Atmospheric Concentrations in the Vicinity of an Asbestos Paper Plant. Unpublished. GCA/Technology Division, Bedford, Mass., September 1979.

56. Bruckman, L., and R. A. Rubino. Monitored Asbestos Concentrations in Connecticut. J. Air Pollution Control Assoc., 28(12) pp. 1221-1226, December 1978.

57. Johns-Manville Corporation, Letter from E. M. Fenner to D. R. Cogley, July 19, 1979.

58. Telecon. Brunner, B., Customer Service Manager, Chicago Gasket Co., 1277 West North Avenue, Chicago, Ill., (312) 486-3060, with M. Shah, GCA Corporation, September 1979.

59. Gordon, W. A., and W. E. Riddle. Industry Profile and Background Information on Asbestos Cement Products, Millboard and Lumber-Related Products. U.S. Consumer Product Safety Commission CPSC-C-78-0091, Task 2, Subtask 2.02, February 1979.

60. Telecon. Hardy, B., Technical Service Specialty Dept., DuPont, Wilmington, Del., (302) 999-3622, with M. Shah, GCA Corporation, September 13, 1979.

61. Fiore, J. V., and R. A. Babineau. Filtration - An Old Process with a New Look. Food Technology, 33(4):67-72, 1979.

SECTION 5

FRICTION MATERIALS

INTRODUCTION

Friction materials are used in clutches for transmitting torque, in brakes for slowing or stopping motion, and in torque limiters. Besides their well-known use in autos, trucks, buses, and railroad cars, friction materials are also found in other applications where motion must be controlled, ranging from bulldozers and tractors to typewriters, tape recorders, and parking meters.

Automobile brake linings have used asbestos since 1908 when Herbert Frood demonstrated that a combination of pure woven asbestos spun on brass wire combined with a specially developed bonding agent resulted in a product with excellent durability and heat resistance. By the first World War, woven asbestos brake linings were in common use on passenger cars, commercial vehicles, and military transports. In 1921, a vulcanized combination of ground-up waste, bonded asbestos, and a rubber-type binder was used to manufacture the first molded brake block, but molded blocks were not widely accepted until after the second World War. Disc brake pads were originally developed for aircraft landing wheel brakes in 1944 and have become more universally used in the intervening years.

Clutch facings followed a similar pattern of introduction. Impregnated cotton replaced leather in automotive clutch facings in 1905 and was, in turn, superseded by asbestos. Today, clutch facings of wire covered with asbestos yarn are widely used and continued progress is being made in die cast and molded clutch facings.[1]

In 1980, an estimated 43,700 metric tons of asbestos, about 12 percent of the United States fiber consumption, was used in the manufacture of friction materials.[2] Five companies dominate the United States friction material market, but foreign competition is becoming more of a factor.[3]

Figures for production volumes were not available but a breakdown of the estimated value of asbestos-bearing friction materials produced in 1979 is given in Table 19. These data were derived by projecting 1972 figures provided by Meylan[4] to 1979 costs. As shown, brake linings are by far the largest component (58.9 percent) of the asbestos friction material industry. Consequently, this section emphasizes the production processes and emissions associated with brake linings, placing lesser emphasis on other products in the friction materials group.

TABLE 19. VALUE OF ASBESTOS FRICTION MATERIAL SHIPMENTS (IN MILLIONS OF 1981 DOLLARS)[a]

Final product	Total product shipments, including interplant transfers		Percentage of total (1981)
	1981	1972	
Brake linings			
Woven, containing asbestos yarn, tape or cloth	$ 27.8	$ 10.2	4.9
Molded, including all non-woven types	308.4	113.1	54.0
Disc brake pads	38.8	14.2	6.8
Clutch facings			
Woven, containing asbestos yarn, tape or cloth	54.2	19.9	9.5
Molded, including all non-woven types	132.2	48.5	23.1
Other	9.8	3.6	1.7
Total asbestos friction material	$571.2	$209.5	100.0

[a] Projected from Meylan, et al. (1972), p. 61,[4] using September 1981 Engineering and Mining Journal cost index factors.

PRODUCT DESCRIPTION

Composition

Many raw materials, including some whose exact roles are regarded as proprietary information, are used in varying quantities in the manufacture of friction materials. The major or foundation constituent of practically all friction materials is asbestos fiber, which can range from 15 to 79 percent of the final product by weight depending on end use.[5] In 1980, chrysotile grades 3 through 7 accounted for all of the estimated 43,700 metric tons of asbestos used to produce friction materials.[2] Fiber sizes and types may be mixed or calcined to improve performance.

Asbestos is used because of its thermal stability, relatively high friction level, and reinforcing properties, but asbestos alone does not offer all of the desired properties. Therefore, other materials known as property modifiers and binders are added. Different types and amounts of modifiers are used to provide desired levels of effectiveness, wear, fade, recovery, and noise. Binders hold the disparate materials together. The average composition of a typical automobile brake lining is shown in Table 20. Individual product mixes vary considerably from these averages. Manufacturers refuse to release their exact product compositions due to proprietary considerations but some details are available in patents. Several examples are given in Table 21.

Table 22 lists binders and property modifiers used in automobile brake linings. Phenolic-type resins are the most commonly used binders because of their high binding efficiency and ability to withstand pyrolytic breakdown. Other resin binding systems are based on elastomers, drying oils, or combinations.

A wide range of materials are used in friction materials as property modifiers. In general, property modifiers can be divided into two classes, nonabrasive modifiers and abrasive modifiers. Nonabrasive friction modifiers can be classified further as being either high friction or low friction material. The most common high friction material is friction dust, a cured resinous material derived from cured or polymerized cashew shell liquid, a phenolic compound. When heated with hardening agents such as hexamethylene tetramine or formaldehyde, it polymerizes becoming sufficiently hard to be granulated. Other friction dusts are different combinations of cured resins, polymers, fillers, and cashew resins. Ground rubber is normally used for noise, wear, and abrasion control in particle sizes smaller to or slightly coarser than those of the cashew dusts.[4]

Low friction nonabrasive modifiers like carbon black, graphite, petroleum, coke flour, or other carbonaceous material may be added to lower the coefficient of friction and reduce noise. Normally the materials are added as fine powders or particles although graphite is occasionally used as coarse particles or pellets.[4]

TABLE 20. AVERAGE BRAKE LINING COMPOSITION (WEIGHT PERCENT)[a]

Material	Automobile	Truck
Asbestos	55	33
Resins and polymers	28	48
Oxides and pigments	9	16
Metals	3	2
Carbon, graphite, etc.	5	1
Total	100	100

[a] Lunch, quoted by Meylan,[4] et al.

TABLE 21. BRAKE LINING COMPOSITIONS FROM PATENT LITERATURE (WEIGHT PERCENT)[4]

Lining No. 1[a]		Lining No. 3[b]	
Asbestos	55	Asbestos	35
Barite	10	Barite	2.5
Phenolic resin binder	20	Graphite	7
Brass	5	Brass	13
Magnesium carbonate	8	Phenolic resin	7
Limestone	8	Lead oxide	11.5
Organic calcium powder	10	Buna N rubber	8
		Naphtha	7
		Copper sulfide	12.5
		Methyl ethyl ketone	4

Lining No. 2[c]		Lining No. 4[d]	
Asbestos	60	Asbestos	50
Phenolic resin	15	Tarry residue	12
Nitrile rubber	3	Barite	20
Cashew dusts	12	Phenolic resin	20
Calcium fluoride	7	Graphite	2
Copper iodide	3		

[a] Sakata, et al., 1974 (Hitachi).

[b] Keller, 1969 (Abex).

[c] Toyota Central Research and Development Labs, 1971.

[d] Mitchell, 1974 (DuPont)

TABLE 22. PROPERTY MODIFIERS IN FRICTION MATERIALS[4]

Binders	Property modifiers	Use function
Phenolic-type resins	Graphite	Lower friction coefficient and noise
Natural rubber	Coke	Lower friction coefficient and noise
Buna N rubber	Coal	Lower friction coefficient and noise
Nitrile rubber	Carbon black	Lower friction coefficient and noise
Tire scrap	Gilsonite	Lower friction coefficient and noise
Pitch	Friction dusts	Lower friction coefficient and noise
Cork	Rottenstone (SiO_2)	Remove decomposition deposits
Gilsonite	Quartz (SiO_2)	Remove decomposition deposits
Elastomers	Wollastonite ($CaSiO_3$)	Remove decomposition deposits
Drying oils	Brass Chips	Remove decomposition deposits
	Zinc and compounds	Remove decomposition deposits
	Aluminum	Remove decomposition deposits
	Limestone ($CaCO_3$)	Improve wear resistance
	Clays	Improve wear resistance
	Silicas	Improve wear resistance
	Barite ($BaSO_4$)	Improve wear resistance
	Lead and compounds	Lubricant to prevent grabbing
	Antimony compounds	Not available
	Calcium compounds	Not available
	Copper and compounds	Not available
	Barium hydroxide	Not available
	Potassium dichromate	Not available
	Magnesium carbonate	Not available
	Iron oxide	Not available
	Cryolite (Na_6AlF_3)	Not available
	Fluorspar (CaF_2)	Not available
	Cardolite	Not available
	Nickel	Not available
	Sulfur	Not available
	Molybdenum sulfide (MoS_2)	Lubricant
	Calcium fluoride	Lubricant

Abrasive modifiers improve brake lining wear resistance at minimum cost but simultaneously increase noise and decrease mating surface compatibility. In organic materials such as whiting (ground limestone), barite (barium sulfate), clays, silicas, and metals or metal oxides may be added to brake linings in small amounts and fine particle sizes to provide desired characteristics. For example, brass chips in heavy-duty friction materials break up undesirable surface films while a small amount of zinc chips can assist in recovering normal performance following a fade. Particle size is limited to 100 mesh or finer because large, hard particles groove and wear mating surface.[4]

Clearly, a wide range of components may be present in any automobile or truck brake lining depending on anticipated application and use patterns. When material variations are combined with manufacturing variations, it is clear that brake linings can vary greatly from company to company, even when intended applications are identical. Thus, emissions during production and use can vary greatly from lining to lining.

Uses and Applications

Friction materials are used wherever motion must be controlled. Friction materials are used in clutches for transmitting torque, in brakes for slowing or stopping motion, and in torque limiters. Although use in automobile brakes is the most important application commercially, asbestos friction materials are used in buses, trucks, railroad cars, military vehicles, and construction equipment as brakes and clutches. Friction materials are also used in farm tractors, presses, hoists, forklift trucks, machine tools, shuttle cars, mining equipment, chain saws, drilling equipment, spinning and knitting equipment, X-ray machines, tape recorders, typewriters, bicycle brakes, snow blowers, washing machines, and parking meters.

Special Qualities

All products containing friction materials rely on the coefficient of friction between mating surfaces to transmit or stop motion. Brakes convert kinetic energy into heat, absorb the heat, and gradually dissipate it into the atmosphere. Disc brakes consist of two parts, the rotor which is connected to the wheel and the stator on which the friction material is mounted. Clutches transfer kinetic energy from a rotating crankshaft to the transmission and wheels. Both brakes and clutches may operate wet or dry. In dry systems, the heat is conducted to the air and surrounding structure while wet systems operate within oil or another fluid which absorbs the heat to maintain temperatures below 200°C (392°F). The special qualities required by friction materials include:

- Possession of the appropriate coefficient of friction for the desired application
- Ability to withstand the high temperatures generated at friction interfaces
- Dimensional stability
- Strength

- Durability
- Lack of abrasive characteristics which could lead to scoring of mated surfaces

Asbestos is used in friction materials because of the properties listed in Table 23. The most important properties are thermal stability, reinforcing abilities, relatively high friction, fiber flexibility, and relatively low cost.

TABLE 23. UNIQUE PROPERTIES OF ASBESTOS APPLICABLE TO FRICTION MATERIALS[3,7]

Properties	Comments
Fibrous form	Flexibility contributes to forming characteristics. Fibers interlace and interlock, enhancing strength. Flexibility reduces wear at friction interfaces.
Fine fiber diameter	Provide strong reinforcing characteristics because of the large number of fibers per unit weight.
High tensile strength	Provides strength and durability to friction products.
Temperature resistance	Chrysotile unaffected by T <200°C (400°F). Stable for short period of time at T around 1000°C. Able to withstand high temperatures generated at friction interfaces, up to 400°C (750°F). The temperature of maximum ignition loss is 1000°C (1800°F).
Cost	Provides low cost/performance or cost/physical property ratio.

SUBSTITUTES

Most large manufacturers of friction materials have active research and testing programs working toward the development of asbestos-free brakes. Incentives to change from asbestos to some other material are numerous. Some new nonasbestos products are at the stage of consumer testing and their manufacturers are optimistic regarding their future use. Possible alternatives which have been considered include:

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 depths below the operating surface.
2. Steel Wool - Compared to asbestos, the overall strength is lower and the cost is much higher.[8,9]

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 good. A major consideration is cost which is a great deal higher than asbestos. It is more efficient than asbestos under high service temperature conditions, but heat flow is uneven and the tensile and impact strengths are relatively low. Carbon fiber has high thermal stability and low density making it especially attractive for aircraft brakes.[8,9]

5. Sintered Materials or Cermets - These materials are now being used to manufacture brake linings for railroad cars and airplanes. Cermets have extremely high thermal stability. The wear resistance is not good enough for automobile use and the cost is too high. Both carbon fibers and cermets are stable to 700°C (1290°F). High thermal conductivity can excessively heat hydraulic brake fluid causing erratic performance. However, this problem may be avoided by proper design.[10]

6. Semimetallic Materials - Semimetallics are stable to temperatures of 400°C (750°F) and exhibit excellent wear resistance.

7. Potassium Titanate Fibers - The National Aeronautics and Space Administration (NASA) has investigated new friction materials and their applications outside the space program. As part of this effort an improved friction material for lightweight cars and trucks was developed which utilized potassium titanite fibers with the DuPont trade name FYBEX. However, unfavorable toxicological effects and other market considerations caused DuPont to withdraw FYBEX from the market.[3]

8. Aramid Fibers - These are being researched for use in high performance clutch facings in automatic transmissions. They do not possess the flexural or physical strength of asbestos, and the fibers are not easily dispersed as they tend to clump together.[3]

9. Vermiculite - Delaminated vermiculite is used in friction materials which are commercially available throughout Europe. It maintains strength at high temperatures, is compatible with phenolic resins, require little attention in manufacturing methods, and may be used with asbestos to help reduce asbestos content.[11]

10. Silicon Nitride - This material was used for the brake pads in prototypes of the Concorde. It has a longer service life than asbestos and higher thermal conductivity (desirable in this application) but is more expensive and heavier than composites eventually adopted.[11]

11. <u>Others</u> - Various other fibers have been used in phenolic binders, such as aluminosilicates (wollastonite). All have drawbacks and none are yet as good as asbestos, especially for high-temperature applications such as disc brake pads.[11]

Borg Warner Corporation and Abex Corporation (among others) have developed proprietary substitutes for automobile brake friction materials. Some are in the consumer testing stage, but no additional information is available at this time. Raybestos-Manhattan has tested a wide range of materials in an attempt to find a substitute for asbestos. Fibrous glass, mineral wool, wollastonite, potassium titanate fibers, heat resistant organic mineral fibers and natural organic fibers such as cotton and sisal have been considered. Except for wollastonite and the natural organics, the fibers are more expensive than asbestos. Unfortunately, the less expensive fibers lack the heat resistance and fiber strength needed in brakes. Another problem is that many of the fibers tend to break up in the milling process and would require some process modification. Although Raybestos stated publicly in May 1979 that the company would "halt the manufacture of brake linings and other parts that contain asbestos"[12] by using a blend of 10 to 15 components (40 percent fiber, 20 percent resin binder, and 40 percent friction modifiers), discussions with company representatives revealed that this was not strictly true.[13] The company has developed some nonasbestos substitute products for certain applications and has committed itself to a search for nonasbestos substitutes, but the complete removal of asbestos from all friction materials is not expected in the foreseeable future.

Cermet or sintered metals, a copper or iron matrix of material reinforced with steel fiber and various ceramic and metallic property modifiers, are used primarily in heavy-duty applications where high torque capacities and longer life are desired. In many applications, cermet products outperform asbestos products. One example is the aircraft brake market where cermet's market share continues to grow. Currently, 95 percent of all new commercial aircraft use cermet brakes. The remaining 5 percent are carbon composite.[13]

Semimetallic or resin bonded metallic brakes are presently used in heavy-duty automotive applications such as police cars and taxis. While their performance is supposedly superior to asbestos brake linings, semimetallic brake linings tend to perform erratically at different temperatures, fade, and produce more noise than asbestos linings. Currently, semimetallics are 50 to 60 percent more expensive than asbestos linings but with increased production it is estimated that costs would drop to within 25 percent of asbestos brake linings.[3] Approximately 20 percent of passenger cars using disc brakes are equipped with semimetallic disc brakes as original equipment and it is estimated that in 5 to 10 years, most original equipment disc brakes in passenger cars and light trucks will be semimetallic.[14]

General Motors has used a hybrid disc brake consisting of one semimetallic and one organic asbestos lining in some mass produced passenger cars. The asbestos lining insulates the brake fluid from heat generated by the semimetallic surface during braking, but never actually touches the motor surface. In effect, the asbestos content of the brakes is reduced. Compared to asbestos-lined disc brakes, the hybrid brakes have a higher coefficient of friction, higher heat resistance, and wear longer but are more noisy and more expensive. While some industry sources feel that hybrid disc brakes will capture the market because of superior performance, others believe that trends to lower speed limits and lighter weight cars will reduce the need for high performance brakes.[3]

The friction material in disc brakes is formed into an intrinsically stronger shape than in drum brakes and consequently needs less fibrous reinforcement. Asbestos is used in many disc brakes to reduce thermal shrinkage and withstand thermal shock, but asbestos-free semimetallic disc brakes have been developed for automotive uses. A typical composition is given in Table 24.

TABLE 24. COMPOSITION OF AN ASBESTOS-FREE DISC BRAKE PAD (IN VOLUME PERCENT)[4]

Carbon	45
Iron powder	25
Steel fiber	10
Phenolic resin	20

Semimetallic disc brakes, originally designed and produced by Bendix Corporation and now also manufactured by two other companies, are expected to increase their market share relative to asbestos disc brakes. In fact, it is projected that in 5 years nearly all original equipment disc brakes made for passenger cars and light trucks will be made with semimetallics. American automobile manufacturers have targeted 1983 as the last model year asbestos disc brakes will be used.[14]

As for drum brake linings, a nonasbestos product for passenger cars is not available commercially at this time. However, intense research in this area is underway, with specifics still proprietary at this time. The first commercially available nonasbestos drum lining may contain some combination of steel fibers, synthetics, cotton, ceramic, carbon, natural materials, glass, and mineral fibers. For model year 1980, commercial nonasbestos lining was not available for drum brakes; however, Bendix Corporation is apparently very close to marketing this kind of product. American automobile manufacturers have targeted 1985 as the last model year asbestos drum brakes will be installed as original equipment.

The use of cermet brake linings may increase once the problem of their interaction with hydraulic brake fluid can be solved. With all of the current research into brake lining substitutes, a nonasbestos product for more universal use should become available in the future.

MANUFACTURING

Primary Manufacture

Plants manufacturing friction products contain a diverse collection of machinery. Typically included are grinders, mixing vats, mills, molds, extruders, curing ovens, lathes, metal stampers, presses, paper machines, conveyors, and drill presses. Chemical operations, such as preparation of specific resins, may also be performed onsite. The exact mix of machinery at any given plant depends upon the manufacturing processes in use. Friction materials can be molded using either a dry mix or a wet mix process, woven like textiles, or formed like papers.

Overview of Manufacturing Process--

In the first steps of manufacturing friction materials, bags of asbestos are typically dumped into mixers that blend the formulations in either a wet or dry state depending on product specifications. A fluffing device may also be used. Next, the mix is fed through a compression molder (dry) or an extruder (wet), to form strips that are cut and bent into various widths and lengths. A release compound is added to prevent sticking. Dry-mixed formulations, which include a small amount of solvent, are transferred to pressing molds where slabs are formed, sometimes after a preheating step. Slabs are then hot pressed, causing resin in the slabs to flow, binding the mixture upon curing. The slabs are sawed into specific parts and sent to a curing oven.

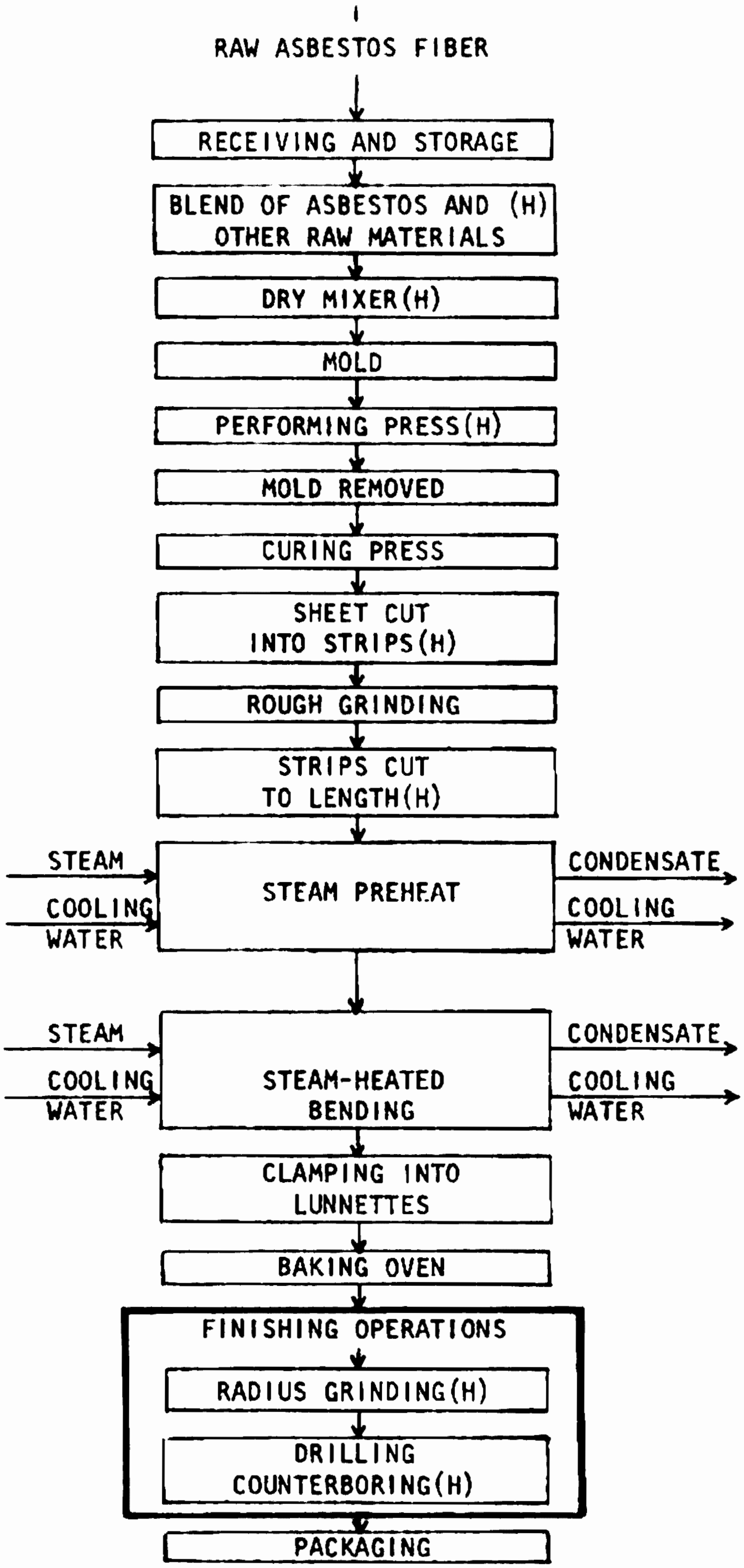
Dry Mix Molding Process--

The steps typically employed in manufacturing friction materials using the dry-mix molding process are shown in Figure 6. Asbestos fibers, metallic constituents, bonding agents, and other additives are weighed, mixed, then placed into a metal mold and formed into a uniform sheet using a preforming press. The mold is removed and the material is heated sufficiently in a curing press to allow the resin to flow and set. Only partial curing occurs during this step. The material is then cut to product-sized segments and rough ground. The resin is then softened by a preheating step after which the proper arc is formed by steam-heated bending. In the final curing step, the segments are placed in compression molds (lunnettes) and baked at a pressure of 1,000 to 2,000 psi. This converts the resin to a permanent thermoset bond so that the desired arc will be retained. Finishing steps, including sanding and grinding to the correct thickness, edge grinding, drilling holes for rivets, inspecting and branding are required before the brake linings can be packaged.

Wet Mix Molding Process--

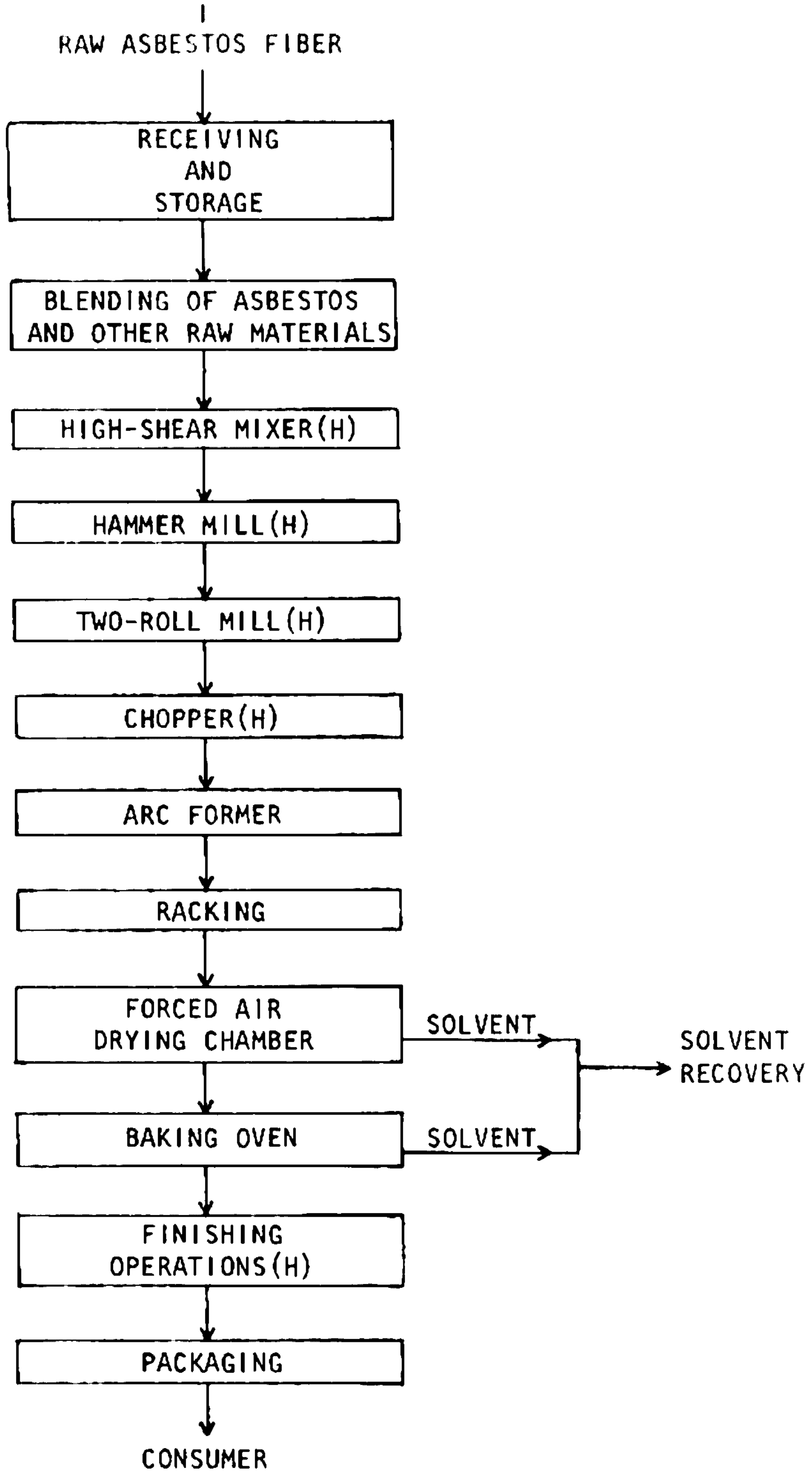
Figure 7 shows the major steps in the manufacture of wet-mix molded brake linings. The term "wet mix" is actually a misnomer since the ingredients of the molded lining are relatively dry. The term arises from the use of a wet solvent in the process.

The raw materials are blended in the proper proportions, mixed and then sent through a hammer mill in order to ensure homogeneity. The mixture is then forced into the nip of two roll formers where it is compressed or extruded into one continuous strip of friction material. A chopper cuts the material to the proper length after which an arc former is used to give the



Note: (H) - Indicates hooded operations.

Figure 6. Dry-mixed molded brake lining manufacture.[15]



Note: (H) - Indicates hooded operations.

Figure 7. Wet-mixed molded brake lining manufacture.[15]

material the desired brake lining shape. The linings are placed in racks, air dried and baked to remove any remaining solvent before final finishing operations.

In an alternative process, arc-formed linings are placed in metal molds and baked in an oven prior to finishing and inspection. Another variation has automatically measured volumes of the raw material mixture dropped into disc brake molds where pressure is applied, shaping the contents which are removed and baked after finishing.

Molded Clutch Facings--

Molded clutch facings are produced in a similar manner, as Figure 8 illustrates. Asbestos fiber, a rubber friction compound and a solvent are combined in a mixer and then conveyed through a two-rolled mill which compresses the mixture into a continuous strip of material. A punch press is used to cut the material into doughnut-shaped pieces. Scraps from this process are mixed and then fed back into the two-roll mill while punched sheets are racked, placed in drying ovens and then into baking ovens for final curing and solvent extraction. Oven dried sheets are finished, inspected and packaged. Finishing operations include sanding, edge grinding, drilling and dusting.

Paper Products--

Some friction materials can be classified as paper products based on their method of manufacture. In particular, discs for automatic automotive transmissions are punched from rolls of asbestos paper formed on a Fourdrinier or cylinder machine. The forming process is discussed in detail in Section 4, Asbestos Paper Products. Since transmission discs are annular, much of the paper produced becomes scrap. About 70 percent of a roll is wasted in cutting and must be recycled. In a later step the paper discs are sprayed with a phenolic resin, heated, and bonded to steel wafers. The product transmission plates, steel cores with friction material on either side, are then ground, inspected, and packaged.

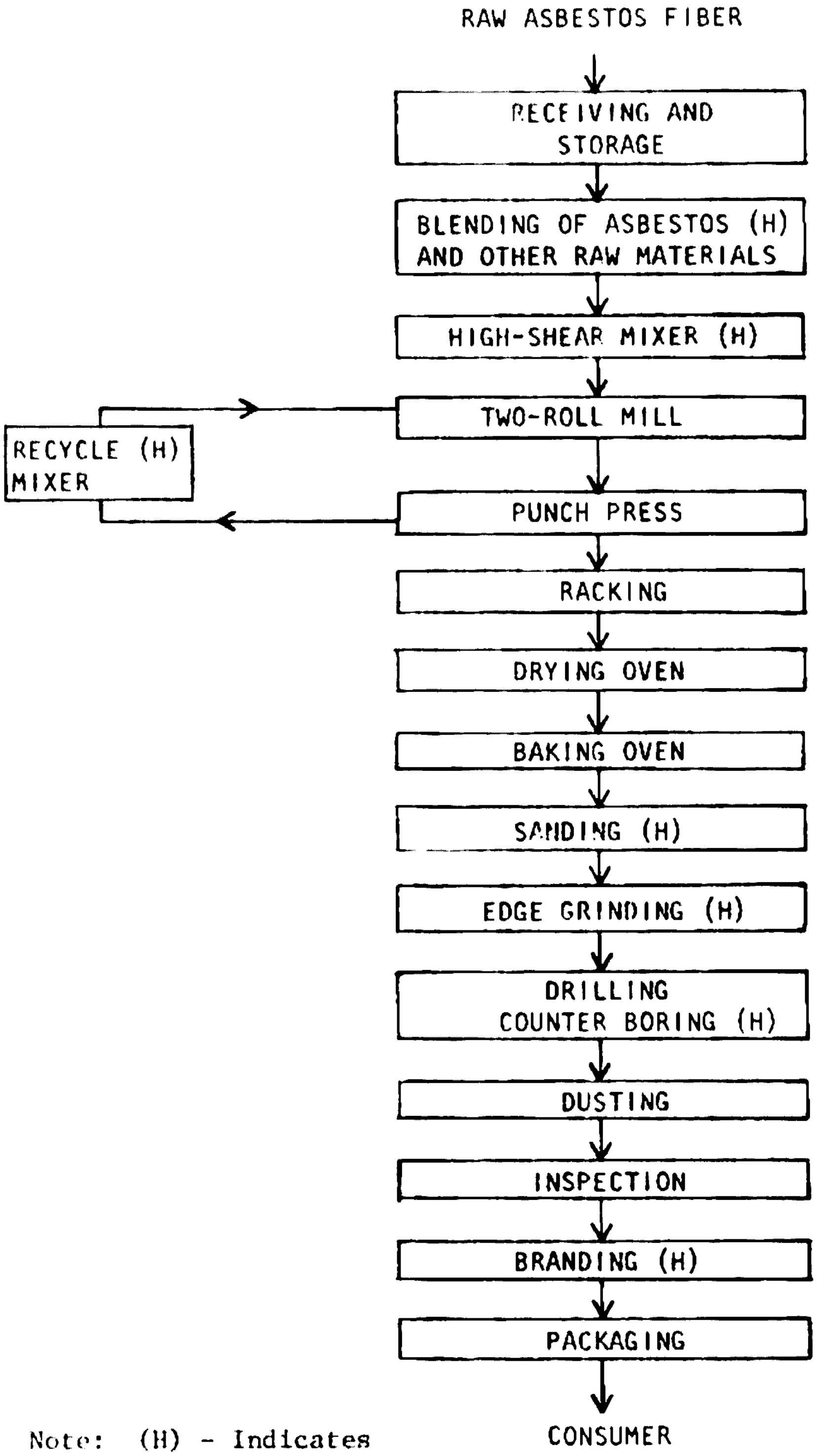
Die Cast Clutch Facings--

Larger clutch facings are frequently die cast. Raw materials which include asbestos and perhaps rubber and metallic oxides impregnated with resin are mixed, then brought to the work station. A worker measures out the necessary amount and pours it into a mold where it is pressed to the required density. After drying, the form is gear cut and bonded to a metal backing. The face is then ground with a pattern designed specifically for the eventual product application.

Woven Products--

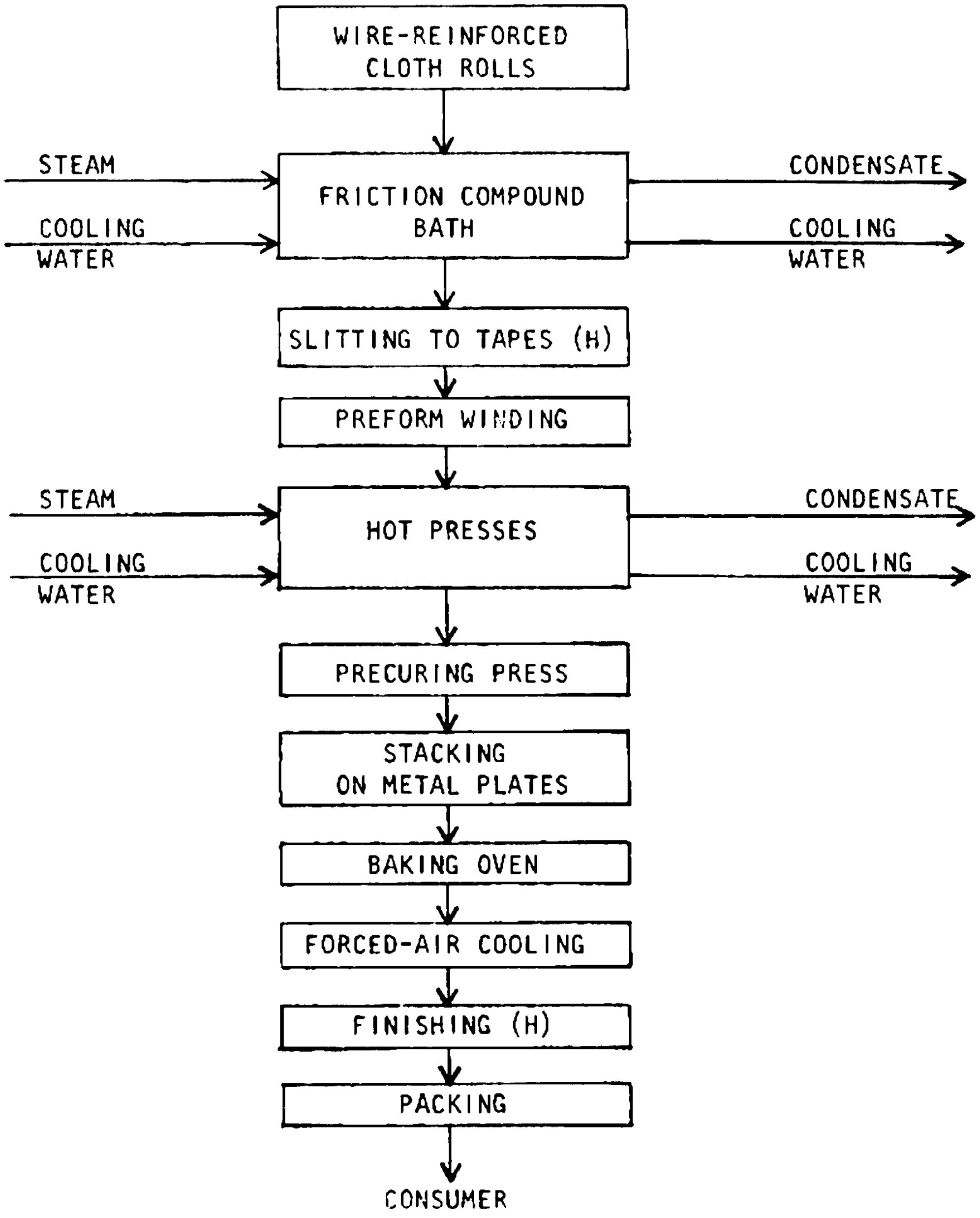
Woven clutch facings are frequently classified as being asbestos friction products. Figure 9 shows the press used in their manufacture. More detail on woven products is available in Section 12, Textiles.

Woven clutch facings and brake linings are manufactured from high strength asbestos fabric that may be reinforced with wire. The fabric is predried in an oven or by autoclave before being impregnated with resin in one of several



Note: (H) - Indicates hooded operations.

Figure 8. Molded clutch facing manufacture.[15]



Note: (H) - Indicates hooded operations.

Figure 9. Woven clutch facing manufacture.[15]

techniques. The fabric may be immersed in a resin bath, exposed to the binder in a pressurized autoclave, mixed with resin before being wound into yarn or pressed beneath a roll whose surface is covered with resin. Once solvents are evaporated from the fabric, it is made into brake linings or clutch facings.

Brake linings are made in a manner similar to that described earlier: woven clutch facings are made differently. Treated fabric is cut into tape width strips by a slitting machine before being wound around a mandrel to form a fabric roll. The roll is placed in a steam-heated press, baked in an oven to cure the resin in the clutch facing, then finished, inspected and packaged in the by now familiar sequence.

Secondary Manufacture

Some brake pads are sold to secondary manufacturers. The division between primary and secondary manufacturers, however, is not particularly important since secondary manufacturers perform a subset of the tasks generally considered the preserve of primary manufacturers. Secondary manufacturers take brake pads, rivet or bond them to brake shoes, inspect them, and package them as the final product. Any defective assembly could discredit their properly built products.

Manufacturing Plants and Production Volumes

The manufacture of friction products is highly labor intensive, with many processing and handling steps. Because of the labor intensive production process, differences between large and small manufacturers are limited to the variety of products formed and the number of work stations devoted to each. There are presently a large number of friction material manufacturers but many of the smaller firms have extremely limited product lines.

Table 25 lists the U.S. manufacturers of asbestos-bearing friction materials including, if known, their respective friction product sales in 1975 and the products they manufacture. Both larger diversified companies such as Raybestos-Manhattan and smaller, single plant companies are included in this list. The first eight companies listed on this table accounted for 75 to 85 percent of the total estimated sales of asbestos friction products in 1975, a pattern consistent with the industry's historical trends. From 1954 to 1967, the eight largest companies together accounted for 86 to 91 percent of the industry's value of shipments.[4]

ASBESTOS RELEASE

For friction materials, release of asbestos fibers will be discussed for four general areas: during manufacture, use, replacement, and disposal. Under manufacture emissions is included workplace concentrations, for various areas, human exposure to airborne asbestos, water emissions, and solid waste. Replacement emissions discuss release as a part of the automotive aftermarket which includes refacing and rebuilding, repackaging and general repairs. Disposal emissions are included within the manufacturing emissions sections (i.e., solid waste, etc.). An input/output figure is shown first to help detail the path of these emissions.

TABLE 25. U.S. MANUFACTURERS OF ASBESTOS-BEARING FRICTION MATERIALS[9,16-37,55]

		Products							
		Brakes				Clutches			
Company	Plant location(s)	Automobile and light truck	Heavy duty truck	Railcar	Industrial	Vehicle	Industrial	Comments	Estimated 1978 sales[a] ($ million)
Raybestos-Manhattan, Inc.[16] RM Friction Materials Co.	Stratford, CT Mannheim, PA Crawfordsville, IN Fullerton, CA	Drum, disk	Disk, segment block			✓	✓		165.0
Bendix Corporation[17] Automotive GRP	Troy, NY Cleveland, TN Southbend, IN	Drum, disk	Block			✓	✓	Brakes - machine tools, off-highway equipment.	94.5
Abex Corporation[17] Friction Products Group	Cleveland, OH Troy, MI Winchester, VA	Drum, disk	Block	✓					86.6
General Motors[17] Delco-Moraine Div., Inland Div.	Dayton, OH	Drum, disk							16.2
H. K. Porter Company[18] Thermoid Div.	Huntington, IN	Drum, disk			✓				26.5
Chrysler Corporation[17] Cyclebond Div.	Trenton, MI	Drum, disk							-
Borg Warner Corporation[19]	Bellwood, IL	Drum, disk				✓			-
Nuturn Company[20] (formerly World Bestos Co.) Maremont Corp., Grizzly Products, Div.	Nashville, TN Paulding, OH		Block						21.5
National Friction Products Corporation[21]	Logansport, IN				✓	✓	✓	Off-road vehicles, cranes, shovels, travel trailers, mobile homes, plant machinery, appliances.	12.0
Auto Specialties Manufacturing Company[22]	St. Joseph, MI	Drum, disk			✓		✓	Off-road vehicles, agricultural equipment.	0.66
Standco Industries[23]	Houston, TX				✓		✓	Off-road equipment, winches, cranes, drilling rigs	8.7
Friction Products Company[24]	Medina, OH		Block		✓	✓	✓		6.0
Royal Industrial Brake Products, Inc.[25]	Danville, KY	Drum, disk						Assembly of parts from Canadian manufacturers.	16.0
Reddaway Manufacturing Company[26]	Newark, NJ				✓	✓	✓		3.0
Molded Industrial Friction Corporation[27]	Prattville, AL		Block					Tractors and trailers.	3.6
Sterling Brake Block Manufacturing Co.[28]	Wheeling, WV Bridgeport, OH		Block						6.0
Force Control Industries[29]	Fairfield, OH			✓	✓			Disk and plate brakes, railcar and diesel engine brakes, tramways, off-road vehicles.	-
Brassbestos Manufacturing Corporation[29]	Patterson, NJ	Drum, disk						Rebuilt.	8.3
Auto Friction Corporation[30]	Lawrence, MA	Drum	Drum						26.5
Gatke Corporation[31]	Warsaw, IN				✓		✓	Custom manufacturing.	12.0
Lasc Brake Products Company[32]	Oakland, CA	Drum, disk	Block						3.8
MGM Brakes, Incorporated[33]				✓	✓			Off-road vehicles, buses, railcars, mining equipment, towing vehicles	<1
Carlisle Corporation[34]	Ridgway, PA		Block	✓				Buses, off-road vehicles	28.2
Thiokol Chemical Corporation[35]	Trenton, NJ	Drum, disk						Rebuilt only.	9.7
F. T. Brake Lining Company Inc.[36]	Lawrence, MA	Drum	Block						-
Eaton Corporation[37]	Kenosha, WI		Block, disk		✓				-
Scan-Pac Manufacturing Company[38]	Menomonee Falls, WI								2.8

Input/Output

Figure 10 shows estimates of process and disposal emissions for the asbestos friction materials industry. These figures are based on Levine's[38] 1974 estimates projected to 1980 U.S. Bureau of Mines consumption figures. Potential sources of emissions include blending mixing, cutting, milling, chopping and finishing operations. Of the 43,700 metric tons of raw asbestos fiber processed in 1980, approximately 42,525 m.t. are incorporated into the product and 1111.9 m.t. are sent to disposal as vacuum cleaner and baghouse dust. An estimated 10.9 metric tons escape through a control device (typically a baghouse). Levin's[38] atmospheric emissions estimates are based on gross assumptions with a reported uncertainty of at least an order of magnitude. Meylan's[4] estimates of emissions are generally 1 to 3 orders of magnitude less. Atmospheric emissions from disposal, based on GCA estimates, are shown to total 2.2 metric tons per year for the friction materials industry. This last estimate, which follows Levine's[38] 1974 data, also takes into account the Asbestos NESHAPS regulations adopted in 1975 regarding the disposal of asbestos-containing waste material.

During Manufacture

Workplace Fiber Concentrations--

Table 26 shows the time-weighted average exposures at different points in the friction material production process. These figures are based on 12 plants which consumed approximately 35,000 m.t. of asbestos in 1975 and made up about 60 percent of the friction products segment during that year. Data was obtained by Weston[39] in a survey using industry questionnaires and is of questionable validity as industries may tend to report biased figures. In addition, the range of data reported is extremely broad, indicating questionable sampling and counting procedures.

TABLE 26. TIME-WEIGHTED AVERAGE FIBER CONCENTRATIONS OF OPTICAL MICROSCOPE VISIBLE FIBERS GREATER THAN 5 μm IN FRICTION PRODUCTS MANUFACTURING PLANTS[39]

Process step	Fiber count Range (fiber/cc)	Fiber count Typical (fibers/cc)
Receiving and storage	0.25 - 2.5	1.0
Fiber introduction	0.4 - 4.6	2.5
Mixing	0.2 - 8.0	2.3
Forming and rolling	0.5 - 22.0	3.3
Curing	0.5 - 3.5	1.5
Finishing	0.6 - 7.4	2.0
Adjustment and printing	0.7 - 1.0	1.0
Inspection	0.1 - 15.0	2.0
Packaging	1.0 - 2.0	1.5

*Based on plants representing 50 percent of asbestos friction material production.

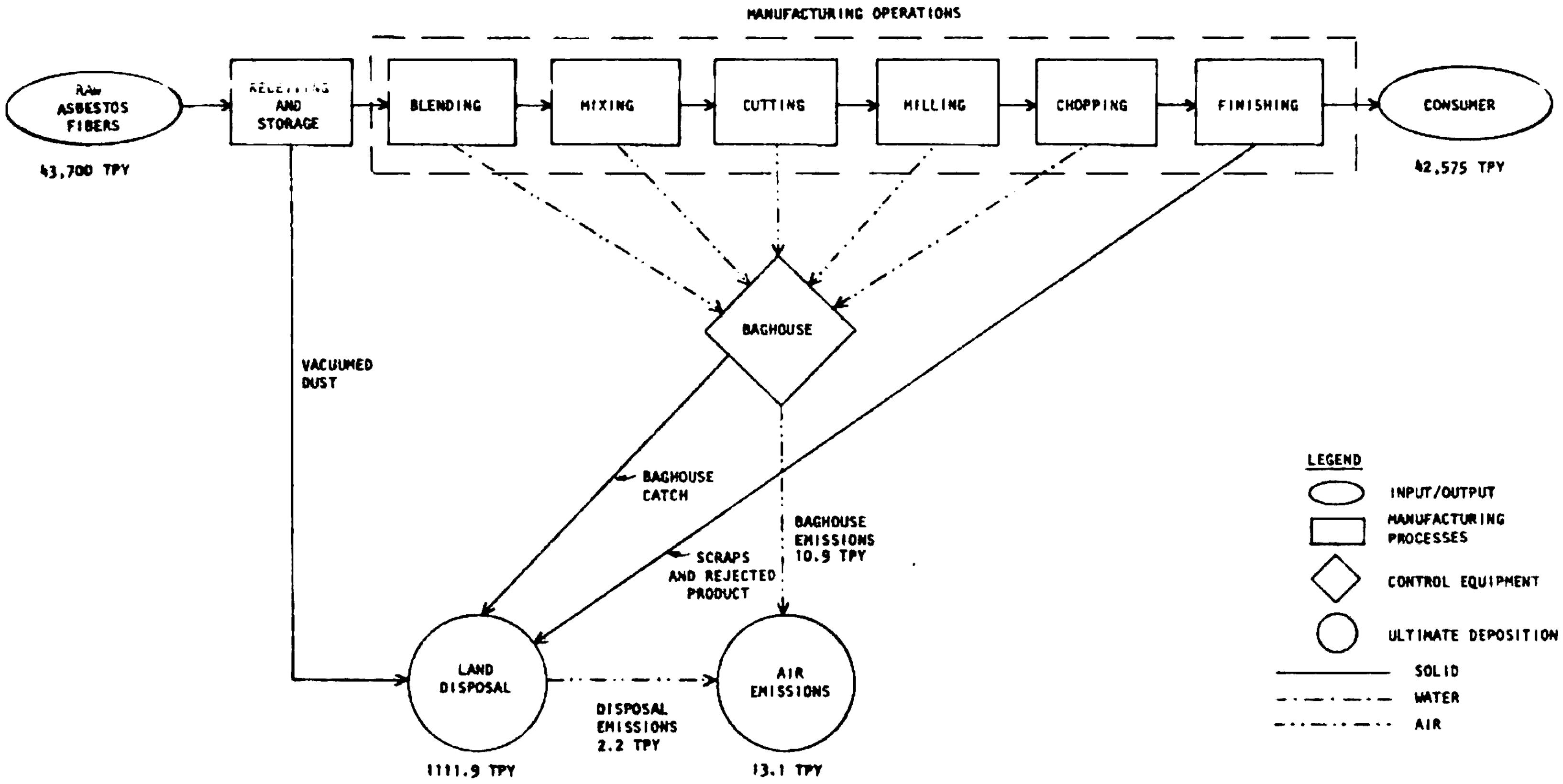


Figure 10. Input/output estimates for the asbestos friction materials industry in metric tons.

A review of the data collected indicates that in addition to variations in sampling and counting procedures there are many reasons for the wide variations in the range of fiber counts. The largely individual manual techniques and worker practices introduce considerable deviations, as does the percentage of asbestos in the product which may range from 30 to 70 percent by weight.

Receiving and storage--Exposures during receiving and storage in asbestos friction material production are identical to receiving and storage exposures in all other primary asbestos industry segments. Consequently, the range reported for asbestos paper, 0.25 to 2.5 fibers/cc TWA and the typical value,[39] 1.0 fibers/cc TWA, are equally valid for friction materials.

Fiber introduction--Bags of the raw material may be manually opened and dumped into hoppers for transport to mixers. Fiber levels during this operation are higher than those in papermaking fiber introduction, ranging from 0.4 to 4.6 fibers/cc TWA for friction materials as opposed to a 0.3 to 2.8 fibers/cc TWA range for papermaking. Typical fiber levels exhibit a similar difference, with 2.5 fibers/cc typical of fiber introduction for friction products and 1.9 fibers/cc typical for papermaking.[39]

It is not clear why such a difference should exist, since the processing step is similar. Perhaps the fact that in some paper applications it is not necessary to dump the fiber out of a bag contributes to lower typical values in papermaking. However, this characteristic should not affect the range reported since some paper applications require that the asbestos be removed from the bag.

Mixing--The combined raw materials may be mixed either dry or wet, depending on product specifications. The state in which mixing occurs greatly influences the workplace fiber levels, since fibers in water are unlikely to become airborne, while dry fibers can easily be dispersed. Fiber levels of 0.2 to 8.0 fibers/cc TWA were reported with 2.5 fibers/cc TWA considered to be typical.[39]

Forming or rolling--The product of the mixing stage is fed to a compression molder or an extruder, again depending on the required product. Levels of 0.5 to 22.0 fibers/cc TWA were recorded; a level of 3.3 fibers/cc TWA was considered typical.[39] The higher exposure levels are caused by the manual handling of the dry preform mix, which is conveyed in open carts, scooped by hand, weighed, and poured into a block mold where it is mechanically pressed into the shape of the finished product.[38]

Curing--Some formulae require a heating step that causes resins to flow and bind the mixture. In the curing step fiber levels ranged from 0.5 to 3.5 fibers/cc TWA. A fiber count of 1.5 fibers/cc TWA was typical.[39]

Finishing--Parts taken out of the curing oven undergo a number of steps to produce the final product. These machine-assisted manual finishing steps may include grinding, sawing, drilling, blanking, tapping, and boring. Fiber levels in finishing were typically 2.0 fibers/cc TWA, although reported values ranged from 0.6 to 7.4 fibers/cc TWA.[39]

Adjustment and printing--After finishing, the friction products are dusted, adjusted, and printed. Fiber levels in this operation are consistently close to 1.0 fibers/cc TWA. The range of exposures during this process is very narrow, 0.7 to 1.0 fibers/cc TWA.[39]

Inspection--Generally considered to be an examination of the finished product, inspection encompasses different activities in different plants. Some plant inspection stations only examine the finished product; if the product is defective or needs more comprehensive finishing it is returned to the finishing area or rejected entirely. Other plants have additional equipment in the inspection area so that any defect in the product can be rectified immediately. Consequently, fiber counts recorded in inspection areas vary widely from 0.1 to 15.0 fibers/cc. Usually, the fiber level will be toward the low end of the range, with 2.0 fibers/cc TWA considered typical.[39]

Packaging--Even workers involved in packaging the final product are exposed to fibers. The range of reported fiber levels in packaging was 1.0 to 2.0 fibers/cc TWA with 1.5 fibers/cc TWA considered typical.[39]

Emissions to Air--

The maximum allowable exposure over a 40 hour week for workers in the asbestos industries has been set at 2 f/cc.* Workers are exposed to an average fiber count of 1.9 f/cc,* with fiber counts as high as 22 f/cc* being reported (see Table 26). The values reported reflect levels recorded in or before 1975 and are probably higher than present day concentrations. With greater worker awareness and increased employer concern, along with the regulatory activities of OSHA, it is very likely that friction product worker exposure concentrations are well below the 2 fiber/cc limit. Documentation in the open literature to substantiate this belief, however, is not available.

With a workplace fiber count of 1.9 f/cc, workers can be expected to inhale 119† billion fibers per year.[40] Estimates of nonoccupational exposure to asbestos have been made using a binormal continuous plume dispersion model with assumed plant emissions. The affected population was assumed to be those people living within a 5 km radius of a friction material manufacturing plant. The atmospheric asbestos concentration around the plant was estimated to be 23,000 f/m^3† and the annual amount of asbestos inhaled was estimated to be 125 million fibers† per person. This compares to a mean ambient urban exposure of 5,000 $fibers/m^3$† with an average annual inhalation of 27.4 million fibers per person.[40]

Release to Water--

Water is not used directly in the production of friction materials except for those products formed on paper machines from a 2 to 3 percent solids slurry. Water usage and consequent water pollution associated with this process is discussed in Section 4, Asbestos Paper Products. Despite the term

---

*Optical-microscope-visible fibers >5 μm in length.

†Electron-microscope-visible fibers.

"wet mix" used in the description of one of the manufacturing processes it is actually dry because no wastewater is generated. Solvents are used to make the mix of raw materials more pliable; no excess water is used and no floor drains are present.

Wastewater is generated in some solvent recovery operations and in wet dust collection equipment used to control dust throughout the plant. Solvent recovery wastes normally have very low suspended solid levels. A typical solvent recovery operation has been reported to have 0 mg/l suspended solids in its waste stream.[41] Wastes from wet dust collection have significantly higher solids concentrations.

Wastewaters from wet dust collectors are slurries of dust from plant operations, and are characterized principally in terms of suspended solids. Clearly, the concentration will be a function of the amount of dust generated and the water flow rate which can vary from 1.9 to 37.9 liters per minute per 28.3 standard cubic meters of air per minute. Plant air systems served by wet scrubbers range from 283 to 7079 scmm, resulting in discharges of 189,250 to 2,838,750 liters per day.[41] Units are for the most part equipped for partial recirculation. Sludge, or settled slurry is discharged to a settling lagoon where it becomes a solid waste problem. In a typical plant using wet collection, about 1566 kg of asbestos are collected annually. About 95 percent or 1488 kg are removed as sludge by clarification. The sludge is disposed of by landfilling while the remaining 78 kg of asbestos are discharged to surface waters.[4]

Release to Land--

Most of the solid waste generated in the manufacture of friction material is produced in grinding. In the past, grinding dust was collected for use as solid fill in marshlands and low-lying areas. It is now trucked to sanitary landfills for disposal but as the hazards of asbestos have become better known, fewer and fewer landfills are willing to accept asbestos-containing materials for disposal.

Estimates of the percentage of asbestos lost in grinding and drilling range from 12.7 percent to 30 percent,[41,42] but even with the high cost of raw materials, asbestos in these scraps is not recovered for reuse. Once the binders and resins have set, it is uneconomical to break them down to salvage the fibers.

In most cased baghouses are used to collect grinding and drilling dusts. It has been estimated that wastes can amount to as much as 12.2 tons/month for a plant producing 40,000 brake shoes per day.[4] Based upon a total asbestos consumption of friction materials of metric tons in 1980, 1,112 tons of asbestos would be lost in product waste. Baghouses would collect about three-fourths of this total, or about 834 tons, while the remainder, 278 tons, would be collected by vacuum cleaners and as damaged product.[4]

During Use

During vehicle operation friction material, whether used as a disc pad, drum lining or clutch facing, engages with a metal rotor to form a sliding friction couple which converts the kinetic energy of rotating members into heat, absorbs heat and dissipates it to the surroundings. Emissions are generated by wear. Asbestos fibers are pulverized into small particles which are either trapped in the brake or clutch housing, fall to the road or are emitted to the atmosphere. Most of the asbestos, however, is heated sufficiently to cause chemical conversion to olivine or forsterite.

A number of articles have discussed asbestos emissions from brake linings. Table 27 summarized the published data. A detailed discussion of the reported information is provided in reference 4.

Jacko and DuCharme reported[42] that approximately 33.6 million kilograms of asbestos in friction material wear away annually. Based on their experimental finding that only about 0.2 percent of the debris is not converted to some other substance, total annual asbestos emissions were estimated to be 71,759 kilograms. Of this amount, 85.6 percent or 61,426 kilograms were estimated to drop out on to the ground, 11.2 percent or 8,037 kilograms was estimated to be retained within the brake or clutch housing and only 3.2 percent or 2,296 kilograms was believed to become airborne.

Rohl, et al.[49] performed a similar calculation based on a separate analysis of friction material wear debris, but otherwise retaining all of Jacko and DuCharme's assumptions. Their best estimates of the total annual asbestos emission were that 1,329,039 kilograms of asbestos dropped out, 172,367 kilograms were retained in brake and clutch housings, and 49,896 kilograms become airborne.

Elevated levels of asbestos were found in a study by Bruckman and Rubino[52] in which airborne asbestos concentrations were monitored at three Connecticut toll plazas. Asbestos concentrations were found to vary between 3 ng/m^3 and 41 ng/m^3. A nearby large industrial asbestos user was suspected of influencing the highest measured concentration. Although no correlation was made between vehicular traffic and the asbestos concentration it was concluded that the decomposition of brake linings is a significant source of airborne asbestos fibers.

During Disposal

Friction materials are usually replaced before they are completely worn out. Most passenger vehicles reportedly use a set of asbestos-containing brake linings every three to four years.[53] Asbestos-containing friction products are disposed of in the form of worn brake linings, disc pads, and clutch facings. These materials may be discarded as scrap pieces separated from any metal component which can be reused or scrapped along with the machinery they were a part of such as automobiles.

Because of the means by which they are manufactured, asbestos fibers are bound within the pieces even though they are worn. During disposal, asbestos material should not be released from the worn pieces due to the lack of sufficient energy to dislodge the fibers bound in the friction material matrix. Ultimately, the nonfriable friction material is either incinerated or landfilled.

TABLE 27. SUMMARY OF PUBLISHED DATA - ASBESTOS EMISSIONS FROM BRAKE LINING USE[42,48]

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[43]	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[44]	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,[45] 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[46]	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)
Anderson et al., 1973[47]	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 and procedures precluded a size distribution estimate	~0.02%
Jacko and DuCharme,[42] 1973 (contains same data as Jacko et al., 1973)[48]	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 Batelle Labs give a figure of 0.171%)

(continued)

TABLE 27 (continued)

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[49]	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[50]	Samples were taken from fresh and worn brake linings and from the atmosphere near a freeway.	Electron microscopy	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 fibers and reducing their average length, but not in altering their crystal structure
Rohl *et al.*, 1977[51]	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 2.5% in France

Emissions in Automotive Aftermarket

The automotive aftermarket in which asbestos exposures may occur is divided into three major sections: refacing or rebuilding of friction materials, repackaging of friction materials, and general brake repair and service.[39]

Refacing and Rebuilding--

The major difference between refacing operations and plants in the primary friction materials segments is that no raw asbestos fiber is handled in the smaller rebuilding plants. Therefore, the control problems are not as acute. Most rebuilt asbestos-bearing parts plants have had local controls for a long time. Asbestos exposure levels measured at three of these establishments were reported by NIOSH during the American Industrial Hygiene Conference in New Orleans in May 1977 and are presented by process step in Table 28.

Repackaging--

Repackaging operations in the automotive aftermarket consist of manually transferring asbestos friction material products from one container to another at a location other than the facility where the friction material was produced. Asbestos exposures for this sector have been reported to range from 0.2 to 0.6 fibers/cc TWA.[4]

General Repairs--

From the existing data on asbestos exposure levels during brake repair work, it appears that an establishment using compressed air for blowing residual dust from brake lining assemblies may exceed the 10.0 fibers/cc ceiling limit under the current OSHA standard. Data reported by Rohl[43] on asbestos emissions during brake lining maintenance indicated that a peak exposure of 29.8 fibers/cc had been encountered 0.9 to 1.5 meters from the workplace. These data are presented in Table 29.

TABLE 28. ASBESTOS FIBER[a] EXPOSURE LEVELS IN REBUILDING BRAKE AND CLUTCH ASSEMBLIES[54]

Facility	Fibers/cc TWA			
	Receiving and cleaning	Bonding and riveting	Cutting and grinding	Inspection and packaging
A				
Mean	1.1	0.6	1.1	0.7
Range	0.4 - 4.8	0.2 - 1.4	0.8 - 1.6	0.8 - 1.1
Number of samples	15	20	6	4
B				
Mean	4.0	2.7	5.0	
Range	1.0 - 7.6	1.1 - 5.8	1.5 - 9.3	–
Number of samples	5	6	6	
C				
Mean	1.3		0.8	
Range	1.2 - 1.3	–	1.5 - 9.3	–
Number of samples	2		6	

[a]Fibers 5 to 100 μm were counted using phase contrast microscopy according to the NIOSH method.

TABLE 29. FIBER LEVELS[a] DURING BRAKE LINING MAINTENANCE[49]

Distance from workplace (meters)	Peak exposure (fibers/cc)
0.9 to 1.5	6.6 to 29.8
1.5 to 3.05	2.0 to 4.2
3.05 to 6.1	0.4 to 4.8
Background samples	0.1 to 0.8

[a]Fibers 5 to 100 μm were counted using phase contrast microscopy.

CONCLUSION

Between 1978 and 1980 there has been a 41 percent decline in the amount of asbestos consumed to manufacture friction products. The decline can be attributed to a slowdown in automobile sales and the increasing use of asbestos substitutes. Atmospheric release of asbestos fibers during primary manufacturing, by far the largest source of emissions in this category, is estimated to have declined to 13.1 tons per year in 1980 from 21.6 tons per year in 1978. Asbestos containing solid waste is estimated to have declined from 1,876 tons to 1,112 tons between 1978 and 1980. Process wastewater discharged from friction products manufacturing plants is not expected to be laden with asbestos fibers. Wastewater from wet dust collectors employed to control fiber release, however, will contain asbestos material. About 95 percent of the asbestos material suspended in the control device wastewater is removed as sludge by clarification. The sludge is typically disposed of by landfilling with the remaining five percent discharged to surface waters. The decline in asbestos releases that has been estimated between 1978 and 1980 is expected to continue through 1981, coinciding with the turndown in the economy and an increased interest in asbestos substitutes.

Beyond 1981, the outlook for the use of asbestos in friction materials is, at best, mixed. The majority of the industry's products are used in passenger automobiles and, as such, are influenced by the vagaries of the buying public. If a lot of new cars are being sold, a lot of new brakes will be required. Conversely, if fewer new cars are sold, more used cars in the marketplace will result in more sales of replacement brakes. Further uncertainty is introduced by the American automobile manufacturers' avowed intentions to eliminate asbestos from original equipment brakes by the 1985 model year. If a successful substitute is found, asbestos consumption in friction materials will drop precipitously.

REFERENCES

1. Bradfield, R.E.N. Asbestos: Review of Uses, Health Effects, Measurement and Control. Atkins Research and Development, Epsom Surry, England. January 1977.

2. Clifton, R.A. Asbestos. 1980 Minerals Yearbook. U.S. Bureau of Mines. Washington, D.C.

3. Wright, M.D., et al. Asbestos Dust Technological Feasibility Assessment and Economic Impact Analysis of the Proposed Federal Occupational Standard: Part I. U.S. Department of Labor, OSHA. September 1978. (Draft).

4. Meylan, W.M., et al. Chemical Market Input/Output Analysis of Selected Chemical Substances to Assess Sources of Environmental Contamination: Task III - Asbestos. EPA 560/6-78-005. August 1978.

5. Bark, L.S., D. Moran, and S.J. Percival. Chemical Changes in Asbestos-Based Friction Materials During Performance. A Review. Wear. 34:131-139. 1975.

6. Zussman, J. The Mineralogy of Asbestos. In: Asbestos, Volume 1, Properties, Applications and Hazards. L. Michaels and S. S. Chissick, eds. John Wiley and Sons, New York, N.Y. 1979. pp. 45-65.

7. Hodgson, A.A. Chemistry and Physics of Asbestos. In: Asbestos, Volume 1, Properties, Applications and Hazards. L. Michaels and S. S. Chissick, eds. John Wiley and Sons, New York, N.Y. 1979. pp. 67-114.

8. Jacko, M.G. and S.K. Rhee. Brake Linings and Clutch Facings. Encyclopedia of Chemical Technology. Third Edition, Volume 4. John Wiley & Sons, New York, N.Y. 1979. pp. 202-212.

9. Telecon. Reginal D. Kelley, Force Control Industries, with Robert Bouchard, GCA Corporation. March 3, 1980.

10. Green, A.K., and A.M. Pye. Asbestos Characteristics, Applications and Alternatives. Fulmer Research Institute, Fulmer Special Report No. 5, ISSN 0427-7457. 1976.

11. Pye, A.M. A Review of Asbestos Substitute Materials in Industrial Applications. Journal of Hazardous Materials (Netherlands). 3:137-138. 1979.

12. Einhaus, J.R. Age of Asbestos on Vehicle Parts Ending. Automobile Industries. p. 27-31. May 1979.

13. Telecon. M. G. Jacko, Bendix Materials Center, with Nancy Roy, GCA Corporation. November 19, 1979.

14. Telecon. M. G. Jacko, Bendix Materials Center, with Nancy Roy, GCA Corporation. August 1979.

15. U.S. Environmental Protection Agency. Control Techniques for Asbestos Air Pollutants. Publication AP-117. February 1973.

16. Telecon. Raybestos-Manhattan, Inc. with David Cook, GCA Corporation. February 28, 1980. Friction products manufactured.

17. Telecon. Kevin Peppard, Bendix Corporation, with David Cook, GCA Corporation. February 28, 1980. Friction product manufacturers.

18. Telecon. H.K. Sleeth, Porter Company, with Robert Bouchard, GCA Corporation. February 29, 1980. Friction products manufactured.

19. Telecon. Terry Blaine, Borg-Warner Corporation, Spring Division with Robert Bouchard, GCA Corporation. March 4, 1980. Friction products manufactured.

20. Telecon. Roy Huckabee, Nuturn Company, with Robert Bouchard, GCA Corporation. February 29, 1980. Friction products manufactured.

21. Telecon. Earl Fygert, National Friction Products Corporation, with Robert Bouchard, GCA Corporation. February 29, 1980. Friction products manufactured.

22. Telecon. Bill Shine, Auto Specialists Manufacturing Company, with Robert Bouchard, GCA Corporation. February 29, 1980. Friction products manufactured.

23. Telecon. Standco Industrial with Robert Bouchard, GCA Corporation. February 28, 1980. Friction products manufactured.

24. Telecon. Jack Payton, Friction Products Company, with Robert Bouchard, GCA Corporation. February 29, 1980. Friction products manufactured.

25. Telecon. Andrews, Royal Industries Brake Products, Inc. with Robert Bouchard, GCA Corporation. February 28, 1980. Friction products manufactured.

26. Telecon. Montgomery, Reddaway Manufacturing Company with Robert Bouchard, GCA Corporation. February 29, 1980. Friction products manufactured.

27. Telecon. Molded Industrial Friction Corporation with Robert Bouchard, GCA Corporation. March 3, 1980. Friction products manufactured.

28. Telecon. Wheeling Brake Block Manufacturing Company with Robert Bouchard, GCA Corporation. February 29, 1980. Friction products manufactured.

29. Telecon. Brassbestos Manufacturing Corp. with Robert Bouchard, GCA Corporation. March 3, 1980. Friction products manufactured.

30. Telecon. Paul Biondo, Auto Friction Corp., with Robert Bouchard, GCA Corporation. March 3, 1980. Friction products manufactured.

31. Telecon. Robert Randolf, Gatke Corporation, with Robert Bouchard, GCA Corporation. March 3, 1980. Friction products manufactured.

32. Telecon. Lasco Brake Products Company with Robert Bouchard, GCA Corporation. March 3, 1980. Friction products manufactured.

33. Telecon. Appollageno, MGM Brakes, Inc., with Robert Bouchard, GCA Corporation. March 3, 1980. Friction products manufactured.

34. Telecon. Carlisle Corporation with Robert Bouchard, GCA Corporation. March 3, 1980. Friction products manufactured.

35. Telecon. Thiokal Chemical Corporation with Robert Bouchard, GCA Corporation. March 3, 1980. Friction products manufactured.

36. Telecon. Joseph Minky, P.T. Brake Lining Company, Inc., with Robert Bouchard, GCA Corporation. March 4, 1980. Friction products manufactured.

37. Telecon. Mr. Baltz, Baltz Company, Inc. (distributors for Eaton Corporation), with Robert Bouchard, GCA Corporation. March 4, 1980. Friction products manufactured.

38. Asbestos: An Information Resource, R.J. Levine, ed. DHEW Publication Number (NIH) 79-1681, U.S. Department of Health, Education and Welfare, National Cancer Institute, Public Health Service, Bethesda, Maryland. May 1978.

39. Daly, A.R., A.J. Zupko and J.L. Hebb. Technological Feasibility and Economic Impact of OSHA. Proposed revision to the Asbestos Standard (construction excluded). Roy F. Weston, Environmental Consultants for Asbestos Information Association/ North America, Washington, D.C., March 29, 1976.

40. Suta, B.E. and R.S. Levine. Nonoccupational Asbestos Emissions and Exposures. In: Asbestos, Volume 1, Properties, Applications and Hazards. L. Michaels and S.S. Chissick, eds., John Wiley & Sons, New York, N.Y. 1979. pp. 171-205.

41. Gregg, R.T. Development Document of Effluent Limitations Guidelines and New Source Performance Standards for the Textile, Friction Materials and Sealing Devices Segment of the Asbestos Manufacturing Point Source Category. U.S. EPA Report No. EPA 440/1-74-035a, December 1974.

42. Jacko, M.G. and R.T. DuCharme. Brake Emission: Emission Measurements from Brake and Clutch Linings from Selected Mobile Sources. U.S. NTIS PB-222 372. 1973.

43. Lynch, J.R. Brake Lining Decomposition Products. J Air Pollution Control Association. 18(12):824-826. December 1968.

44. Hatch, D. Possible Alternatives to Asbestos as a Friction Material. Ann Occup Hyg. 13:25-29. 1970.

45. Hickish, D.E. and K.L. Knight. Exposure to Asbestos During Brake Maintenance. Ann Occup Hyg. 13:17-21. 1970.

46. Bush, H.D., D.M. Rowson and S.E. Warren. The Application of Neutron Activation Analysis to the Measurement of the Wear of a Friction Material. Wear, 20:211-225. 1972.

47. Anderson, A.E., R.L. Geacer, R.C. McCune, and J.W. Sprys. Asbestos Emissions From Brake Dynamometer Tests, Paper 730549 presented at SAE Automotive Engineering Meeting, Detroit, Michigan. 1973.

48. Jacko, M.G., R.T. DuCharme and J.H. Somers. How Much Asbestos do Vehicles Emit? Automotive Engineering, 81:38-40. 1973.

49. Rohl, A.N., et al. Asbestos Exposure During Brake Lining Maintenance and Repair. Environmental Research. 12:110-128. 1976.

50. Alste, S., D. Watson and J. Bagg. Airborne Asbestos in the Vicinity of a Freeway. Atmos Environ. 7:583-589. 1976.

51. Rohl, A.N. et al. Asbestos Content of Dust Encountered in Brake Maintenance and Repair. Proc Roy Soc. Med. 70:32-37. 1977.

52. Bruckman, L. and R.A. Rubino. Monitored Asbestos Concentrations in Connecticut, J Air Pollution Control Association. 28(12):1221-1226. December 1978.

53. Federal Register, Commercial and Industrial Use of Asbestos Fibers; Advance Notice of Proposed Rulemaking, Wednesday October 17, 1979, Vol. 44, No. 202. p. 60062.

54. Unpublished NIOSH data presented at American Industrial Hygiene Conference, New Orleans, Louisiana. May 5, 1977.

55. Telecon. Bill Ferk, Scan-Pac Manufacturing Company, Mequon, WI (414) 241-3890, with Nancy Krusell, GCA Corporation, GCA Technology Division. April 22, 1981.

SECTION 6

ASBESTOS-CEMENT PIPE

INTRODUCTION

Asbestos-cement (A/C) pipe, an admixture of asbestos fibers and portland cement, was introduced into the U.S. market in 1931.[1] This corrosion resistant pipe had been developed for the high pressure, salt water street flushing system of Genoa, Italy. Worldwide use increased from about 321,800 kilometers in service in 1950 to about 2,252,600 kilometers in 1970.[2]

Estimates of A/C pipe in domestic use vary widely. Industry estimates of A/C pipe use were unavailable.[3] The estimates of the amount of pipe in service range from 160,900[4,5] to 321,800 kilometers. A 1978 estimate by Meylan et al.[6] placed the number closer to 611,920 kilometers. The wide variation in estimates may be due to the type and use of the A/C pipe. The lower number reflects pipe used for water and sewer transmission lines only. Over 50 percent of all A/C pipe sold in the U.S. is for high pressure water conduits; next in quantity is nonpressurized sewer pipe, and the remainder includes a wide range of applications including telephone and electrical wire conduit and air ducting.[6]

In 1980, according to the U.S. Bureau of Mines,[7] A/C pipe consumed some 144,000 metric tons of asbestos, or about 40 percent of total consumption. This approximation was based on Bureau of Mines data and compares with similar approximations of 36,080 metric tons for floor tile, 43,700 metric tons for friction products and 90,020 metric tons for paper products (including roofing).* Generally speaking, asbestos consumption parallels new construction but in 1976-1977, the former declined while the latter climbed, possibly an indication of "loss of markets because of environmental problems."[8] Also in 1976 A/C pipe imports began to increase dramatically (Figure 11). Geographically, A/C pipe markets are larger in the faster growing sections of the country west of the Mississippi rather than in the east where water systems generally have been in the ground for many years.[8]

---

*These consumption figures are for GCA-defined product categories. Other sources (for example, see Reference 8) claim that A/C pipe is second to roofing as the largest asbestos user. The apparent discrepancy results from different product categorization.

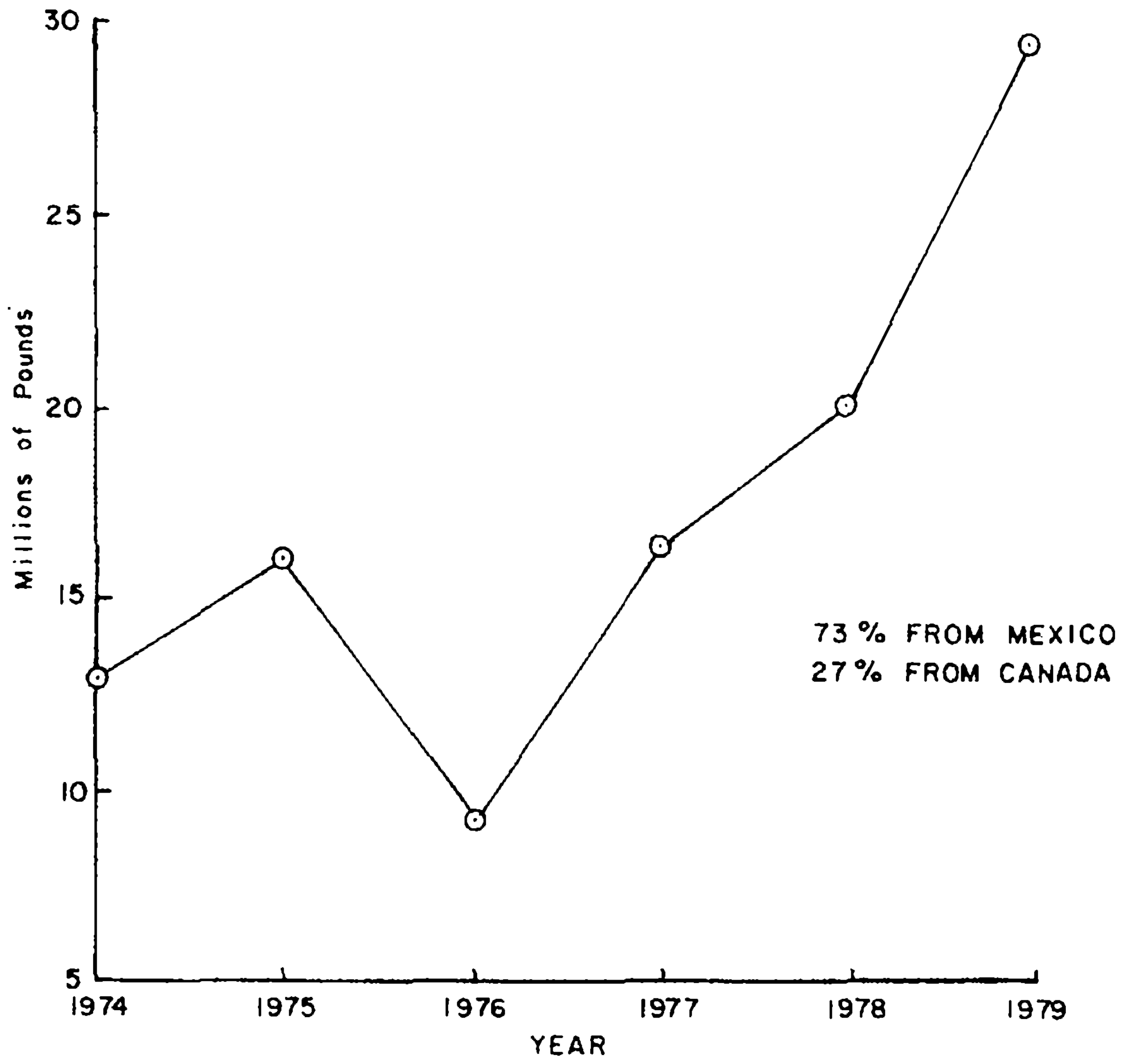


Figure 11. U.S. A/C pipe imports in millions of pounds of pipe.[9]

PRODUCT DESCRIPTION

Composition

Pipe Specifications--

Specifications for A/C pipe ranging in internal diameter from 0.1 to 1.07 meters have been set by the American Water Works Association.[1] Standard length is 3.96 meters and random lengths less than 2.13 meters are not recommended. The pipe is classified on the basis of its design internal pressure, ranging from 21.1 to 63.3 kg/cm^2. The pipe is also chemically classified as follows:

- Type I--no limit on uncombined calcium hydroxide
- Type II--1 percent or less uncombined calcium hydroxide

The pipe's ability to withstand attack (and possible resultant release of asbestos fibers) from "aggressive" water* depends upon this chemical type. Only Type II is recommended for moderately aggressive water whereas either Type I or II can be used for nonaggressive water.† For external corrosion from soil water, in addition to acidity, soluble sulfate is an important parameter in determining pipe durability.[1]

Formulations--

If the pipe material simply sets under specified conditions†† (Type I) representative formulations are 15 to 25 percent asbestos and 75 to 85 percent cement; however, if the pipe is "cured" by autoclave (Type II) - the practice in the U.S. - silica is added so that a representative formulation becomes 15 to 25 percent asbestos, 42 to 53 percent cement, and 34 to 40 percent silica. Up to 6 percent finely ground solids from crushed damaged pipe may be added as a filler material. The average asbestos content is 18 to 20 percent.[6] In 1980, 83.2 percent of the asbestos used in A/C pipe was chrysotile, grades 4 through 7; 16.7 percent was crocidolite; and 0.1 percent was amosite.[7]

Uses and Applications

The majority of the A/C pipe produced is used for water mains (pressure pipe) and sewer lines (nonpressure pipe). The exact historical use breakdown is unavailable as this information is considered confidential and/or unknown. An indeterminate, smaller amount of A/C pipe is also used as conduits for electrical and telephone cables, air ducts, and for laterals from street mains to the user.

Special Qualities

A/C pipe products are strong, resilient, flexible, durable, inert, and corrosion resistant. Asbestos imparts a flexural strength in pipe which allows for a certain amount of deflection without failure. The laminar structure of

---

*Aggressiveness is defined as: pH + log (AH) where A is the total alkalinity and H the total hardness, both expressed as ppm $CaCO_3$. Highly aggressive water has a value of pH + log (AH) <10.0; moderately aggressive a value of ≈ 10.0 to 11.9, and nonaggressive a value of ≥ 12.0.[1]

†The serviceability of Type II pipe for aggressive water applications should be established by the purchaser in conjunction with the manufacturer.

††Emursed in water for a period of 28 days.

the pipe, which results from the basic method of manufacturing, also contributes to greater strength.[8] This allows for easy tapping for lateral line or other connectors without a loss of strength. Because of the nature of the raw materials (Portland cement and asbestos fibers) used to manufacture A/C pipe, it resists corrosion and most chemical action, and is not subject to electrolysis.

The primary purpose of asbestos fibers in A/C pipe is to act as a reinforcing agent. Properties which make asbestos suitable as a reinforcing agent are its high fiber strength, resistance to alkali attack, and adhesion to cement. The raw fibers are also readily wetted and thus contribute favorable and controllable drainage properties to an asbestos cement mix enabling A/C pipe to be produced by a relatively simple and flexible process similar to that used in papermaking.[10] Asbestos can also withstand the autoclave (heat and pressure)[8] process in the manufacture of pipe and resists the alkali attack of Portland cement. The large surface area of asbestos fibers promotes good adhesion between the cement mixture and the fiber surface.

SUBSTITUTES

Fiber Substitutes

Fiber substitutes for asbestos as a strengthening fiber in cement pipe are not currently considered cost-competitive. Potential fiber substitutes, which include glass, metals, graphite and various natural fibers, have not, to date, proven to be equal to asbestos as a fiber replacement. Although glass fibers are possibly the best fiber substitute, they are two to four times more costly than the equivalent asbestos fibers and tend to dissolve in the highly alkaline cement matrix.[11] To circumvent this difficulty, recently developed alkali-resistant glass fibers are being examined, but they are four to seven times more costly than equivalent asbestos fibers. Glass is being substituted for asbestos in some couplings and fittings, maintaining strength by greater thickness.

Pipe Substitutes

Pipe substitutes include ductile iron pipe, concrete pipe, plastic pipe and vitrified clay pipe. None of these products alone could substitute for all asbestos cement pipe uses; however, as a group, they can meet all the technical requirements placed on asbestos cement pipe.[12]

Asbestos cement pipe is economically the most suitable for intermediate range pipe diameters (0.15 to 0.61 meters). However, even in this size range, it is not always the preferred choice. Ductile iron is more suited for situations involving shock loads, vibration and ground movement in general.[13] In addition, the number of asbestos cement pipe manufacturing facilities is small and transportation costs may be substantial.

In the range of small pipe diameters, plastic pipe, vitrified clay pipe and iron pipe all offer strong competition. For very large pipe sizes, reinforced concrete pipe is preferred.[4]

MANUFACTURING

Primary Manufacture

The manufacturing process for A/C pipe is similar to the wet mechanical process for making A/C sheet and related products. The basic process is outlined in Figures 12 and 13 and is used by most manufacturers. As with any process, minor variations between different plants may exist. The following description is based upon literature descriptions and a site visit to an A/C pipe plant.[14]

The process starts with the arrival of the raw asbestos fibers at the plant. Asbestos is usually transported by truck or railcar. Weight of the individual bags of fiber varies but 100 lb (or 50 kg) bags are common. Packaging of the fiber varies, but it is usually wrapped in plastic and/or Kraft paper bags. Fibers may be loose or pressed into "bricks" in the bags. Asbestos shipped as "bricks" is becoming popular because this form could reduce the potential for air emissions due to ripped bags or spillage.

The bags of fiber may be loaded individually or, as is common in large single container shipments, placed on pallets to facilitate forklift moving. Palletized bags of asbestos are often shrink-wrapped with plastic to further reduce the potential for fiber release. The received fiber is stored in a warehouse prior to use.

The fibers are transported from the central storage area to the head of the production line by forklift or manually. The asbestos is opened, weighed, and added to the dry mixer. Other ingredients including Portland cement and possibly sand are added. The dry mixer serves to fluff the asbestos fibers and prepare a uniform mixture.

From the dry-mixer the dry mix is conveyed to the wet-mixer or beater where water is added to make an A/C slurry consisting of approximately 97 percent water. The slurry flows or is pumped to the pipe-forming machine vats where it is deposited on one or more rotating, horizontal, cylindrical screens. Excess water is removed from the slurry layer on the screen. The resulting layer of asbestos-cement material, 0.5 to 2.5 mm thick, is transferred to an endless-felt conveyor belt that travels over suction boxes to remove water. The wet mat is then transferred to a mandrel or accumulator roll which winds the mat into pipe (or sheet) stock of the desired thickness. Pressure rollers bond the mat to the layer previously deposited and remove further excess water.[6] The pipe is usually cast in 3.05 to 4.6 meter lengths.

The pipe is removed from the mandrel, air cured, and final cured in an autoclave using saturated steam. The pipe may, as a final step, be lined with a coating to further increase its corrosion resistance and improve flow characteristics. Vinyl is a commonly used liner.

The finished pipe is sent to stock, which may be in the open. Stock is often palletized to form uniform loads and facilitate handling. This operation also reduces breakage.

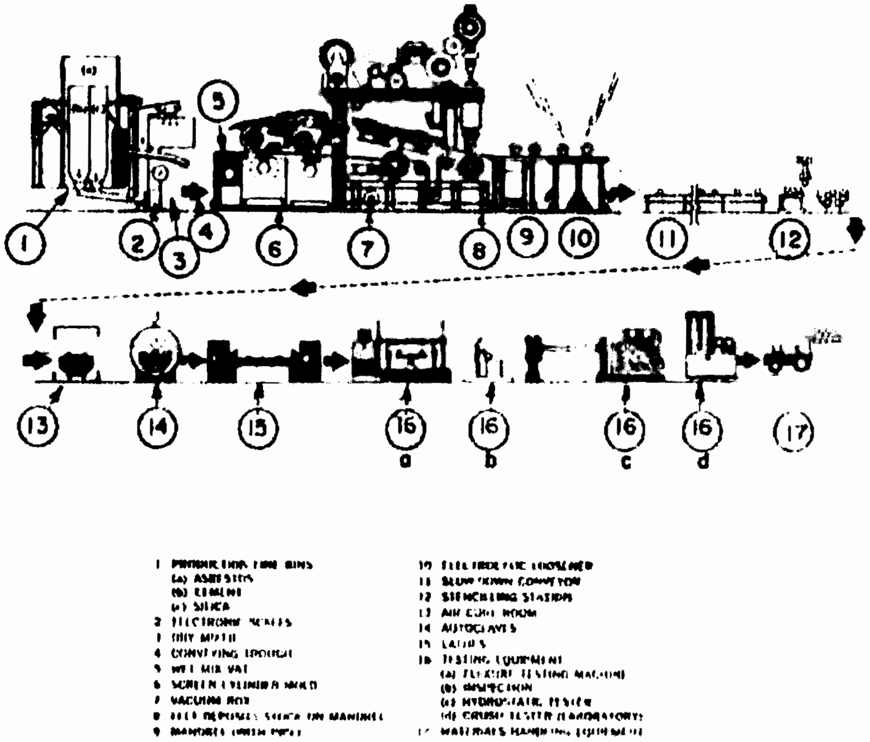


Figure 12. Manufacture of asbestos-cement pipe.[15]

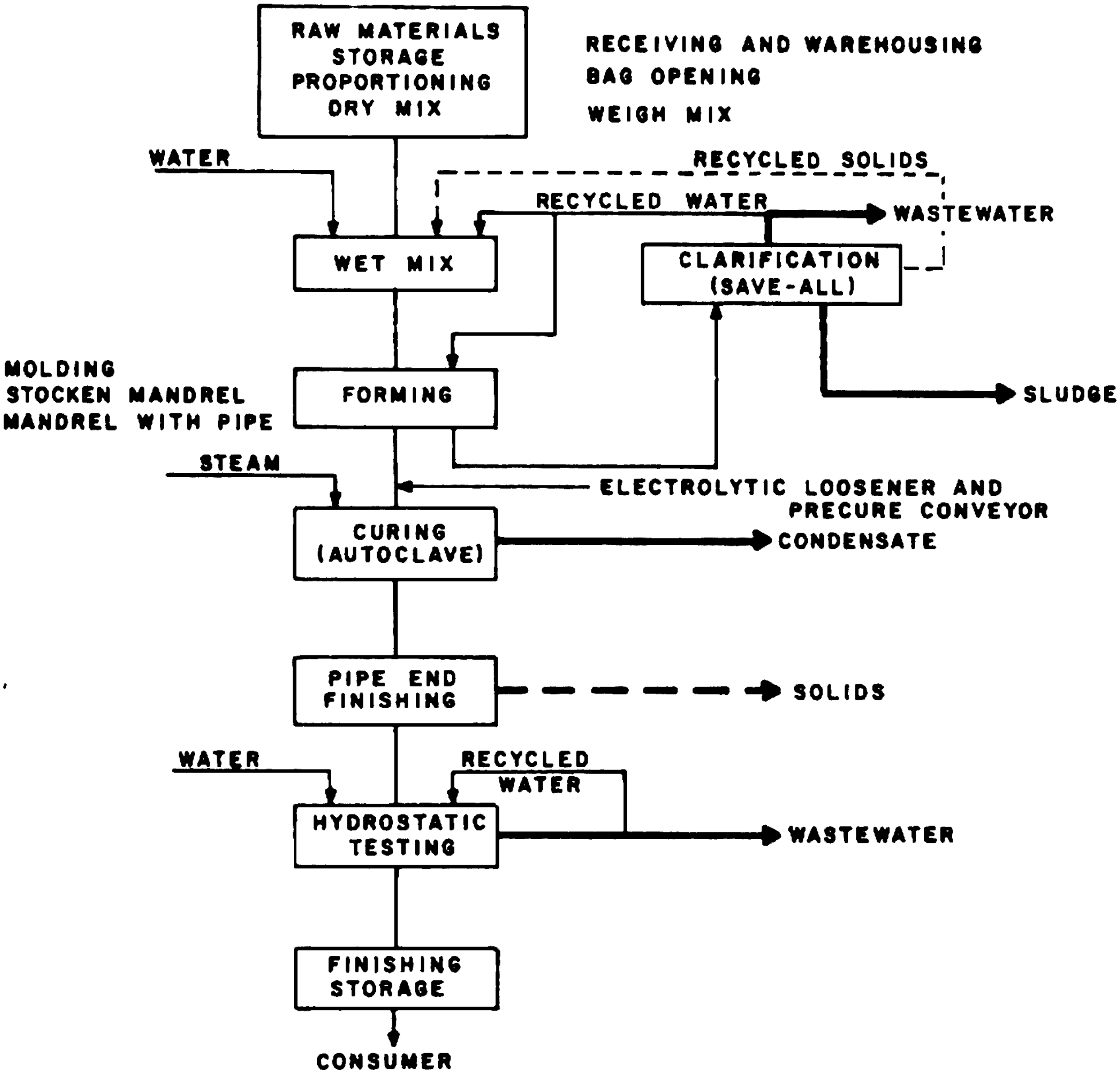


Figure 13. Flow diagram of asbestos-cement pipe manufacturing operations by the wet mechanical process.[15]

Manufacturing Plants

The locations and estimated 1975 sales figures for A/C pipe plants in the U.S. are given in Table 30. The major plants listed in this table are estimated to account for more than 95 percent of total A/C pipe production in the U.S. These plants are primary manufacturers and there is no secondary fabrication of A/C pipe.

Production Volumes

Recent, reliable production volumes of A/C pipe are considered proprietary and are unavailable. The total quantity of asbestos consumed by A/C pipe in 1980 was 144,000 metric tons,[7] but recent information concerning the asbestos consumption or pipe production of individual plants is not available.

Projected trends for A/C pipe consumption vary from modest growth (5 to 7 percent for the next 3 to 7 years), through market stability,[6] to actual decline. PVC pipe inroads on the water pipe market are predicted to be primarily at the expense of ductile iron pipe rather than A/C pipe. However, in the case of sewer pipe, especially in the southern half of the U.S. where higher temperatures and lower flow rates accelerate acidic deterioration of A/C pipe, PVC pipe may claim a substantial share of the market, perhaps even eventually displacing A/C pipe if the latter's cost cannot be lowered.[8]

ASBESTOS RELEASE

Input/Output

A mass balance for asbestos use within the A/C pipe industry was constructed and may be found in Figure 14. The figures were achieved by incorporating Levine's[16] 1974 estimates projected to 1980 U.S. Bureau of Mines[7] consumption figures. Of the 144,000 metric tons entering the process as raw asbestos fiber, approximately 140,346 metric tons are incorporated into the product and 3,599 metric tons are sent to disposal as vacuum cleaner and baghouse dust, product scraps, and clarifier sludge. An estimated 14 metric tons escape through a control device (typically a baghouse). Levine's atmospheric emission estimates are based on gross assumptions with a reported uncertainty of at least an order of magnitude. Meylan[6] reports emissions of 1 to 3 orders of magnitude less. Atmospheric emissions from disposal, based on GCA estimates, are shown to be 7 metric tons. This estimate is loosely based on Levine's data, and takes into account new regulations adopted in 1975 regarding the disposal of asbestos.

During Manufacture

Workplace Exposure--

Exposure to asbestos fibers may occur during manufacture. Table 31 shows some asbestos exposure levels within A/C pipe manufacturing facilities. The OSHA workplace standard is currently 2 fibers/cc based on an 8-hour time weighted average (TWA).

TABLE 30. LOCATION AND SALES OF MAJOR A/C PIPE PLANTS[a] [6,8]

Company	Plant location	Estimated 1975 sales	Percent of market[b,c]		Estimated asbestos consumption[b,d] (thousand metric tons)
Johns-Manville	Manville, NJ[e,h]	$ 78,000,000	42	76	54
Johns-Manville	Waukegan, IL[e,h]	15,000,000	8		11
Johns-Manville	Denison, TX	14,400,000	8		10
Johns-Manville	Green Cove Springs, FL[h]	5,700,000	3		4
Johns-Manville	Long Beach, CA	29,000,000	15		20
Johns-Manville	Stockton, CA	-	-		-
Certain-Teed	Santa Clara, CA	4,600,000	2	18	3
Certain-Teed	Hillsboro, TX	8,700,000	5		6
Certain-Teed	Ambler, PA	7,200,000	4		5
Certain-Teed	St. Louis, MO	10,400,000	6		7
Certain-Teed	Riverside, CA	2,200,000	1		2
Capco Corporation (Cement Asbestos Products Co.)	Ragland, AL	4,300,000	2	7	3
Capco Corporation	Van Buren, AR	8,700,000	5		6
Flintkote Company	Ravenna, OH[f]				
		$188,200,000			139[g]

[a] Augmented by GCA telephone contact.

[b] To the nearest whole number.

[c] Excluding Stockton plant.

[d] Excluding Stockton plant but based on a total consumption which presumably includes this plant.

[e] Plant also manufacturers other asbestos products.

[f] Closed in 1976.

[g] U.S. Bureau of Mines estimates.

[h] Not producing pipe at this time.

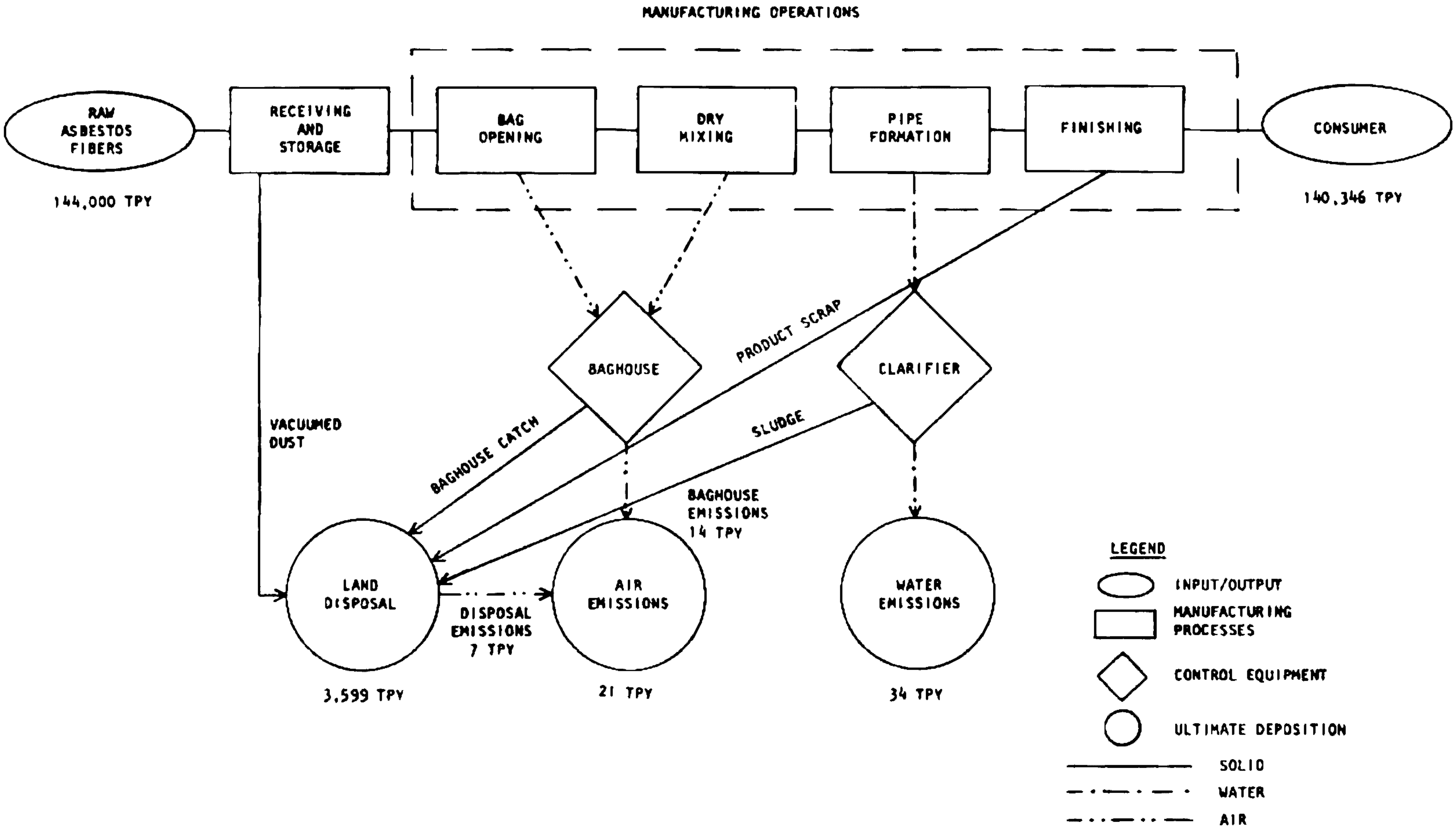


Figure 14. Input/Output of asbestos disposal and emissions for the asbestos cement pipe industry, (metric tons).

TABLE 31. ASBESTOS-CEMENT PIPE MANUFACTURE - ASBESTOS EXPOSURE LEVELS[17]

Process-related work areas	Asbestos exposure levels (fibers/cc)	
Fiber receiving and storage	0.2 - 2.5 TWA[a]	
Fiber introduction	0.1 - 4.8 TWA	
Dry mix - wet mix	0.4 - 3.0 TWA	
Pipe formation	0.1 - 1.4 TWA	b
Air/cure/autoclaving	0.2 - 0.3 TWA	
Pipe finishing		
Sawing	0.1 - 1.9 TWA	
Finishing lathes	0.1 - 0.7 TWA	
Coupling cutoff machinery	0.2 - 2.3 TWA	
Fitting and specialties	1.5 - 2.1 TWA	
Drilling	<0.1 - 0.5 TWA	
Rework saw and crushing	2.0 - 2.9 TWA	
Quality control inspection	<0.1 - 0.2 TWA	
Floor sweeping	<0.1 - 0.3 TWA	

[a] TWA - 8-hour, Time-Weighted Average.

[b] It is not clear whether the fibers counted are free fibers or whether asbestos fibers attached to or partially imbedded in cement particles are also counted.

Workplace exposures may take place at virtually every step of the production process, but the potential is greatly reduced as the process proceeds. Initially, the fibers are dry and could easily become airborne. Once the fibers have been wetted the potential for exposure decreases. The final product should have little or no potential for fiber release since the fibers are in a cement matrix.

Exposure at fiber receiving docks and storage areas would arise if broken bags of fiber are present. Careful handling will prevent breakage. Repairing rips immediately will remove the fiber release threat. In addition, the packaging of the fibers as bricks will reduce the fiber release if a rip in the packaging does occur.

Bag opening, prior to introduction into the dry mixer may present the potential for the highest level of worker exposure. This operation is largely done manually. Exposure risk is greatly reduced if the bags are opened in enclosed "glove boxes" which are also aspirated. The exclusive use of mechanical opening devices is hampered by the lack of standardized packaging.

Dry mixing creates large amounts of dust but this dust is typically controlled with air pollution devices like cyclones and baghouses. Once the mixture is wetted the potential for exposure is greatly reduced. However, this wet mixture is very messy. Inevitably there is spillage which forms on machines and may be picked up by workers on their clothes and shoes. Proper precautions must be taken to reduce exposure from this occurrence.

Housekeeping may have a fiber release associated with it. Cleanup is preferably performed either with a vacuum or by washing. These methods reduce the dust which may be created by sweeping. All wastes should be carefully packaged to prevent fiber release during disposal.

In the finishing area pipe is machined, cut or worked, and these operations have the potential to create air emissions. Emissions may be minimized by the use of wet saws and drills or by performing the work under well aspirated hoods and enclosures (which vent through some type of air pollution control device). Proper housekeeping procedures should be followed to ensure safe cleanup.

Emissions to Air--

Actual measurements of asbestos fiber concentration in the vicinity of an asbestos cement manufacturer are very limited. However, Suta and Levine[18] estimated concentrations near asbestos industrial facilities using mathematically derived dispersion curves of assumed plant emissions. In the case of asbestos cement, it was estimated that a population within 5 km of a manufacturing plant would be exposed to a median asbestos concentration of 27.0 and 7.2 ng/m^3 for urban and rural facilities, respectively. Comparing this data with the median U.S. atmospheric fiber concentration (20 ng/m^3),[18] it appears that asbestos cement manufacturing contributes little to nonoccupational exposure. Actual ambient monitoring in the vicinity of an asbestos cement facility is necessary to confirm Suta and Levine's estimates.

Release to Water--

Raw wastewater discharge from A/C pipe manufacturing plants typically contains about 2.86 kilograms of suspended solids per metric ton of product.[15] These solids include organic materials such as grease, tar, oils, fats, non-asbestos fibers, and sawdust as well as inorganic materials such as sand, silt, clay, and cement in addition to asbestos. The amount of asbestos in the waste stream is relatively low compared to the cement, silica, and clay raw materials. Using Levine's estimates, scaled to 1980 consumption figures, it is estimated that 34 metric tons of asbestos is released to the water from A/C pipe production.

In the United States, approaches to the treatment of wastewaters from A/C product facilities vary widely from plant to plant, ranging from no treatment at all to 100 percent water recycling in some of the larger plants. Most asbestos plants do have some form of sedimentation treatment for their water, either a clarifier or a sedimentation pond. The settled sludge is usually hauled away to a landfill, while the clarifier water is recycled or discharged to surface waters or sewers. The overall efficiency of this treatment process is estimated to be about 94 to 96.7 percent.[15]

Release to Land--

On the basis of an examination of the waste pile of one asbestos products plant, Harwood and Ase[19] found that about 5 to 10 percent of the A/C product material is dumped as scrap of which about 10 percent is fine dust from baghouses, and 90 percent is coarse scrap from trimmings, breakage, and rejected product. They concluded that asbestos-manufacturing plant waste piles pose a potential emission hazard to nearby populations; however, because of variations in climate, moisture, and operating procedures, they found it impossible to quantify such emissions. The troublesome material appears to be the baghouse fines. Possible solutions to the problem are: (1) pelletizing the dust, (2) encapsulating it in cement or some other solid matrix, and (3) reprocessing the material. In the last case, baghouse fibers are too short to add strength to the cement matrix. Several plants[2] mix baghouse fines with cement and then dispose of them in landfills, which are commonly located on company grounds.

Harwood and Oestreich[20] report measurements for their study made downwind from the dump of an A/C pipe plant (Table 32), but, inasmuch as they fail to report upwind values or the dump's location (so that a guess can be made of background levels), their numbers are not very useful for estimates for this report. The authors also discuss water, foam sprays, chemical fixation, vegetative stabilization, and waste commingling as dust control measures at dump sites.

During Use

Installation Exposure--

One of the major advantages of A/C pipe is the ease of installation and the quality of joints and fittings. There is relatively little in situ sawing, cutting, drilling, or machining of A/C pipe necessary during installation. The onsite fabrication that is required, however, may lead to high instantaneous (15-minute) fiber concentrations. One industry study[21] reported peak fiber counts of up to 64 f/cc when an abrasive disc is used to cut A/C sewer pipe. However, this and similar cutting and drilling operations occupy only 1.1 percent of total field installation time,[21] and the 8-hour time weighted asbestos concentration for these operations is still below the 2 f/cc occupational limit. Thus, while there may be transitory worker exposure, there is little likelihood of significant asbestos fiber release into the environment, especially since the fibers are immobilized in the cement matrix. A/C pipe, it should be noted, is not a consumer product. Installation is almost always by professional workers, who should be familiar with installation procedures. However, in the case of the enlargement or modification of existing water pipeline systems, Millete, et al.[22] cite evidence that residents may have been exposed to transitory increased asbestos levels in drinking water as a result of improperly performed pipe tapping work. Available tapping devices flush cutting debris away, thereby avoiding contamination. The American Water Works Association has published[1] recommended work practices for shipping, handling, and installation of A/C pipe including both dry and wet tapping.

TABLE 32. REPRESENTATIVE FIBER COUNT VALUES OBTAINED AT THREE ASBESTOS WASTE DUMPS (FROM HARWOOD AND OESTREICH)[20]

Dump site	Sampler		Optical microscope data--fibers 1.5-30 µm length (fibers/m^3)	Electron microscope data--fibers 0.05-1.5 µm length (fibers/m^3)
	Location (meters)	Elevation (meters)		
Asbestos cement pipe plant	710 downwind	2	1.7×10^6	6.2×10^6
		7	1.9×10^4	6.7×10^6
General asbestos products plant[a]	336 downwind	2	2.0×10^2	1.5×10^8
		7	2.5×10^2	2.7×10^8
Asbestos ore mill	224 downwind	2	9.3×10^5	5.9×10^8
		7	7.3×10^5	---

[a] Including A/C pipe.

User Exposure--

The principal avenue of asbestos exposure for users of asbestos concrete pipe is the potable water which is transported through the pipe. Responding to concern about the possible contamination of drinking water by A/C pipe conduits, an American Water Works Association committee carefully reviewed the problem in 1974.[23,24] Their findings were based primarily on work by the Johns-Manville Research Center which examined two municipal A/C pipe systems over a 1-year period and found that on the average the asbestos content of the water flowing out was only 4 x 10^3 to 70 x 10^3 fibers/l greater than the water flowing in. Hallenbeck, et al.[25] examined 15 A/C pipes located in northeastern Illinois and found no significant release of chrysotile from the pipes. In a detailed study which took water aggressiveness into consideration, Buelow, et al.[26] found little or no increase in asbestos fiber levels in nonaggressive water transported through A/C pipe but significant increases in the case of aggressive water. Reviewing these studies, Meylan, et al.[6] conclude that "use of asbestos-cement pipe for water transport does not seem to contribute any large amounts of asbestos into the general environment."

Very recently a study of 365 urban water suppliers has been compiled.[22] The findings are summarized in Table 33. This review concludes:

> "The majority of persons receiving water from asbestos-cement pipe distribution systems are not exposed to significant numbers of fibers from the pipe. Many residents using asbestos-cement pipe may be exposed to intermittent amounts of asbestos fibers in their water if pipe tapping work is done improperly. In areas of very aggressive water (estimated to be 16 percent of the U.S. water utilities) consumers using asbestos-cement mains may be exposed to high concentrations of fibers, over 10 million fibers/ℓ."

TABLE 33. DISTRIBUTION OF REPORTED ASBESTOS CONCENTRATIONS IN DRINKING WATER FROM 365 CITIES, 43 STATES, PUERTO RICO, AND THE DISTRICT OF COLUMBIA[22]

Asbestos concentration (10^6 fibers/l)	Number of cities	Percentage of samples
Below detectable limits	110	30.1
Not statistically significant	90	24.6
Less than 1	90	24.6
1 to 10	34	9.3
Greater than 10	41	11.2
Total	365	99.8

In only one community, Bishopville, S.C., did the maximum fiber level, 547 x 10^6 f/l), believed to be attributable to release from corrosion of A/C pipe by aggressive water, exceed the maximum levels found in anthropogenically uncontaminated natural waters (130 x 10^6 fibers/l for San Francisco--fibers from the natural erosion of serpentine rock). Unfortunately, information as to the representativeness of the samples and the reproducibility of these maximum values found was not included. No unequivocal evidence is given that proves asbestos fiber release from A/C pipe increases fiber levels outside the range encompassed by uncontaminated natural waters. On the other hand, there is no question as to the fact that highly aggressive water can corrode

A/C pipe and that asbestos fibers must be released as a consequence. In the case of sewer systems, pipe deterioration might also be generated by the dumping of highly aggressive chemicals into sewer pipes. A/C pipe may also be corroded from the outside by certain soil conditions. This corrosion of the pipewall should not contaminate the water flowing within and, inasmuch as migration of asbestos fibers in soils is ordinarily exceedingly slow,[27] it would not be apt to create any hydrospheric or atmospheric contamination problem.

Finally, asbestos fibers released to the water from A/C pipe may potentially become airborne. Meylan, et al.[6] studied the possibility of this air emission when the water is atomized in certain types of commercial and residential humidifiers. They made a rough estimate that the asbestos level in the air of a house might be raised by as much as 6×10^5 fibers/m^3 with humidifier use. No ambient air sampling has yet been conducted to substantiate this estimate.

If it can be established that fiber release from A/C pipe does in fact represent a hazard to the public health, a number of corrective alternatives are available including:

1. Do not use A/C pipe to carry highly aggressive waters.
2. Pretreat the water to reduce aggressiveness.
3. Filter the water after passage through the A/C pipe.
4. Coat the inside of the pipe with a protective material designed to prevent pipe corrosion and reduce fiber release.
5. Substitute other pipe materials, provided, of course, they do not represent a greater health hazard than A/C pipe.

During Disposal

Because of its relatively recent introduction (about 50 years ago) and very long service life, there is a paucity of information concerning the abandonment and/or disposal of A/C water pipe supply systems. Except under very aggressive water conditions, practically speaking, once in the ground, A/C pipe lasts forever. Engineering standards recommend that urban lines be replaced every 75 years.[28] However, this is often not the case due primarily to the lack of monies and the inconvenience of digging up streets. The water line replacement cycle in New York City is 300 years and in Jersey City 500 years.[28] In high population density urban areas, A/C pipe when replaced, might be removed, crushed, and trucked to a landfill. In lower density areas, the old pipe might be left in the ground and new pipe laid down beside it. In the former case, there should be minimal asbestos fiber mobilization from the old pipe and in the latter instance, none.

CONCLUSION

Asbestos-cement pipe has many qualities which make it suitable for use under a variety of conditions. However, only modest growth is expected in the near future. One reason is the abundance of satisfactory product substitutes such as plastic pipe (PVC), ductile iron pipe, vitrified clay and cement pipe. These pipes may have equal or superior qualities and enjoy a price advantage, particularly as transportation costs rise, as there are few A/C pipe plants and many of the other pipes are locally produced. The demand for all pipe will plateau as new construction decreases. With replacement schedules lagging years behind due to financial considerations, A/C pipe cannot reasonably be expected to have continuous high growth.

The potential for human exposure to asbestos from the manufacture and use of A/C pipe exists. Workers in A/C pipe plants may be exposed to asbestos fibers in the air in excess of OSHA workplace standards, especially in fiber receiving and storage and dry mixing areas (up to 4.8 fiber/cc TWA). Impermissible levels also may occur as the result of cutting, drilling, and machining operations. These same operations during pipe installation may also expose workers for short periods of time to significant fiber levels (up to 64 fiber/cc TWA). In areas where the water is highly aggressive, there may be a release of asbestos fibers from A/C pipe into water systems. However, appropriate abatement of any excessive fiber levels appears to be feasible.

Existing sampling data are inadequate to draw accurate conclusions on the levels of asbestos in the general environment attributable to A/C pipe. More accurate data are needed on the quantities of asbestos released to the environment due to the production and subsequent use of A/C pipe.[6] Sampling must be conducted to ascertain fugitive emissions, storm run-off levels and possible transport on work clothing. Despite the Millette, et al.[22] report, data is generally lacking on fiber release from water systems and wastewater pipes. This is perhaps the greatest data need, as waterborne asbestos potentially affects the greatest number of people. Specifically, with respect to potable water, reproducible average asbestos concentrations are needed as a function of A/C pipe length, suspended solids content, temperature and water aggressiveness. Such data is needed on both inlet and outlet water streams to quantify the specific source of the asbestos fibers.

REFERENCES

1. American Water Works Association. AWWA Standard for Asbestos-Cement Transmission Pipe, 18 in. through 42 in. for Water and Other Liquids. AWWA C402-77. January 30, 1977.

2. Olson, H. L. Asbestos in Potable Water Supplies. J. American Water Works Association. 66. 515-518. 1977.

3. Letter from Ed Mussler, GCA Corporation to Joe Jackson of Asbestos Cement Pipe Producers Association. January 30, 1980. Notebook 3. Call 3.

4. Survey of Water Main Pipe in U.S. Utilities over 2500 Population. American City. Morgan-Grampian Pub. Co. Pittsfield, MA. 1975. p. 52

5. Survey of Sewer Main Pipe in U.S. Utilities over 2500 Population. American City. Morgan-Grampian Pub. Co. Pittsfield, MA. August 1975. p. 33

6. Meylan, W. M., et al. Chemical Market Input/Output Analysis of Selected Chemical Substances to Assess Sources of Environmental Contamination: Task III--Asbestos. EPA 560/6-78-005. August 1978.

7. Clifton, R. A. Asbestos. 1980 Minerals Yearbook. U.S. Bureau of Mines. Washington, D.C.

8. Wright, M. D., et al. Asbestos Dust Technological Feasibility Assessment and Economic Impact Analysis of the Proposed Federal Occupational Standard: Part I. U.S. Department of Labor. OSHA. September 1978. (Draft)

9. Asbestos Magazine. January 1980. p. 4.

10. Michaels, L. and Chissick, S. S., eds. <u>Asbestos: Volume 1, Properties, Applications, and Hazards</u>. John Wiley and Sons. New York, NY. 1979.

11. Farahar, R. M. Glass Reinforced Concrete. Publication of Unknown Origin. Received from Cem-FIL Corp., Nashville, TN, in response to phone call from Ed Mussler, GCA Corporation. GCA No. 7-03-007-0035. 6 p.

12. Preuti, Russell. American Concrete Pipe Association, 703/821-1990. Personal communication with Ed Mussler, GCA Corporation. February 11, 1980. Notebook 3. Call 17.

13. <u>American Pipe Manual</u>, 15 ed. American Cast Iron Company. Birmingham, Ala. 1979.

14. LaShoto, P. W. GCA/Technology Division Trip Report on Visit to Johns-Manville, Manville, N.J. October 22, 1979.

15. Carton, R. J. Development Document for Effluent Limitation Guidelines and New Source Performance Standards for Building, Construction, and Paper Segments of the Asbestos Manufacturing Point Source Category. U.S. Environmental Protection Agency. U.S. National Technical Information Service. PB-230. February 1974.

16. Levine, R., ed. Asbestos: An Information Resource. May 1978.

17. Chapman, J. H., et al. Asbestos Dust Technological Feasibility Assessment and Economic Impact Analysis of the Proposed Federal Occupational Standard: Part III. U.S. Department of Labor, OSHA. September 1978. (Draft).

18. Suta, B. E., and R. J. Levine. Nonoccupational Asbestos Emissions and Exposures. Asbestos, Properties, Applications and Hazards. Volume 1. John Wiley and Sons, New York, N.Y. 1979.

19. Harwood, C. F., and P. K. Ase. Field Testing of Emission Controls for Asbestos Manufacturing Waste Piles. Industrial Environmental Research Laboratory, Office Research and Development, U.S. Environmental Protection Agency. Cincinnati, Ohio. 1977.

20. Harwood, C. F., and D. K. Ostreich. Asbestos Emissions from Baghouse Controlled Sources. 1975.

21. Recommended Standard for Occupational Asbestos Exposure in Construction and Other Non-fixed Work Operations. The Asbestos Information Association of North American and the Association of Asbestos Cement Pipe Producers, Washington, D.C. February 7, 1980.

22. Millette, J. R., et al. Exposure to Asbestos from Drinking Water in the United States. Health Effects Research Laboratory Office of Research and Development, U.S. Environmental Protection Agency. Cincinnati, Ohio. August 1979.

23. Kuschner, K., et al. Does the Use of Asbestos-Cement Pipe in Potable Water Systems Constitute a Health Hazard? J. Amer. Water Works Assoc. 66, 1-22. 1974.

24. Safe Drinking Water Committee. Drinking Water and Health. National Academy of Science. Washington, D.C. 1977.

25. Hallenbeck, W., et al. Asbestos in Potable Water. University of Illinois Water Resources Center. Report No. 178. January 1979.

26. Buelow, R. W., et al. Field Investigation of the Performance of Asbestos-Cement Pipe Under Various Water Quality Conditions. Prepub. copy. Water Supply Research Division, Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, Ohio. 1977.

27. Fuller, W. H. Movement of Selected Metals, Asbestos and Cyanide in Soil, Applications to Waste Disposal Problems, Municipal Environmental Research Laboratory, Office of Research and Development. U.S. Environmental Protection Agency. Cincinnati, Ohio. April 1977. EPA-600/2-77-020.

28. Epstein, A. Knight Ridder Service. Water and the Big Old City: Trouble Ahead. Boston Globe. p. 1. October 9, 1979.

29. Craun, G. E., et al. Exposure to Asbestos Fibers in Water Distribution System. Paper presented at Ninth American Water Works Association Conference, Anaheim, Calif. May 1977.

SECTION 7

ASBESTOS-CEMENT SHEET

INTRODUCTION

Asbestos-cement (A/C) products represent the largest single use category of asbestos in the United States, accounting for approximately 42 percent of total 1980 asbestos consumption.[1] Although A/C pipe is the largest component of this product category, A/C sheet accounted for an estimated 7,900 metric tons of asbestos use in 1980 or 2 percent of total U.S. market consumption. A/C sheet has been employed since the late 19th century, when an Austrian discovered a process for reinforcing cement using asbestos fibers. The first A/C plants in the U.S. were constructed around 1900. Many A/C applications first developed at that time are still in use today.

A/C sheet is currently used in many construction applications including roofing and siding for both industrial and residential buildings. As such, asbestos use in this industrial segment is highly dependent on changes in the construction industry. This is demonstrated by the wide variation in asbestos consumption for A/C sheet over the 1969 to 1980 time frame. During that time asbestos use varied from a low of 7,900 metric tons in 1980 to a high of 86,000 metric tons in 1974.[1,2]

Several distinct products are produced within the A/C sheet industry. They include flat and corrugated sheet and siding and roofing shingles. The relative production mix of these products is demonstrated by Table 34. This table relates product distribution by the value of product shipments for 1967, 1972, and 1977.

PRODUCT DESCRIPTION

Composition

A/C products may contain from 10 to 70 percent asbestos, although these are extreme ranges only found in specialty items.[4] A/C sheet products typically contain 30 to 40 percent asbestos, with chrysotile grades 6 and 7 the forms most commonly employed.[1] Additional asbestos forms, including crocidolite and amosite may be incorporated to enhance reinforcement, dispersion of fiber and drainage properties of the A/C mix.[5] Table 35 presents a breakdown of 1980 A/C sheet asbestos consumption by fiber type and grade.

TABLE 34. SHIPMENT VALUES OF ASBESTOS-CEMENT SHEETS, INCLUDING A/C ROOFING PRODUCTS[3,4]

SIC product code	Product	Total product shipments, including interplant transfers (millions of dollars)		
		1967	1972	1977
32929 41	Flat sheet and wallboard	15.2	20.7	25.3
32929 51	Corrugated sheets	3.5	5[a]	5[b]
32929 77	Asbestos cement shingles and clapboard	24.0	20.8	18.7

[a] Estimate made by authors of Reference 4.

[b] GCA assumes shipment value remains unchanged.

TABLE 35. A/C SHEET ASBESTOS CONSUMPTION IN 1980 (METRIC TONS)[1]

Chrysotile	
Grade 5	100
Grade 6	4,300
Grade 7	3,500
Total asbestos	7,900

Portland cement, the A/C sheet binder, is used in quantities ranging from 25 to 70 percent. Consistent cement quality is very important as any variations in the chemical content or fineness of the grind can affect production techniques and final product strength.[6] The remaining raw material, from 5 to 35 percent of the total product composition, is finely ground silica and any necessary dyes or pigments. Some A/C plants have onsite facilities for grinding silica as part of their operations. Finely ground solids from damaged A/C sheet trimmings may also be recycled in some plants for filler material. A maximum of 6 percent of such filler material can be used in some products before affecting the strength of the material.

The asbestos fibers in A/C products interweave to act as a reinforcing medium in imparting increased tensile strength to the cement. As a result, there is a 70 to 80 percent decrease in the weight of the product to attain a given structural strength, which could not be accomplished without the addition of a fibrous material such as asbestos to the cement. It is important that the asbestos be embedded in the product in a completely fiberized or willowed form. Willowing is frequently carried out prior to the addition of cement and silica. However, in some cases this fiber opening may be accomplished while the wet mixture is agitated by a pulp beater or hollander.

Uses and Applications

A/C sheet is widely used in construction applications, including roofing and siding both for industrial and residential buildings. It is also used in the manufacture of such items as heaters, boilers, vaults and safes, electrical equipment mounting panels, and welding shields.

The flat sheet has a variety of construction uses. Different types of this sheet are made, with densities varying according to the ultimate function desired. Ordinary or high density sheets may be used for external cladding applications and special low density panels containing a larger proportion of asbestos fibers are designed for use as infill panels for curtain wall systems, fire-resistant partitions, ducting, fume hoods, and doors.[7]

Currently, one of the larger areas of use for flat sheet is as a substrate for curtain walls. In this application, the building contractor applies an epoxy-type finish to the sheet before attaching it to the building exterior.[4] Another widely used product is laboratory furniture. Here solid sheets make very strong and chemically resistant bench-tops. A/C sheet is also used in fire-protective equipment including wood stove installations.

Corrugated sheet is used primarily in industrial applications including roofing, siding, and warehouse construction. Warehouses for phosphate fertilizers or other corrosive materials are particularly likely candidates for A/C corrugated sheets since metal materials would rust and corrode in these environments.

Special Qualities

The most desirable qualities of asbestos-cement products are their durability, corrosion resistance, and noncombustibility. Asbestos increases the strength of the cement product thereby reducing weight. The strength of A/C in compression is far higher than in tension; as a result several types of corrugated sheet products have been designed to exploit this property. These products are extensively employed for roofing and vertical cladding of factories, industrial buildings, and domestic garages.[5] In addition, the mechanical properties of A/C sheet may be further improved by cementing thin sheets of glass-reinforced plastic on each side of the A/C product.[7]

Asbestos fibers in A/C sheet products reinforce the cement, protect from fire, absorb heat from friction, insulate from heat, cold, and sound, insulate from condensation, and protects from corrosion.[5] For fire protection purposes, A/C sheet has successfully passed appropriate tests to be classified as noncombustible. The slow rate of heat conduction through A/C materials even helps retard the spread of fire through structures of which they are a part.[5] A/C products are therefore versatile, protective, and extremely useful.

SUBSTITUTES

The main competitors to A/C sheet products are:

- galvanized steel
- aluminum sheet
- masonry
- precast concrete
- plastics
- wood
- asphalt

In building construction, the rot and chemical resistance of A/C sheet makes it superior to metal since metal corrodes and is subject to rust. However, metal is cheaper and estimates indicate that in 1979, 15 percent of the nonresidential building market will use metal wall panels, and perhaps as much as 40 percent within 10 years.[8] These panels of preinsulated steel are ready to install as walls and are thought to maximize energy efficiency.

Precast concrete is not only more expensive than asbestos, but also involves more costly erection procedures, although this gap is narrowing. For fume hood use, welded stainless steel is available, but costs more than A/C sheet. Albarene stone, which may be a replacement for lab bench tops, is also more expensive. Impregnated plywood may also be used for lab tops, but only for nonrigid work; to date, A/C sheet is the most cost-effective product for this use.

Cladding panels are frequently manufactured from glass-reinforced thermosetting plastic (GRP). However, these materials do not possess the fire resistance of asbestos cement, and if combustion occurs, toxic fumes may be created. Thermoplastics, often using acrylic, have also been used for cladding, expecially in cases which call for their properties of high transparency. Caution must be taken in this application, however, as several recent fires, notably in England, have occurred in buildings using these panels. In such occurrences, the buildings have been completely lost due to the spread of surface flames on the panels.[9]

PVC may also be used in asbestos-cement type roofing applications. The corrugated, sometimes wire-reinforced form of PVC is applicable to conditions warranting light transmission. A UV stabilized, flame-retardant grade of PVC is used for this purpose. Metals such as aluminum are also widely used in this application.[10]

As has been the case with many other substitutes for asbestos products, most plastics are more expensive than A/C products, although certain thermoplastics may be cost-competitive in specific applications.

Replacement of asbestos fibers in A/C products by an alternative fiber or filler is currently under investigation by major manufacturers. Potential alternatives in this case include fiberglass, carbon fibers, and various natural, synthetic, and mineral fibers.

Perhaps the most promising use of a substitute fiber currently under investigation is the development of glass-reinforced cement. The common E-glass fiber, conventionally used in glass-reinforced plastics, cannot be used for this purpose as the severe alkaline conditions produced during the setting of Portland cement degrade these glass fibers, with the resultant composite material losing its favorable mechanical properties. However, experimentation within the last 10 years has produced a high-zirconia, alkali-resistant glass fiber, first introduced where the development took place, in England. The fiber is presently marketed by Pilkington Brothers, Ltd., of St. Helens, England under the trade name "Cem-FIL."[9] It has been found to be considerably more impact resistant than A/C sheets of comparable strength. In addition, the "green" boards have wet strength, allowing them to be molded. Large bore pressure pipes can also be produced from this material. The final product performs adequately in preventing fire penetration, yet several drawbacks still remain, including higher price, poor drainage characteristics, and lack of time-tested durability.

A/C sheet is generally more expensive than corrugated steel, competitive with aluminum sheets, and less expensive than conventional concrete blocks and built-up roofing. One of the main selling advantages of A/C sheet, especially for industrial use, is its resistance to rot, corrosion, and mildew, along with its fire resistance.[4] However, reports indicate that there is virtually no application in which A/C sheet could not be replaced by a substitute product that is currently on the market, although the cost may be somewhat higher in the use of the alternative product.[4]

MANUFACTURING

Primary Manufacture

A/C sheet and shingles may be made by either a dry, a wet, or a wet mechanical process. The product is formed, basically, by making a dilute water slurry of mixed raw ingredients, and then brought to the desired size, thickness or shape by accumulating the solid materials on a roll while removing most of the carriage water.[6]

Dry Process--

In the dry process (Figure 15), plastic bags containing asbestos are slit and dumped in a mixer. After the necessary additions of cement, silica and additives, this dry mixture is uniformly distributed onto a flat conveyor belt, sprayed with water, and then compressed by steel rolls to the thickness required for the desired product. The raw material make up is a batch operation with production rates depending on sheet thickness. Fiber introduction occurs 2 to 6 hours per shift.[11] This process is especially suited to the manufacture of shingles and other sheet products.[6] As the formed sheet continuously moves, rotary cutters are used to form the size of sheet desired or to cut the sheet into shingles. Finally the product is removed from the conveyor while still in this form and steam cured in an autoclave. Cut-off saws using diamond or carborundum wheels are then used to trim the cured sheet to standard size.[11] Corrugated sheets may be produced without the final sanding step that the flat sheets need. The water used to clean the forming equipment (which is the major source of process water) is normally collected for clarification and then either recirculated or discarded. Settled solid material from the clarification can be recycled with any unusable excess going to landfills.[4]

Wet Process--

The wet process for making A/C sheets is shown in Figure 16. Here, asbestos fibers are blended with cement and additives as in the dry process, but are then mixed with water. This slurry mix is in turn introduced into a mold chamber where it is compressed into a dense sheet, forcing out any extra water.[6] This material is allowed to harden for 24 to 48 hours. Then air or steam (or both) is used to cure the final product. The large, thick monolithic sheets used for such purposes as laboratory bench tops are manufactured by this process. Grinding operations used to finish the sheet surfaces often produce large quantities of dust which may get discharged into the process wastewaters. As in the dry process, the water from the forming step is clarified and recycled, with the same sludge and wastewater disposal requirements.

One plant visited uses a process similar to this wet process.[12] Asbestos is shipped by train or truck to the plant and stored until use. The plastic-wrapped asbestos bags are then moved to a mixer where they are hand slit under a vacuum hood, and dumped into a dry mix of concrete, silica, and, if color is necessary, pigment. From this stage, a closed operation mixes this material, water is added, and the material is pressed in forms to force out excess water. These sheets, are then air-dried for 3 to 4 days, and depending

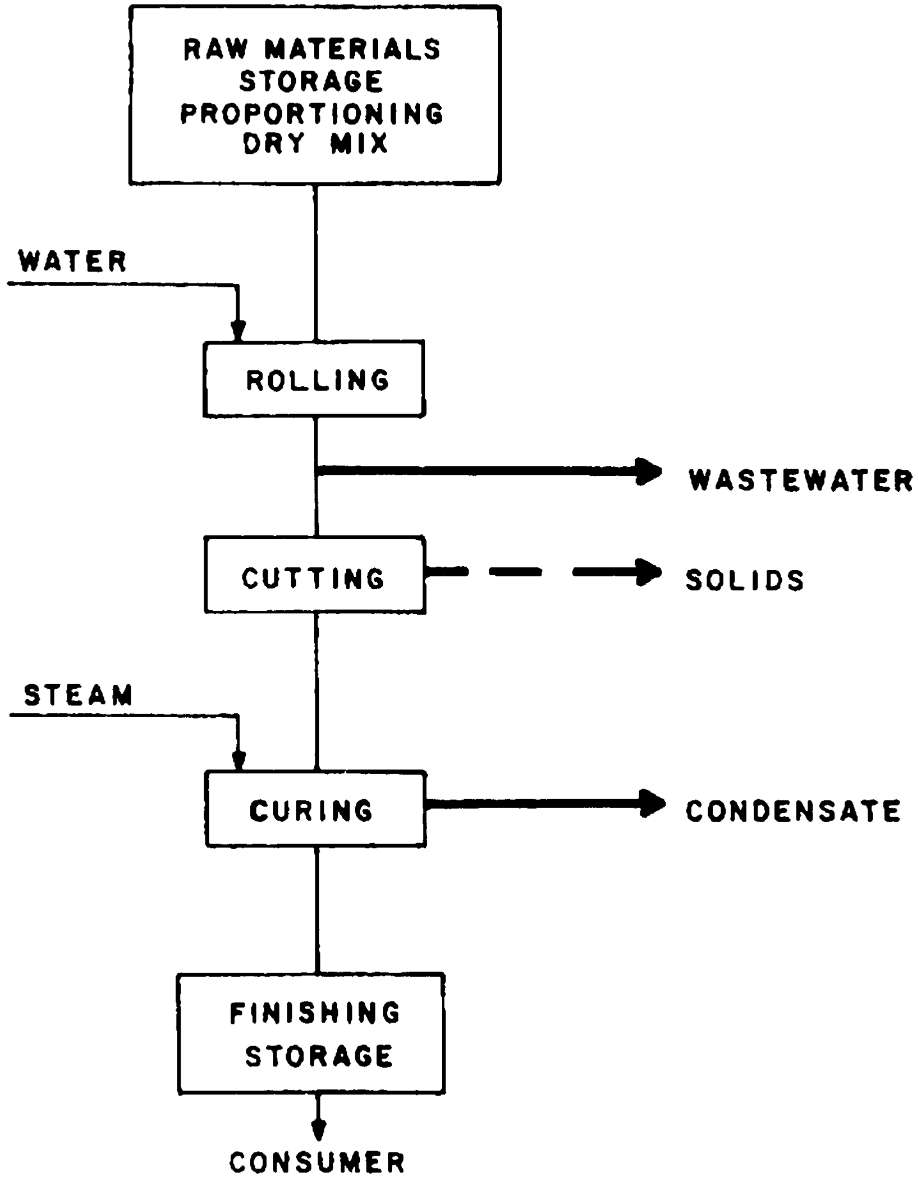


Figure 15. Asbestos-cement sheet manufacturing operations, dry process.[6]

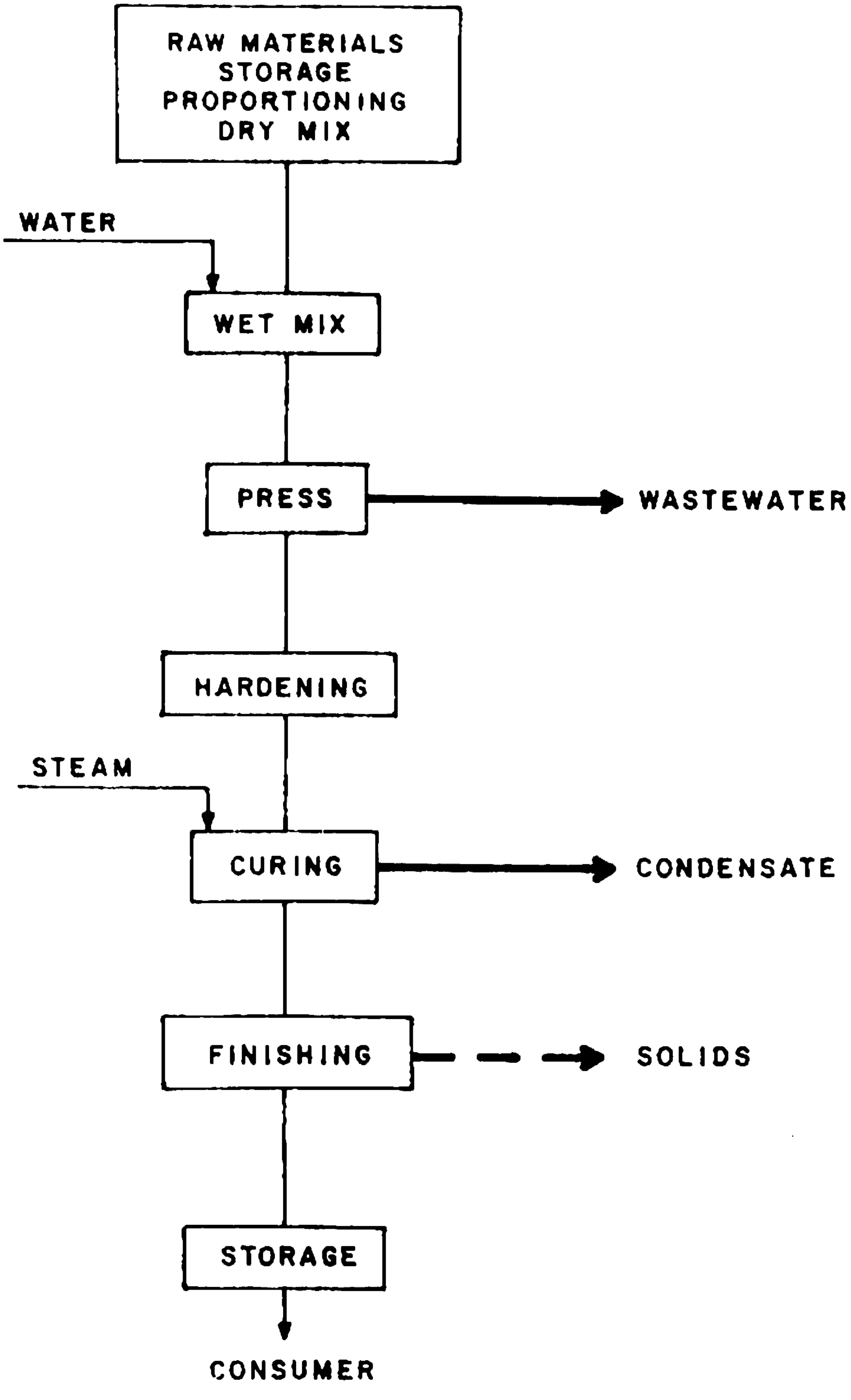


Figure 16. Asbestos-cement sheet manufacturing operations, wet process.[6]

upon use, steam cured. The steam-curing process is faster than air curing. The product is subsequently sanded by machine (with vacuum hood) to assure appropriate thicknesses, and machine cut to size. Customer specifications may be met at this stage for some products; others have secondary or even tertiary steps where they are cut to even more specific sizes (for example, as in adapting a sheet to use as a sink hole).

Wet Mechanical Process--

There is a third process used, called a wet mechanical process, for both A/C sheet and A/C pipe production. This process, shown in Figure 17, is similar in principle to some papermaking processes. Willowed asbestos is thoroughly blended with silica, cement, and filler solids in a dry mixer. These raw materials are then transferred to a wet mixer (or beater). A slurry of about 97 percent water is formed by adding underflow solids and water from the saveall (material being recycled from previous operations). After more mixing, this slurry is pumped to cylinder vats for deposition onto one or more horizontal screen cylinders. Water is removed from the underside of the slurry layer through fine wire mesh screening around the circumferential surface of each cylinder.[6]

A layer of A/C material from 0.5 to 2.5 mm thick is produced by the above process. This is then transferred to an endless felt conveyor so that a single mat can be built up. Additional water within this matted material is removed by a vacuum box prior to transfer of the material to a mandrel or accumulator roll. This roll winds the mat into a sheet of the desired thickness for the specific product being made. Pressure rollers are used to bond this mat to stock already deposited on the roll or mandrel and additionally, to remove excess water. The built-up layer of A/C sheet on the accumulator roll is then periodically cut and peeled away. The resultant sheet is sufficiently tough to be handled freely but can nonetheless be molded and shaped. Afterward, the sheet is passed through a pair of press rollers to shape its surface and then, depending upon the application, cut into sheet sizes or shingles. Corrugated sheets may be produced by this method, or flat sheets can be made by placing the material on a flat surface for curing. The asbestos-containing water from this slurry is recycled to the ongoing process, so that very little asbestos is thought to be lost from the operation.

Methods such as cylinder showers are used by manufacturers to ensure satisfactory operation of this process sequence. Both the cylinder screen and the felt conveyor are kept clean by this method in which water is sprayed on the screen surface each time the mat is removed by the felt.[6] Cement or fiber particles caught in the holes of the screen are washed out to prevent "blinding." Acetic or hydrochloric acid is also used upon occasion to remove cement deposits from the cylinders, mandrels, and accumulator rolls. This may take place while the machine is in operation. Cylinder screens are also easily removed for separate washing. Felt washing showers are used to wash fibers out of the felt after the mat of fiber product has been picked up by the mandrel or accumulation rolls. This row of high-pressure nozzles, aided by a "whipper" can control fiber buildup in the felt, which in turn could prevent vacuum boxes from removing the excess water from the mat, an indespensible part of the manufacturing process.

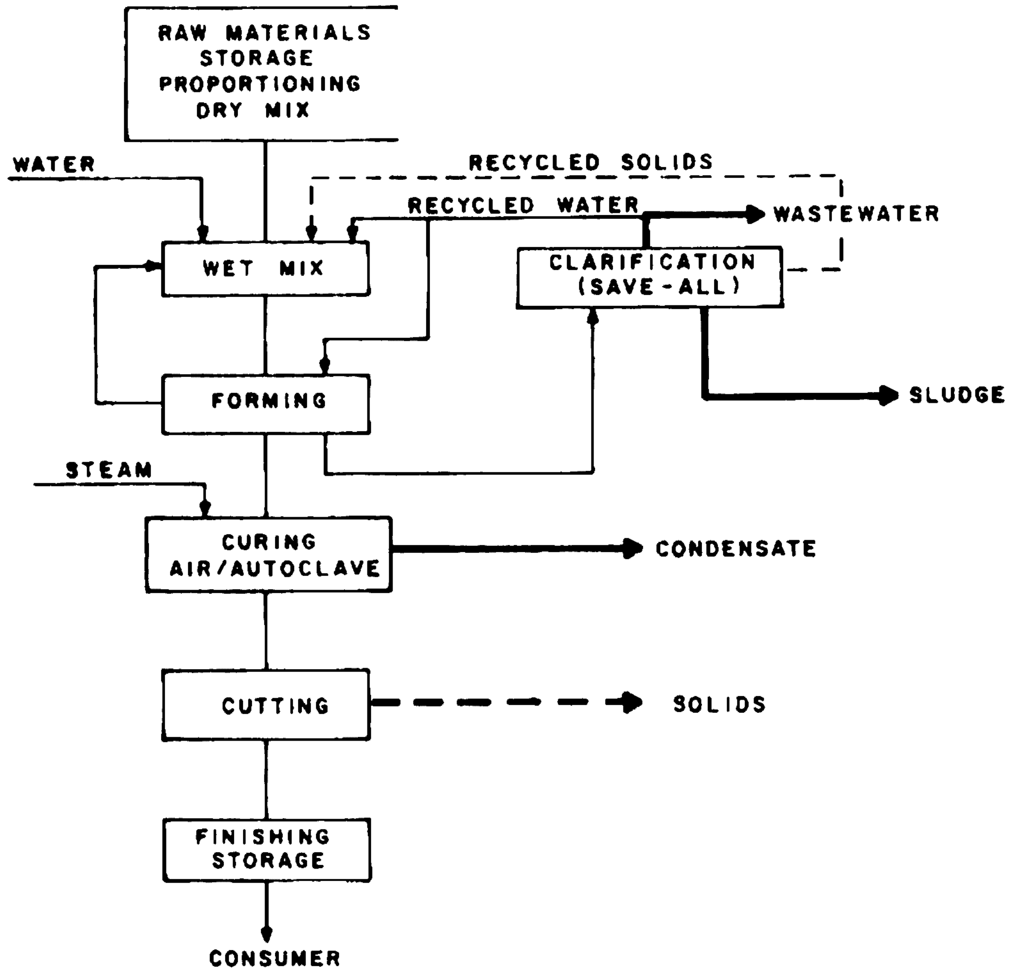


Figure 17. Asbestos-cement sheet manufacturing operations, wet mechanical process.[6]

Secondary Manufacture

There is some secondary manufacture of A/C sheet products consisting mainly of central fabricating shops which cut and shape the material to specific sizes. This may involve sawing, trimming, drilling, or grinding and may be done as part of field fabrications also. Flat asbestos sheets used on homes, barns, or other inexpensive construction are usually installed with fasteners or nails and require little drilling. With A/C products that do require field fabrication, knives or saws may be used, as well as drills; however, EPA has found that dust-collection devices are usually installed on such equipment, so major emissions of asbestos particles to the air do not occur.[13] The amount of dust generated by central fabrication shops working on A/C building products is estimated at about 90 kg/wk (200 lb/wk).[4] This corresponds to 4717 kg/yr (10,400 lb/yr) going to landfills or dumps. About 18 percent or less than 1 ton of this is thought to be asbestos.

Many A/C sheets come out of the original manufacturing sites ready for use. However, as described above, others require additional work before being ready for sale to consumers. These may go from the manufacturer to a distributor to, say, a furniture manufacturer, and finally to a company buying laboratory furniture, before the company at the end of the line receives the products. The intermediary steps may involve cutting or drilling but the final purchase of the product is in ready-to-use form.

Manufacturing Plants

Table 36 gives the locations of the five major manufacturers of A/C sheet. In the next section, Asbestos Release, both the pollution control processes seen at one plant visited and possible control measures used by the other manufacturers listed will be discussed. This includes emissions to air, land, and water, and all pollutant control and health protection measures taken.

TABLE 36. MAJOR MANUFACTURERS OF ASBESTOS-CEMENT SHEET[6,14,15]

Manufacturer	Location	A/C products[a]
Johns-Manville	Waukegan, IL	A/C sheet (flat)[b]
	Nashua, NH	A/C sheet (flat)
International Building Products, Inc.[c]	New Orleans, LA	A/C sheet (corrugated)
Supradur Mfg.	Wind Gap, PA	A/C sheet (flat and corrugated) A/C shingles (roofing and siding)
Nicolet Inc.	Ambler, PA	A/C sheet (flat)

[a] Products other than those mentioned may also be manufactured at these sites.

[b] A/C sheet produced at this plant may undergo job site fabrication in-house to a greater extent than that product originating from Nashua.

[c] Operation used to be owned by Gold Bond Building Products, a Division of National Gypsum. (Asbestos Magazine, March 1981, p. 32).

Production Volume

Production volumes are not known, although it is known that 7,900 metric tons (8,690 short tons) of asbestos was used in 1980 for the production of all types of A/C sheet products.[1] Chrysotile asbestos was the predominant fiber used, along with a small amount of amosite.[1]

ASBESTOS RELEASE

Input-Output

Figure 18 shows estimated process disposal and emissions for asbestos cement manufacturing based on Levine's[16] 1974 estimates projected to 1980 U.S. Bureau of Mines[1] consumption figures. Of the 7,900 metric tons entering the process as raw asbestos fiber, approximately 7,699 metric tons are incorporated into the product and 198 metric tons are sent to disposal as product scrap, clarifier sludge, and vacuum cleaner and baghouse dust. An estimated 0.8 metric tons escape through a control device (typically a baghouse) and 1.8 metric tons are discharged to water. Levine's[16] emission estimates are based on gross assumptions with a reported uncertainty of at least an order of magnitude. Meylan[4] reports emissions of 1 to 3 orders of magnitude less. Atmospheric emissions from disposal are shown to be 0.4 metric tons. This last estimate, which follows Levine's[16] 1974 data, also takes into account the Asbestos NESHAPs regulation adopted in 1975 regarding the disposal of asbestos-containing waste material.

During Manufacture

Workplace Exposure--

As shown in Table 37, exposure to airborne asbestos fibers during A/C sheet manufacturing varies greatly within and between processing steps. A typical exposure for most operations is 2.0 fibers/cc TWA.[16] Table 37 also presents the lowered fiber counts that may be possible if best available technology (BAT) steps are taken (hoods, ventilation, proper bag handling, etc.). The model site visited had initiated such controls. It is also interesting to note here that the TWA fiber counts at the fiber introduction and dry mix steps for the A/C sheet process are higher than for the same process for A/C pipe, as fiber is introduced more directly for A/C sheet.[11] The fiber counts (0.3 to 8.7 f/cc) at this stage represent the highest in the manufacturing steps for A/C sheet. The highest typical fiber count (3.0 f/cc), however, occurs during sheet sanding. Although control equipment has proven effective here, it is difficult to control fiber loss from the large surface areas of the sheet during sanding, and loose fibers remaining on the sheet tend to become airborne as the material is handled.[11]

Emissions to Air--

Asbestos release to the atmosphere may come both from baghouse emissions and disposal emissions. Actual measurements of the asbestos fiber concentration in the vicinity of an asbestos cement sheet manufacturer are very limited. However, Suta and Levine[16] estimated concentrations near asbestos industrial

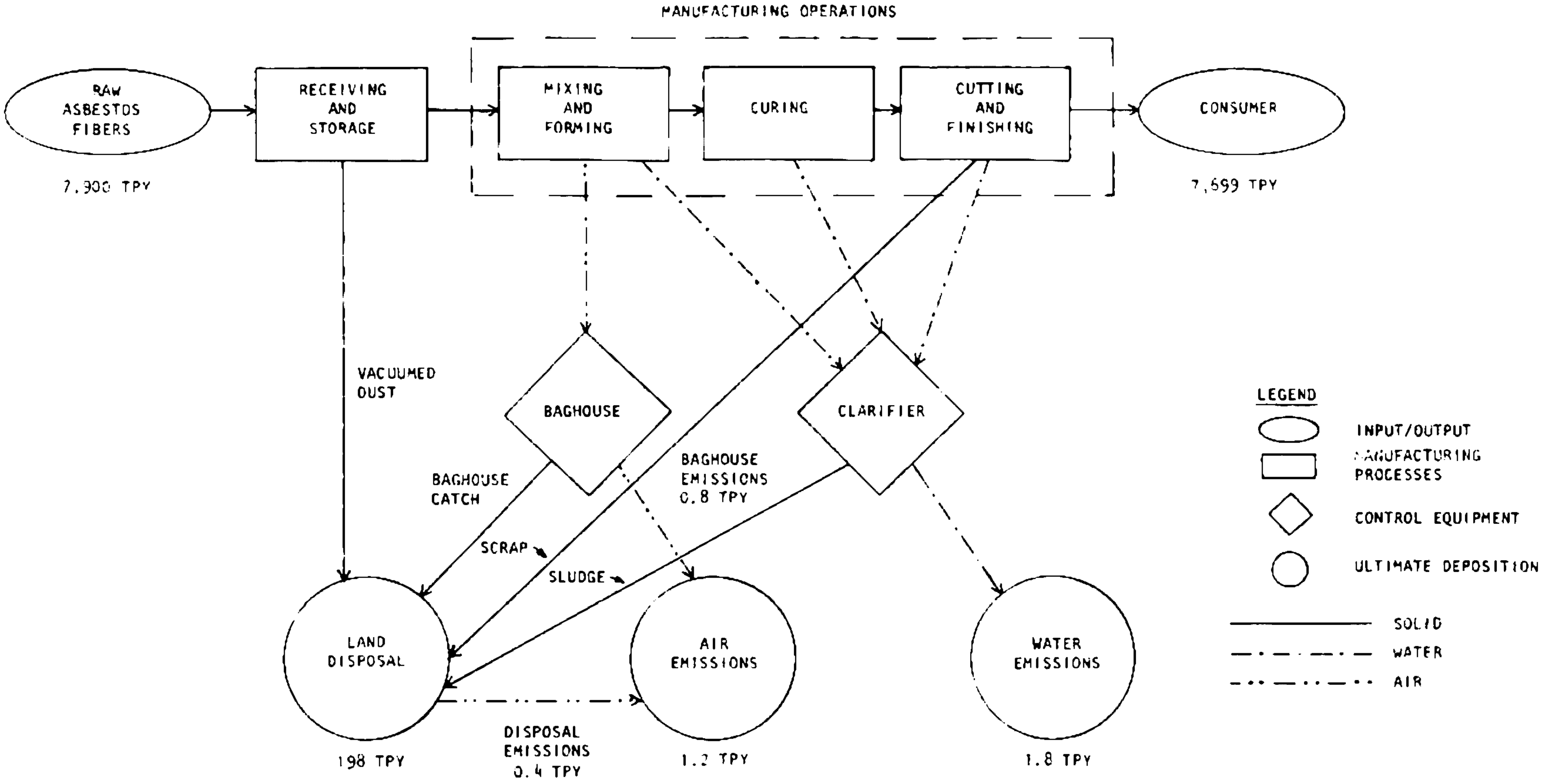


Figure 18. Input/output of asbestos in the asbestos cement industry (metric tons).

TABLE 37. MEASURED TIME-WEIGHTED AVERAGE FIBER COUNTS DURING THE MANUFACTURE OF ASBESTOS-CEMENT SHEET[a,b][11]

	Process step	Fiber count with existing control technology		Fiber count with best available technology[c]
		Typical Fibers/cc	Range Fibers/cc	Fibers/cc
1	Receiving & storage	1.0	0.25-2.5	0.5 or 1.0
2	Fiber introduction	2.3	0.3-8.7	1.0
3	Dry mix	2.5	1.1-8.4	1.5
4	Wet mix	1.25	–	0.9
5	Sheet formation	2.0	1.6-3.5	1.25
6	Dry/cure	1.9	1.3-2.5	1.25
7	Cut/trim	2.5	0.6-6.7	1.0
8	Sand	3.0	0.9-8.0	2.0
9	Finishing & fabrication	1.8	0.9-3.6	1.0

[a] Optical-microscope-visible fibers, 5 μm long or longer.

[b] Data Base: Data collected from plants consuming 89 percent of the asbestos used for A/C sheet production.

[c] Projected fiber counts are estimates of average exposure after implementing BAT. Variations of these values are expected depending upon individual installations.

facilities using mathematically derived dispersion curves of assumed plant emissions. In the case of asbestos cement, it was estimated that a population within 5 km of a manufacturing plant would be exposed to a median atmospheric asbestos concentration of 27.0 and 7.2 ng/m^3 for urban and rural facilities, respectively. Comparing this data with the median U.S. atmospheric asbestos fiber concentration (20 ng/m^3), it appears that asbestos cement manufacturing contributes little to nonoccupational exposure. However, actual ambient monitoring in the vicinity of an asbestos cement sheet facility is necessary to confirm Suta and Levine's estimates.

Release to Water--

Water usage in A/C sheet plants ranges from 280 to 2,040 cubic meters per day.[6] This varies not only from plant to plant, but within a particular plant, depending upon cement type and other variables needed to make the product the correct consistency. A minimal effluent volume from a plant was found to be 7.5 cubic meters per metric ton (1,800 gal/ton) of production. Using Levine's[16] 1974 estimates of release to water scaled to 1980 asbestos consumption figures as reported by the U.S. Bureau of Mines,[1] it is estimated that annual asbestos release to water for the entire asbestos cement sheet industry is 1.8 metric tons.

A/C plants recycle most of the water they use, which serves as a recovery method for all usable solids contained in their wastewater. After leaving the machine vat, this water (which is 80 to 90 percent of all the water used in the A/C process) passes through a save-all where solids settle to the bottom, later to be pumped to the wet mixer to become part of the slurry therein.[6] If the save-all is efficient, much of the water it clarifies can be used for such purposes as showers, dilution, etc. Any overflow from the save-all can be discharged from the plant or treated and returned to the plant to be used as its quality justifies. Uses for such water may include water needed for vacuum seals, wet saws, cooling, hydrotesting, or plant start-up. If the treated water cannot serve in these uses, fresh water must be used in its place. The quality and temperature of save-all overflow water is rarely acceptable without additional clarification.[6]

At least one A/C sheet plant is known to completely recirculate the water it uses. Benefits of such a system include reduced water cost, reduced sewer service charges, minimal asbestos loss, and in addition, a reportedly stronger product. The major problem encountered in complete water recycling at a plant is scaling.[6] As spray nozzles build up with mineral deposits, they require occasional unplugging. Water lines are regularly scored with a pneumatically driven cleaner, with the introduction of fine sand to the pumps to help eliminate deposits. While this system works in a study plant, it is not known if the same measures would work in plants producing sheet products that have more stringent quality specifications. However, current progress indicates that complete water recirculation systems such as this are realistic future goals. For example, one plant studied used a completely closed loop circulation system for all the water used. In an enclosed setting tank, beneath the plant, the water is continuously cleaned and reused. The filtered solids are pelletized and placed in a landfill. As the asbestos fibers are bound in cement, wrapping is not even necessary before they are disposed of in this manner.

Release to Land--

Estimates indicate that 5 to 10 percent of all A/C products (A/C sheet, A/C pipe, etc.) are dumped as scrap.[6] Of this, 10 percent is thought to be fine dust from baghouse collections and 90 percent is coarse scrap from trimmings and breakage from products that fail quality assurance tests.[6] Baghouse emissions are generally pelletized at the plant to transform free fibers into tightly bound balls of cement. Since the asbestos shipped to a landfill is encapsulated in cement, emissions to air or water is minimal.

Most worn out asbestos cement sheet is probably disposed of in landfills. As in the case of manufacturing wastes, the worn out material is encapsulated in the cement matrix, resulting in minimal release to water or air.

Quantities of solids associated with treatment and control of wastewater from A/C product manufacture are of significant volume, especially when compared to the small volume coming from paper millboard, roofing, and floor tile manufacturing. However, even though losses to solid wastes may be great, the loss of asbestos fibers themselves is thought to be minimal (1 percent or less).[6] The fiber content of the waste solids is low, which is why they have no salvage or recovery value.

During Use

Loss of asbestos fibers during installation and laying of A/C sheet materials is not considered to be significant, as the asbestos fibers are encased by asphalt or cement. Field fabrication of A/C sheet can release some dust during fitting, cutting, drilling, or grinding operations; but it has been found that emission control devices, such as bags to collect dust, are usually used in the field when such operations take place, and further, that cutting and fitting processes are more often carried out by central fabricating shops (secondary producers). If there are no adequate control measures, exposure within such shops could be high. As before, the scrap materials from cutting operations end up in dumps and landfills.[4] The amount of dust generated by central fabrication operations for all A/C building products is estimated to be 90 kg/wk (200 lb/wk), or 4,717 kg/wk (10,400 lb/yr).[4] If the asbestos content of this dust is 18 percent, slightly less than 1 ton/yr is generated by such shops. A/C sheets are primarily installed in industrial buildings, warehouses, and to a more limited degree, residential applications. Flat asbestos sheets used in homes, barns or other more expensive construction, are usually installed with fasteners or nails, requiring only minimal drilling, if any. If adjusted in the field, these are usually cut with knives or saws.

The probable asbestos dust concentrations at the actual construction site where A/C sheet (and/or pipe) is being used, range from less than 2 fibers/cc to as high as 20 fibers/cc.[16] Concentrations from both machine drilling and machine sawing (using effective exhaust ventilation in the field, as mentioned above) fall towards the lower end, indicating emissions of less than 2 fibers/cc of probable asbestos fiber. Concentrations from hand sawing range from 2 to 4 fibers/cc and machine sawing (without controls) with a jigsaw from 2 to 10 fibers/cc, rising to 10 to 20 fibers/cc using a circular saw, the highest level for the A/C sheet category. For comparison, the asbestos dust concentrations from use of a circular saw on insulation board (also without effective ventilation) range from 20 fibers/cc upwards, and spraying of asbestos, extensively used in past applications, is thought to expose over 100 fibers/cc.[16]

Considering that an estimated 1.13 x 10^6 Mt of A/C sheet is in place, estimates indicate that 1,130 Mt/yr of asbestos fibers may be released.[16] This figure excludes roofing uses, which would perhaps double the estimate. Weathering and wear rates are expected to be low, roughly 0.1 percent per year of the installed tonnage mentioned above. No free asbestos fibers are expected to be emitted from A/C sheet products that are not exposed to weather or corrosive materials; asbestos released, if any, would be bound in the cement matrix. A/C sheets used in the construction of warehouses and bulk storage for corrosive materials and fertilizers may release asbestos fibers if the cement contained in the binder material disintegrates due to the corrosive atmosphere. However, asbestos is used in this product specifically for this reason--it provides resistance from corrosion. Figures for such asbestos tonnage installed in corrosive atmospheres are not currently available.

High concentrations (up to 543 million fibers per liter) of waterborne asbestos have been reported for drinking water collected in cisterns receiving runoff from asbestos-tile type roofing materials.[17] Insignificant waterborne asbestos concentrations, however, were found in cisterns receiving water from the more typical asphalt-asbestos roofing shingles. Seemingly, the asphalt binds the fibers well enough to prevent significant fiber release.[17]

During Disposal

A/C sheets are thought to have a life expectancy of about 15 to 25 years before being replaced by new materials.[4] However, life expectancy varies with product. Laboratory table tops last until the building of which they are a part is torn down, as do the textured A/C sheets used in architectural construction. Flat sheet pieces have a more practical lifetime, wearing out as the products they are part of (arc shields, welding tables) require replacement. A/C roofing shingles are thought to last 20 to 25 years.

If 75 percent of all annual production really is used for replacement purposes, 187,000 tons of A/C sheet products are replaced each year (this number includes roofing applications but does not consider weathering effects) representing about 34,000 tons of asbestos. Most worn out sheet is probably dumped in landfills.

CONCLUSION

The growth in the market for A/C sheet products in the U.S. has lagged behind that of the construction industry in general in recent years.[4] Although the present market for corrugated sheet is stable and projected to remain so, the flat sheet market has declined, with future decreases predicted.[4] Growth in this area is only a few percent per year. Competitive pressures from alternative products, along with increasing concern about asbestos fiber exposure from both contractors and homeowners have contributed to the slight market decreases. For construction purposes, A/C sheet is now more often used only when its specific properties are needed.

Currently, there is a growing interest in substitutes for A/C sheet. Representatives of companies either manufacturing substitute cement sheet or planning to make asbestos-free cement sheet products report an increased interest from other parties using or requiring A/C sheet products.[19-21] Alternatives include the manufacture of flat glass-reinforced concrete sheets that can be produced at competitive prices.[20] Cement/wood board could also be formed into textured siding and roofing shingles that, if produced, could compete effectively with A/C roofing and siding shingles.[22] Aluminum vinyl siding is reportedly forcing A/C siding from the residential market except where special fire protection is required or where slate-like appearance is desired.[23]

No material that can adequately match A/C sheet's qualities as a lab table is available, though other products are currently used. (Slate is one of the materials used here but it is inordinately expensive.) At this time no single material could replace ebonized asbestos sheet in all electrical applications, but Benelex®, a laminated hardboard product manufactured by Masonite Corporation, Laurel, Mississippi, has been shown to be a usable substitute for some.[24]

Asbestos-cement sheet still stands as a versatile, all-purpose material that is relied upon for its excellent durability, heat resistance, workability, and relatively low cost. This unique combination of qualities has until now given it an unrivaled niche in various markets in the United States. While no single product matches A/C sheet's qualities exactly (companies such as Johns Manville claim that all nonasbestos sheets degrade more rapidly than asbestos), there are products that can be identified as suitable substitutes for A/C sheet for most applications. With new replacements, some recognition of the performance requirements of the end use has to be clarified with the user; such requirements have often been neglected in favor of the ease of A/C in that the decision has been made in the past. However, with properly defined requirements, many of these substitute products can adequately fulfill uses delegated to asbestos in the past, even though this may require a certain amount of testing and design work to come up with the right thickness and formulation to make the alternative product work. Most substitutes are currently more expensive than A/C but the differential is shrinking.

REFERENCES

1. Clifton, R. A. Asbestos. 1980 Minerals Yearbook. U.S. Bureau of Mines, Washington, D.C.

2. U.S. Bureau of Mines. Mineral Commodity Profiles: Asbestos. July 1979.

3. U.S. Bureau of the Census, 1977 Census of Manufacturers.

4. Meylan, W. M., et al. Chemical Market Input/Output Analysis of Selected Chemical Substances to Assess Sources of Environmental Contamination. Task III - Asbestos. EPA 560/6-78-005. August 1978.

5. Bradfield, R. F. N. Asbestos: Review of Uses, Health Effects, Measurement and Control. Atkins Research and Development, Epsom Surrey, England. January 1977.

6. Carton, R. J. Development Document for Effluent Limitation Guidelines and New Source Performance Standards for Building, Construction, and Paper Segments of the Asbestos Manufacturing Point Source Category. U.S. Environmental Protection Agency. EPA-440/1-74-017a. February 1974.

7. DeKany, J. P. Economic Impact Assessment for the Proposed Revisions to the Occupational Exposure Standards for Asbestos Dust. OSHA, 1979.

8. Pre-Insulated Panels Maximize Energy Efficiency, Electr. Comf. Cond. News, Vol. 6, No. 1, p. 19-20. Jan. 1979.

9. Fabbrocino, V., and E. R. Ermolli. Hybrid Composites in an A/C and Glass-Reinforced Plastic, Ingegnere, Italy, Vol. 51, No. 10, p. 417-27. October 1976.

10. Pye, A. M. A Review of Asbestos Substitute Materials in Industrial Applications, Journal of Hazardous Materials, Vol. 3, p. 125-147. 1979.

11. Weston, Roy F. Environmental Consultants. Technological Feasibility and Economic Impact of OSHA Proposed Revision to the Asbestos Standard (Construction Excluded). Asbestos Information Association/North America. March 26, 1976.

12. Roy, N. Final Trip Report to Johns-Manville Corporation, A/C Plant in Nashua, N.H. GCA/Technology Division, Bedford, MA. October 23, 1979.

13. U.S. Environmental Protection Agency, 1974. Background Information on National Emission Standards for Hazardous Air Pollutants: Proposed Amendments. Research Triangle Park, N.C.

14. W. E. Davis and Assoc. (Leawood, KS). National Inventory of Sources and Emissions: Asbestos - 1968. U.S. Environmental Protection Agency, Office of Air and Water Programs OAQPS, Research Triangle Park, N.C. APTD-70, February 1970.

15. Telecon. E. Fenner. J/M Corporation, Denver, CO with N. Roy, GCA/ Technology Division. October 24, 1979.

16. Levine, R., (ed.). Asbestos: An Information Resource. DHEW Publication Number (NIH) 79-1681, U.S. Department of Health, Education and Welfare, National Cancer Institute, Public Health Service, Bethesda, Maryland, May 1978.

17. U.S. Environmental Protection Agency. Exposure to Asbestos from Drinking Water in the U.S. EPA-600/1-79-028. August 1979.

18. Suta, B. E, and R. J. Levine. Non-Occupational Asbestos Emissions and Exposures. Asbestos, Properties, Applications and Hazards. Volume 1. John Wiley and Sons, New York, N.Y. 1979.

19. Telecon. J. Jones, Assistant General Manaber, CEM-FIL Corp., Nashville, Tennessee, with S. Duletsky, GCA/Technology Division, January 31, 1980.

20. Telecon. W. H. Lewis, GRC Products, Inc., Schertz, Texas, with S. Duletsky, GCA/Technology Division, February 11, 1980.

21. Telecon. J. Bostian, Asbestos Fabricators, Inc., Charlotte, North Carolina, with S. Duletsky, GCA/Technology Division, March 7, 1980.

22. International Housing Corporation. Notebook Containing Information About Cement/Wood Board. Sacramento, California. 1979.

23. Masonite Corporation. Siding: 1980. Form 902180. Towanda, Pennsylvania. 20 pages.

24. Krusell, N., and D. Cogley. Asbestos Substitute Performance Analysis. Prepared by GCA/Technology Division, Bedford, Mass., for Office of Pesticides and Toxic Substances, U.S. Environmental Protection Agency, Washington, D.C. May 1981. EPA Contract No. 68-02-3168.

SECTION 8

FLOORING PRODUCTS

INTRODUCTION

The fourth largest industrial use of asbestos fiber is the manufacture of floor tile. Approximately 10 percent of all asbestos consumed in the United States in 1980 was used in the manufacture of floor tile. This industry produces two major product lines utilizing asbestos. The vast majority of asbestos (up to 95 percent) is used in the production of vinyl-asbestos floor tile while the remainder is used to produce asphalt floor tiles.[1] Both types of tile have been used extensively in commercial and industrial applications as well as in homes and offices. Asbestos tile utilizes the shortest chrysotile asbestos fibers (grades 5 through 7) to impart strength, dimensional stability and resistance to cold. In addition, the asbestos fibers perform an important function in giving the polymer sheets "wet-strength" during the manufacturing process.[1] The production of both vinyl-asbestos and asphalt tile is similar, involving batch blending of ingredients in Banbury mixers followed by continuous tile sheet forming using mills and calenders. The production processes differ basically in that higher temperatures are needed to flux and process vinyl copolymer.[2]

PRODUCT DESCRIPTION

Composition

Only the chrysotile form of asbestos is used in tile production, with 1980 usage amounting to approximately 36,080 metric tons.[3] A typical formulation of vinyl-asbestos floor tile[4] indicates the composition shown in Table 38.

While specific ingredient formulas vary with manufacturer and the type of tile, the asbestos content of the tile ranges from 8 to 30 percent by weight,[5] or up to 0.64 kilograms of asbestos per square meter of tile.[6] Although exact percentages are not available, most manufacturers have indicated an asbestos content in the lower end of this range while one manufacturer has indicated the asbestos content to be significantly less than 8 percent.[7]

Actual tile formulations demonstrate a range of weight percentages of these individual constituents. PVC resin serves as the binder and makes up from 15 to 25 percent of the tile. Chemical stabilizers usually vary little from 1 percent of the total formulation. Limestone and other fillers represent 40 to 70 percent of the weight, while pigment content usually averages about 5 percent, but may vary widely depending upon the materials required to produce the desired color.[8]

TABLE 38. FORMULATION FOR A VINYL-ASBESTOS FLOOR TILE[9]

Material	Percent by weight
Vinyl chloride-vinyl acetate copolymer	15
Extender resin	2
Phthalate esters (plasticizer)	5
Extender plasticizer	1
Epoxidized soybean oil	1
Stabilizer	1
Asbestos short 7R fibers	28
Limestone filler	43
Pigment	4

The tile is typically produced in 9 x 9 inch or 12 x 12 inch sizes, with thicknesses varying from 1/32 to 3/32 inches. A large volume of vinyl-asbestos tile is embossed and simultaneously valley printed with a wide and attractive array of designs, to enhance its appearance.[9]

Uses and Applications

Asbestos flooring is used for protective and decorative covering of floors in industrial, commercial, and residential applications. In the early 1970's asbestos flooring comprised approximately 20 percent of the total flooring market. The use of asbestos in flooring has since decreased due to an increase in popularity of other types of flooring.[1] However, it still commands a high percentage share of the resilient floor covering market.

Vinyl-asbestos floor tiles and sheet vinyl flooring may be installed on concrete, prepared wood floors or over old tile floors. Chief competitors include ceramic tile, brick, stone, wood, terrazo, and carpet.

Special Qualities

Asbestos is used in flooring products because of its structural properties, which aid not only in creating an efficient covering but also in the manufacture of the tile and sheet products themselves. Asbestos fibers provide durability, resilience, flexibility, dimensional stability, moisture resistance, chemical and fire resistance, and indentation strength. In the manufacturing process, asbestos contributes to the mill tack, or adherence to the roll mills in production; it also provides heat resistance necessary for processing as one continuous sheet and dimensional stability to prevent expansion or shrinkage during production.

SUBSTITUTES

Substitutes for asbestos fibers are currently being researched for possible use in the production of vinyl and asphalt tile. Potential substitutes include glass fiber, sintered metal, steel wool, mineral wool, carbon fibers and cellulose fibers. All of these products lack the overall structural and thermal qualities of asbestos at comparable prices. The Monsanto Company has developed Santoweb®, a natural cellulose fiber substitute for asbestos in floor tile.[10] Cost is considered to be the major barrier to use of Santoweb.

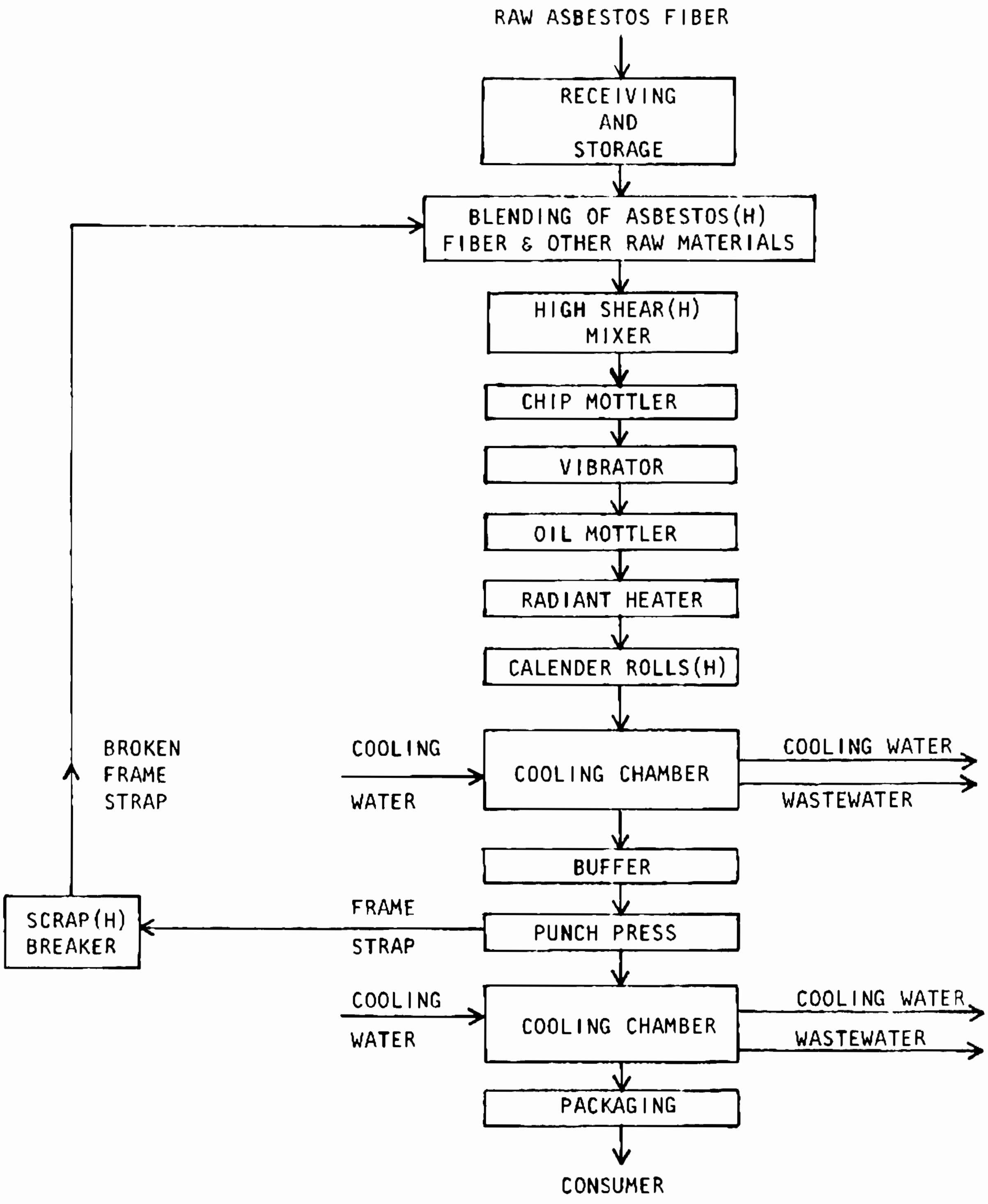
The Armstrong Cork Company offers an asbestos-free vinyl floor tile.[11] in which the limestone content is increased to replace the asbestos. The limestone alone is not sufficient to maintain all of the tile's desired qualities, such as durability. It is also necessary to increase the plastic binder content to meet these goals. These tiles meet the certification requirements for fire resistance, durability, dimensional stability and resilience as specified by several government agencies. The tile costs about 25 to 50 percent more than its asbestos counterpart. For this reason it is better suited to the residential replacement market, as opposed to large commercial installations. Coated types of vinyl flooring (plastisol-coated felts) are another relatively new type of flooring which is beginning to capture a portion of the vinyl-asbestos market. Non-asbestos flooring is specified for some resilient flooring installations and non-asbestos products now comprise between 5 and 10 percent of the resilient flooring market.[12]

MANUFACTURING

Primary Manufacture

Asbestos floor tile is manufactured by a process represented schematically in Figure 19. While each individual manufacturer employs a proprietary production line process geared to his specific product, the general flow of raw and finished materials in the industry is similar.

Asbestos fibers arrive by truck and railroad at most facilities in 50, 70, and 100-pound polyethylene plastic bags which are stacked on wooden pallets. Forklift trucks transport the pallets to a storage area where they are stacked up to four pallets high. Bags are inspected upon delivery and tears are immediately taped. Often the entire pallet is shrink-wrapped with an additional plastic wrapping. Asbestos is sometimes shipped in pressure-packed bags in which the asbestos is pressed into a hard consolidated mass. Asbestos can also be pressed into small pellets and can then be shipped either in bulk quantities or bagged. One flooring company receives 75 percent of its asbestos in bagged, pelletized form.[14] Fibers in pelletized form



NOTE: (H) indicates hooded operations.

Figure 19. Floor tile manufacturing operation.[13]

and in pressure-packed bags are less likely to leak and those which do leak are less likely to become airborne.[13]

Pneumatic conveying systems are used to transport pelletized asbestos from railway cars and trailers to intermediate or primary storage bins.

From storage, the pallets are transported to the fiber introduction area. Here, when possible, an entire bag of asbestos fiber is added unopened, to a batch mix. The plastic bag is incorporated into the product. Plant personnel at one facility indicated that approximately 55 percent of batch mixes utilize entire bags while the remaining mixes require that a bag be manually opened and the asbestos fibers weighed to predetermined mix requirements.[14] Automatic bag openers are available, but are in most cases not practical in the flooring industry due to the relatively small batches used. However, automatic bag openers would reduce worker exposure by increasing the physical distance between workers and asbestos.

Ingredients for tile production, including raw asbestos fiber, pigment, and fillers are weighed and mixed dry in a Banbury mixer (high shear mixer). The mixer works the dry materials into an agglomerated plastic mass. As the material is sheared in the Banbury, the asbestos, fillers, and pigments are dispersed throughout the vinyl mass. Liquid constituents, if required, are then added and thoroughly blended into the batch. While the mechanical working of the material itself generates heat, more heat may be added, if required, to raise the batch temperature to 300°F (150°C) and flux the polymer resin. The warm plastic mass is then fed to a mill where it is joined with recycled scrap and undergoes final mixing. From this point on, the process is continuous. The mill consists of a series of hot rollers (calender rolls) that squeeze the mass of raw tile material down to a desired thickness. During the milling operation, surface decoration in the form of small colored chips of tile (mottle) may be sprinkled onto the surface of the raw tile sheet and pressed in to become a part of the sheet. Some tile has a surface decoration embossed and fused into the tile surface during the rolling operation. After milling, the tile passes through calenders until it reaches the required final thickness and is ready for cooling. Tile cooling is accomplished in many ways and a given tile plant may use one or several methods. Direct water contact in which the tile is immersed in, or sprayed by water is one method. Indirect water cooling utilizing water-filled rollers is another. Some plants pass the tile through a refrigeration unit to cool the tile surface. After cooling, the tile is waxed, stamped into squares, inspected, and packaged. Trimmings and rejected tile squares are chopped up and reused.[1] Asbestos in the floor tile is thought to be completely encapsulated when it is shipped. Only mechanical action, such as additional cutting and shaping by wholesalers, retailers, and installers will liberate the individual asbestos fibers from the floor tile after it is shipped.

Sheet vinyl flooring (flooring carrier, flooring felt) is an asbestos paper product which forms the underlayer of sheet vinyl flooring. The backing is produced on a paper machine, following production techniques outlined in Section 4 of this report. During manufacture, the asbestos fibers are coated with latex and are reported to be fully encapsulated when the sheet backing is readied for use in the manufacture of sheet vinyl flooring. The major steps in the manufacture of sheet vinyl flooring are coating, printing, fusion, trimming and packaging. The flooring may be manufactured in the same plant as the sheet backing or in a separate facility.

Production of sheet vinyl flooring begins with a coating operation. Here the sheet backing is coated with a latex and/or plastisol coating. These coats are applied by reverse roll coaters or blade coaters. Once the coatings are applied, the sheet is passed through an oven where these layers are dried and jelled. The coated sheet is then transported to a printing operation where one or more engraved cylinders transfer designs to the coated sheet. In some cases, there will be several printing stations which separately apply one color or aspect of the design patterns. The printed sheet then goes to a fusion step where the sheet is coated with another layer of material called the "wearlayer." The wearlayer is a homogeneous polymer application that provides an impervious surface for the finished product. The coated and printed sheet is next fed through an oven where the backing itself, the layers of latex and plastisol and the wearlayer are fused into a single product. After fusion, these layers remain distinct but are no longer chemically or mechanically separable. The vinyl sheet is then cooled, cut to size, packed and shipped.

Manufacturing Plants

The major asbestos floor tile manufacturers and their plant locations are presented in Table 39. Actual plant-by-plant asbestos use was unavailable as manufacturers regard this information as confidential. The asbestos content of the finished floor tile is also kept confidential, precluding the establishment of "typical" asbestos use and emission rates. As the manufacturers sell floor tile directly to retailers, lumber yards, etc., there are no secondary fabricators in this industry.

TABLE 39. MAJOR U.S. MANUFACTURERS OF ASBESTOS FLOORING[1,15]

	Plant location	
Manufacturer	Vinyl asbestos tile	Sheet backing
American Biltrite, Inc. Amtico Flooring Division	Trenton, New Jersey	Norwood, Massachusetts
Armstrong Cork Co.	South Gate, California Kankakee, Illinois Jackson, Mississippi Lancaster, Pennsylvania	Fulton, New York
Congoleum Corporation Resilient Flooring Division		Cedarhurst, Maryland
GAF Corporation Consumer Products Group	Long Beach, California Vails Gate, New York	Whitehall, Pennsylvania
Kentile Floors	Brooklyn, New York Chicago, Illinois	
Mannington Mills, Inc.	Salem, New Jersey	
Uvalde Rock Asphalt Azrock Floor Products Division	Houston, Texas	

Production Volumes

The principal forms of resilient flooring used include vinyl-asbestos, asphalt-asbestos and solid vinyl. In 1975 asbestos flooring accounted for approximately 91 percent of the resilient floor covering market.[4] Of this total, 38 percent was floor tile and 53 percent was sheet flooring. Only 9 percent of the resilient floor covering market was held by nonasbestos-containing products. The manufacture of linoleum, another type of resilient flooring, was discontinued in 1974 due to competition with vinyl floorings.[12] Asbestos flooring competes principally with carpeting and solid vinyl flooring. This figure has decreased primarily due to the growing popularity of carpeting, especially the use of tufted carpets in both residential and commercial buildings. From 1971 to 1980 the use of asbestos in flooring decreased by about 48 percent with asbestos use in flooring decreasing from 173,000 metric tons to 90,020 metric tons. The market share of all forms of vinyl flooring is now believed to be well established and is not expected to change significantly in the foreseeable future.[12] Carpeting is expected to fulfill any increased demand for flooring.

Tile is typically replaced before it completely wears out for reasons of style and decoration. A large percentage of production, estimated to be from 40 to 60 percent,[1] is therefore intended as flooring replacement.

ASBESTOS RELEASE

Atmospheric emission of asbestos fiber and asbestos-bearing scrap from the production of asbestos tile can be in the form of air, water, and solid waste discharges. These discharges are not completely independent as fibers collected in a control device limiting air emissions must be handled as a solid waste, and some solid waste is ultimately disposed of through incineration which may re-release the asbestos to the air. While few data are available on individual plant emissions, estimates have been made on total industry discharges and these will be discussed. In addition, those process points within a facility where the asbestos may be released to the atmosphere will be examined and available data, such as worker exposure levels, will be presented. Asbestos emissions due to product end use will be included when available.

Input/Output

Figure 20 shows estimates of process and disposal emissions for the asbestos floor tile manufacturing industry. These figures are based on Levine's[16] 1974 estimates projected to 1980 U.S. Bureau of Mines[3] consumption figures.* Of the 36,080 metric tons of raw fiber entering the process, approximately 35,135 m.t. are incorporated into the product and 945 m.t.

---

*GCA emission and cumulative exposure estimates are computed on the assumption that vinyl-asbestos floor tile constitutes 40 percent of the asbestos usage for asbestos-containing flooring products with the remaining 60 percent going to manufacture of sheet vinyl-flooring and flooring felt. These latter products are discussed in Section 4, Paper Products.

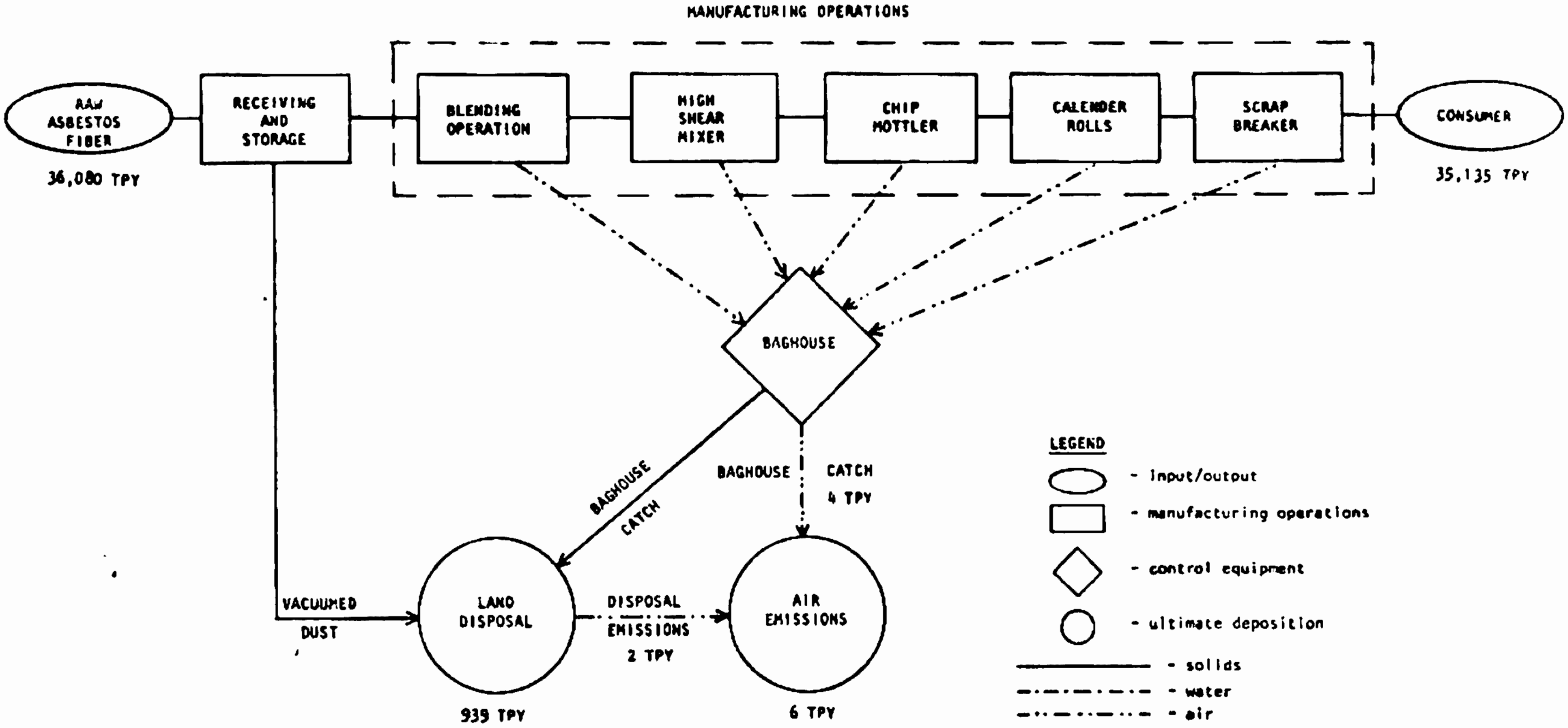


Figure 20. Process and disposal emissions (in metric tons) vinyl-asbestos floor tile industry.

are sent to disposal as vacuum cleaner and baghouse dust. An estimated 4 metric tons escape through a control device (typically a baghouse). Levine's[16] atmospheric emissions estimates are based on gross assumptions with a reported uncertainty of at least an order of magnitude. Meylan's[1] estimates of emissions are generally 1 to 3 orders of magnitude lower. Atmospheric emissions from disposal, based on GCA estimates, are shown to total 2 metric tons per year for the floor tile industry. This estimation is loosely based on Levine's 1974 data and takes into account new regulations adopted in 1975 regarding the disposal of asbestos.

During Manufacture

Workplace Exposure--

Airborne asbestos emissions from floor tile production are of the greatest concern as these will consist primarily of the raw asbestos fibers. Asbestos process air emissions were estimated to be 3.6 metric tons for 1980, or 0.01 percent of all asbestos processed by the floor tile industry.[16] Inasmuch as the asbestos fibers are encapsulated once they are mixed with polymer in the Banbury mixes, the major potential emission points for fiber release precede this mixing operation. These air emission points include fiber receiving and storage, fiber introduction, blending and mixing. The relative severity of emission levels in these areas, as well as in the entire production process, is shown by a comparison of available fiber count data presented in Table 40.

TABLE 40. TIME-WEIGHTED AVERAGE FIBER COUNTS - FLOOR TILE[17]

	Fiber count (with existing control technology)[a]	
Process step	Typical (fibers/cc)	Range (fibers/cc)
Receiving and storage	1.0	<0.1 - 2.5
Fiber introduction	1.5	<0.1 - 4.3
Blending	1.75	<0.1 - 4.3
Banbury mixer	1.5	0.8 - 4.3
Milling	0.75	-
Calendering	0.75	-
Embossing	0.75	-
Cutting	0.75	-
Inspection	0.75	-
Packing	0.5	-
Scrap and rework	0.5	-

[a] Optical microscope visible fibers >5 μm.

The maximum permissible asbestos concentration in industry is now 2 fibers* per cubic centimeter which are greater than 5 μm in length. Workers exposed to this concentration over a 40-hour week would inhale an estimated 2.5 billion fibers each year.[18] Assuming each worker is exposed to the average fiber count of all process steps cited in Table 40 (~1 f/cc),* then each inhales approximately 1.25 billion fibers each year.

Emissions to Air--

Due to the limited data on atmospheric concentrations of asbestos near manufacturing plants, an accurate assessment of nonoccupational exposure cannot be made. However, exposure has been estimated using a binomial continuous plume dispersion model with assumed plant emissions. The affected area is assumed to be bounded by a 5-km radius around the manufacturing plants. The asbestos concentration within this area is estimated to be 21,000 f/m^3 and the average person can be expected to inhale 115 million fibers per year compared to 220 billion fibers for asbestos workers. As a point of reference, the median ambient asbestos concentration for urban areas is 5,000 f/m^3.[18]

Receiving and storage has only an average fiber count, yet has a high potential for ambient fiber release since there are no control devices other than exhaust fans in this area. Asbestos is pelletized, shipped in plastic bags and/or shrink wrapped in plastic to decrease possible emissions in this area. In spite of these measures, the potential for accidental spills exists and a dropped bag or pallet can result in airborne fiber release. Accidents are most likely to occur when asbestos is being transported into and out of the storage area. Airborne emissions in the storage area are particularly dangerous since ventilation to an air pollution device is not practical. Strict packaging requirements would serve to minimize this potential problem area. A cyclone-type collector is used to remove pelletized asbestos from the air stream. Worker contact using this system is significantly less than when asbestos is transported by bag. Transport of the pellets causes some release of fibers and is a potential source of atmospheric asbestos emissions. Exhaust from the conveying system is therefore filtered through a baghouse before discharge.

Typically, plants are equipped with vacuum cleaners, respirators and bags to aid in cleaning up spillage. Once the vacuum cleaner bags are filled, they are labeled, securely tied and transported to a dumpster for ultimate disposal. Individual plant emissions from this area are impossible to estimate as the amount of asbestos stored, the rate of accidental spillage, the size of the storage area, and the number of air changes in this area are all variables that change from plant to plant. Fiber counts in this area have been found to range from 0.25 to 2.5 fibers/cc with a typical value of 1.0. By receiving asbestos in pressure-packed bags or in pelletized form on shrink wrapped pallets, repairing damaged containers, immediately cleaning spills and floor accumulations and vacuuming the floor at least once per shift the fiber count can be kept at or below 0.3 f/cc.[12]

---

*Optical-microscope-visible fibers >5 μm.

All fiber introduction takes place beneath hooded enclosures. These enclosures are vented to a baghouse for capture of the asbestos fibers that are released in the batch mixing operation. The size of the enclosure and the surface velocity maintained at the mixing face have been established to minimize worker exposure to the asbestos fibers. The vast majority of asbestos released from mixing is emitted to the local mixing area which is controlled by baghouse. Some is released directly to the atmosphere through area rooftop ventilation ducts, however, due to the diversity of mixing rates, mixing station configurations, and area ventilation rates, no estimates could be made on these uncontrolled rooftop asbestos releases.

Filler, pigment, and copolymer are added to the asbestos in a blending station. The addition of these dry ingredients increases localized dust levels; therefore, this step also takes place under a hooded enclosure. This enclosure is also vented to a baghouse for control of the asbestos fibers as well as fugitive filler, polymer, etc. Analysis of the baghouse catch at one tile manufacturing plant indicated that only 2 percent of the collected particulate was asbestos.[14] This estimate, however, is substantially lower than other published data[1] on the amount of asbestos captured in baghouses. Therefore it should not be considered typical of industry baghouse composition. Due to the semienclosed nature of the dry blending station, this area reported the highest typical fiber level, as demonstrated in Table 40.

Once all ingredients have been weighed and added to the batch mixture, the materials are transported by conveyor to a Banbury mixer where final mixing takes place. Typically, openings are provided on both sides of the Banbury inlets as well as deep in the inlet throat to control emissions generated by this mechanical transfer operation. These openings are operated at a negative pressure and are vented to the common collection baghouses. The asbestos is encapsulated in the plastic tile mass in the Banbury mixer, and from here on all processes demonstrate relatively small workplace fiber counts, and concurrent small potential atmospheric releases of asbestos through rooftop ventilation ducts.

Release to Water--

As indicated in Figure 20, there are negligible amounts of waterborne asbestos emissions attributable to the production of asbestos floor tile. Water is used regularly in the manufacturing process only for cooling of the tile after it has passed through the calenders. By this time, the asbestos fibers have been encapsulated and will not be carried off in the waste water stream. While the cooling water may contain dirt, oil, grease, wax, ink, glue and other contaminants that must be treated before discharged to a receiving water,[8] asbestos fibers are not an environmental threat to this waste stream. Waste water production varies for different plants from 79 to 1703 liters per 1000 pieces of tile produced.[5] The lesser amounts are produced by plants using a closed system with noncontact cooling. Cooling towers are used to dissipate heat and only periodic wasting of water is needed to prevent scaling. When direct contact cooling is used, larger amounts of water are needed since recycle is impossible due to a build-up of contaminants. Water used to wash the floors of receiving and storage areas may be contaminated by asbestos fibers. However, if these areas are thoroughly vacuumed on a regular basis, the total quality of asbestos released to receiving waters will be minimal.

Release to Land--

In terms of absolute tonnage, solid waste containing asbestos represents the greatest asbestos-related environmental problem, as this form of asbestos pollution accounts for greater than 99 percent of all manufacturing-related asbestos discharge and 99.99 percent of all end-use asbestos waste. It has been estimated[1] that 0.2 percent of production volume or approximately 72 tons of asbestos fiber are annually collected in floor tile manufacturing baghouses. This fiber is mixed with other tile constituents and cannot be easily extracted and recycled and is thus landfilled. Typically, baghouse waste solids are wrapped in plastic bags or containers, labeled to alert the disposal contractor of the hazardous nature of the contents, and shipped to a landfill where they are deposited in a separate hazardous section and covered with soil. Exposed to the mixing and transport actions of the wind, this asbestos fiber presents a problem. Once covered with soil, however, the environmental impact decreases substantially, as little evidence exists that the asbestos will leach into ground waters. Asbestos fibers collected in baghouse filters represent approximately 7.7 percent of all landfilled asbestos waste for the entire flooring industry.

During Use

Asbestos flooring has a service life varying from 10 to 30 years, depending upon the severity of usage. Normal traffic and cleaning result in a slow breakdown of the vinyl matrix and thus may allow a gradual release of asbestos fiber. The major release the tile is cut to size and when old tile is removed and disposed to landfills.[1] When old asbestos flooring is removed, sanding may be required to remove residual material. In a test simulating working conditions during sanding, the airborne asbestos concentration was found to be 1.2 to 1.3 f/cc and the potential for greater air emissions is thought to exist during actual working conditions.[19] While atmospheric emissions from this operation would total less than 175 mg per hour, worker exposure could exceed OSHA regulations. A second reference[1] has estimated the potential increase in the average asbestos concentration in the air above an asbestos tile floor due to use and cleaning to be from 0.008 to 0.08 fibers/cc. In order to estimate this fiber concentration it was first assumed that each square meter of floor tile contains 0.64 kg of asbestos, that the average service life is 20 years, that approximately 10 percent of the flooring is worn away during the service life by use and cleaning and that about 1 percent of the "worn-away" flooring becomes airborne. Stated in another form, on average, 0.003 grams of asbestos may be released to the atmosphere each year for every square foot of installed tile. To minimize air emissions a floor can be wetted prior to sanding operations.[19]

Waterborne asbestos emissions from the cleaning of floor tile can be estimated using these same assumptions. This permits a comparison of air and water emissions from the same activity. This calculation demonstrates that up to 0.3 grams of asbestos are discharged to receiving waters each year for every square foot of installed tile. This is 100 times the air emission estimate and it indicates that this type of emission, while not producing high localized emissions, may be a broad-based source of asbestos in receiving waters and deserves follow-up investigation.

During Disposal

Additional solid waste is disposed to the land in the form of manufacturing waste, or used floor tile. The asbestos contained in this waste is bound in a solid, plastic-like matrix. Unless these wastes are crushed or incinerated, there should be insignificant levels of free-fiber asbestos released to the atmosphere. Approximately 10 percent of floor tile solid waste is incinerated.[1] Since chrysotile asbestos (the form used in floor tile) decomposes into a different mineral form at 480°C,[1] the release of free asbestos fibers into the atmosphere is dependent upon the temperature at which the solid waste is incinerated. If one assumes that all incineration systems (municipal and private) currently operating are carefully controlled to minimize particulate emissions and that temperatures of 760° to 980°C are required for this proper combustion, then the incineration of floor tile waste results in minimal ambient asbestos release. Estimated asbestos air emissions of metric tons from tile manufacturing waste disposal as presented in Figure 20 appear to substantiate these assumptions.[5]

CONCLUSION

According to Bureau of Mines statistics,[3] the amount of asbestos used in flooring products has decreased by approximately 48 percent from 1971 to 1980. This decrease was considered to be a short-term phenomenon attributable to the popularity of newer products such as carpeting, and solid vinyl flooring. Contingency forecasts for the year 2000 made by the Bureau of Mines indicate that the use of asbestos by the flooring industry should increase by the year 2000 to 170,000 metric tons. This forecast is based on 20-year historical trends and assumes that the lower cost of asbestos flooring as compared to its competitors will give it an increasingly larger share of the flooring market. Flooring industry asbestos use is projected to increase from 25 percent of total U.S. asbestos demand (1980) to 28 percent of asbestos consumption by the year 2000.[20] This projection assumes that manufacturers will not adjust flooring formulas to minimize asbestos use and that asbestos flooring imports will not displace domestic production. It further assumes that no equally low cost substitute will be found for asbestos and that cost considerations will be the main factor in determining the increased use of asbestos flooring. Santoweb, a natural cellulose fiber, has been recently developed by Monsanto as a direct replacement for asbestos in vinyl flooring. Vinyl flooring using Santoweb is reported to have all of the desirable qualities of asbestos-vinyl at a 10 percent higher cost.[12] Higher cost is reported to be the main factor limiting Santoweb use. Direct replacements for fiber-reinforced vinyl tile are also being considered. Since replacement of floor tile is often made for decorating reasons and not because the tile itself has worn out, the newer, coated types of vinyl flooring (plastisol-coated felts) may actually garner a larger portion of the flooring market in the future than has been predicted, and this may serve to lessen the actual growth of asbestos use in the flooring industry.

The use of advanced technology in the manufacture of asbestos floor tile would reduce the amount of asbestos released to the atmosphere by the plants due to the increased asbestos fiber consumption predicted for the year 2000. Improved packaging techniques, the use of pressure-packed and pelletized asbestos, and the use of pneumatic conveyors would not only reduce worker exposure in the industry, but also decrease ambient emissions that result from accidental spills, breaks, etc. These ideas are currently in use at some newer plants, and can be expected to be installed in the new facilities that would be required to meet the increased production that is forecasted.

The flow of asbestos fibers through floor tile manufacturing facilities is well documented. Within the plants, processes that handle raw asbestos fiber are hooded and vented to baghouse collectors. Once the tile formulations have been mixed, the asbestos fibers are encapsulated and do not present an environmental hazard. While stricter packaging standards may be required to minimize the effects of accidental spills, by and large, the industry is controlling asbestos emissions reasonably well.

REFERENCES

1. Meylan, W. M., et al. Chemical Market Input/Output Analysis of Selected Chemical Substances to Assess Sources of Environmental Contamination: Task III - Asbestos. EPA-560/6-78-005. August 1978.

2. Bikales, N. M. Executive editor. Encyclopedia of Polymer Science and Technology, Plastics, Resins, Rubbers, Fibers. Volume 7. John Wiley and Sons, Publishers, N.Y. 1967.

3. Clifton, R. A. Asbestos. 1980 Minerals yearbook. U.S. Bureau of Mines, Washington, D.C.

4. Wright, M. D., et al. Asbestos Dust Technological Feasibility Assessment and Economic Impact Analysis of the Proposed Federal Occupational Standard: Part I. U.S. Department of Labor, OSHA. September 1978. (Draft)

5. Sittig, M. Pollution Control in the Asbestos-Cement, Glass, and Allied Mineral Industries. 1975.

6. Daly, A. R., et al. Technological Feasibility and Economic Impact of OSHA Proposed Revision of the Asbestos Standard (Construction Excluded). Asbestos Information Association/North America. March 26, 1976.

7. Telecon. Joost, F. Armstrong World Industries, with Patinskas, John, GCA. October 2, 1980.

8. Carton, R. J. Development Document for Effluent Limitation Guidelines and New Source Performance Standards for Building, Construction, and Paper Segments of the Asbestos Manufacturing Point Source Category. U.S. Environmental Protection Agency. U.S. National Technical Information Service. PB-230. February 1974.

9. Department of Health, Education, and Welfare. Criteria of a Recommended Standard: Occupational Exposure to Asbestos. Public Health Service. HSM 72-10267. 1972.

10. Telecon. Paul Graham, Monsanto Company, St. Louis, MO, with David R. Cogley, GCA Corporation/Technology Division. March 1980.

11. Telecon. Robert Luders, Sales Administration, Armstrong Cork Co., with Ron Bell, GCA Corporation. February 28, 1980. Notebook 1, Call 18.

12. GAF Corporation. Document No. OTS-61005, 1980.

13. U.S. Environmental Protection Agency. Control Techniques for Asbestos Air Pollutants. February 1973.

14. McInnes, R. G. Trip Report on visit to Kentile Floor Company, Brooklyn, N.Y. October 23, 1979.

15. Comments on the Advance Notice of Proposed Rulemaking on the Commercial and Industrial Use of Asbestos Fibers. The Resilient Floor Covering Institute. Washington, D.C. February 18, 1980.

16. Levine, R., ed. Asbestos: An Information Resource. May 1978.

17. Weston, Roy F., Environmental Consultants. Technological Feasibility and Economic Impact of OSHA Proposed Revision to the Asbestos Standard (Construction Excluded), Asbestos Information Association/North America. March 26, 1976.

18. Suta, B. E., and R. J. Levine. Non-Occupational Asbestos Emissions and Exposures. Asbestos, Properties, Applications and Hazards. Volume 1. John Wiley and Sons, New York, N.Y. 1979.

19. Murphy, R. L. et al. Floor Tile Installation as a Source of Asbestos Exposure. American Review of Respiratory Disease, Vol. 104. 1971.

20. Clifton, R. Asbestos, A Chapter from Mineral Facts and Problems, 1980 edition. U.S. Department of the Interior. 1980.

SECTION 9

GASKETS AND PACKING

INTRODUCTION

Asbestos fiber used in the production of gaskets and packing was estimated to be 12,300 metric tons in 1980.[1] This represented 3.4 percent of U.S. asbestos consumption and ranked this category fifth in industrial asbestos use. Based on sales data, roughly 66 percent of asbestos consumption in this category is used for gasket production, while the remainder is used to produce packing. Asbestos is widely used for gaskets and packing because of its resilience, strength, chemical inertness, and heat resistance. Asbestos gaskets and packing have found use in both static and dynamic applications in a variety of industrial, commercial, and residential uses as well as in motor vehicles. For gasket manufacture, the asbestos is typically bonded under heat and pressure with materials such as nitrile rubber or chloroprene for resistance to oil and solvents. A wide variety of materials may be used in this compounding process to produce a gasket with the correct temperature, pressure, and resistance qualities required. Packing generally incorporates a lubricant and is typically made by braiding asbestos yarns that are impregnated with a grease base lubricant. Most of the asbestos used for gaskets and packings is chrysotile, although a small percentage is crocidolite asbestos used in certain high temperature applications.

The gaskets and packing industrial segment somewhat overlaps the other asbestos categories. Gaskets may be made from compressed sheet or from beater-add gasket paper. However, only compressed sheet manufacture will be discussed in this section as beater-add gaskets have previously been discussed in Section 4 on asbestos paper manufacture. Similarly, packing is made from impregnated millboard and yarn, and the twisting and braiding of asbestos fibers into yarn is also covered in the asbestos textile description in Section 12.

PRODUCT DESCRIPTION

Composition

Specific gasket and packing ingredient formulas vary with manufacturer and grade of product. Compressed sheet for gaskets is made from a plastic mixture of fiber, an elastomeric binder and a solvent. The proportion of fiber and binder in the gasket varies with the temperature at which it will be used. Commercial grade gasket sheet contains 75 to 80 percent asbestos and is used for temperatures of 204°C. Temperatures of 483°C or more require gasket sheet of 99 to 100 percent asbestos. Both white (chrysotile) and blue (crocidolite) asbestos are used up to about 483°C. Above this temperature, the chrysotile becomes unstable and use of crocidolite predominates.[2] A breakdown of asbestos consumption in gaskets and packings is shown in Table 41.

TABLE 41. ASBESTOS USED IN GASKETS AND PACKINGS[1] (1980)

Asbestos type	Amount (metric tons)	
Chrysotile		
Grade 3	800	
Grade 4	2,300	
Grade 5	6,200	
Grade 6	100	
Grade 7	2,800	
Total chrysotile		12,200
Crocidolite	100	
Total	12,300	

Packing is made from a dry asbestos yarn that is coated with lubricant. Asbestos content in packing varies considerably - up to 100 percent for some applications such as sealing furnace doors[3]. The impregnated yarns are braided into continuous lengths of packing and a second impregnation may follow. A variation of braided packing is made by extruding a mixture of asbestos fiber, binder, and lubricants, and then braiding lubricated asbestos yarns over the extrusion. The amount and type of lubricant and binder used in these processes varies considerably and no "typical" formulation can be given. Polymers used in the production of gaskets packing include phenolic resins, furan resins, asphaltic materials, fluorocarbon polymers and rubbers.[4] Some typical elastomeric binders used in the packing and gasket industry include:[5,6]

- silicone based rubber,
- neoprene,
- Buna-N rubber,
- natural rubber,
- nitrile rubber,
- Teflon®,
- glue-glycerine,
- styrene-butadiene,
- nitrile Buna-N, and
- Hypalon®.

Tables 42 and 43 list the comparative properties of some elastomers.

TABLE 42. COMPARATIVE PROPERTIES OF ELASTOMERS[7]

Property	Elastomer-ASTM designation								
	NR	SBR	CR	IIR	NBR	BR	SIL	CSM	R
Tensile strength	E	G	G	F	G	F	P	G	--
Elongation	E	G	G	G	F	F	--	--	--
Resilience	E	G	G	P	F	E	G	G	--
Abrasion resistance	G	E	G	F	G	E	P	E	G
Oil resistance	P	P	G	P	E	P	F	F	P
Heat resistance	P	F	E	G	G	F	E	E	G
Low-temperature service	G	G	F	G	P	E	E	G	G
Aging-weathering resistance	F	P	E	G	F	G	E	E	G
Gas impermeability	F	F	G	E	E	G	P	--	--
Flame resistance	P	P	E	P	P	--	F	G	--
Resistance to alcohol	G	F	F	E	E	F	--	--	--
Electrical resistivity	E	G	F	E	F	G	E	F	G
Dielectric strength	G	F	F	E	F	--	E	--	G

Key:
E - Excellent
G - Good
F - Fair
P - Poor

TABLE 43. ELASTOMER CLASSIFICATIONS[7]

ASTM D-1418	Chemical name	Common name	ASTM D-1418	Chemical name	Common name
BR	Polybutadiene	Cis-4	NBR	Acrylonitrile butadiene	Nitrile Buena N
CR	Chloroprene	Neoprene	NR	Natural polyisoprene	Natural rubber
CSM	Chlorosulfonated polyethylene	Hypalon	SBR	Styrene-butadiene	Buena S GRS
IIR	Isobutylene isoprene	Butyl	SIL	Polysiloxane	Silicone
IR	Synthetic polyisoprene	Synthetic natural			

Some of the more common lubricants used in packing manufacture are:[3]

- petroleum based oils and waxes,
- high grade animal fats and waxes,
- Teflon®,
- mineral oil,
- natural rubber,
- Buna-S rubber,
- vegetable oil,
- glycerine, and
- graphite.

For some applications, a lubricant may not be necessary.

Uses and Applications

Asbestos gaskets are used for static applications to obtain tight nonleaking connections for piping and other joints, such as the covers and openings on all types of industrial and commercial equipment. For dynamic applications, packing is used as a form of bearing for revolving or moving parts in stationary supporting members that also prevents leakage of the contained fluid along the bearing surface. The packing, usually in the form of rings of the material, is held by pressure against the moving part. Lubrication required at the interface is provided by external or impregnated lubricants. Some dry asbestos packing is used to seal furnace doors, rotary kilns and high-temperature refractory equipment.

It has been estimated that 25 percent of gasket materials have less than a 1-year life, 60 percent is used for maintenance and long-time replacement and 15 percent is intended for new installations. For packing materials, 10 percent of installed material wears immediately, and 90 percent has an annual life of 1 year or less.

Special Qualities

Asbestos has been successfully used in both gasket and packing applications because of its unique combination of qualities. It is not only heat resistant, resilient, and strong, but it is also relatively chemically inert which is important for many chemical applications. Both gaskets and packings are normally composed not only of asbestos but also of some form of elastomeric binder and, in the case of some packings, a lubricant. The asbestos imparts strength, heat resistance, and chemical inertness to the gasket while the binder holds the fibers together.

Assuming the gasket is properly designed for its operating temperatures and pressures, the service life of asbestos gaskets is influenced essentially by two factors: (a) the reaction of the fluid being contained with the binder and (b) scheduled and nonscheduled maintenance of the device being sealed. Although asbestos is essentially chemically inert, the binder used with the asbestos fibers can be affected by the fluid being contained causing the product to fail due to binder properties rather than to the asbestos itself. Selection of the gasket with the most inert binder for the particular application is extremely important. Maintenance, whether scheduled or nonscheduled, prematurely ends the service life of the gasket by requiring replacement of the gasket, which is damaged when the seal is broken.

The service life of asbestos packings is determined primarily by wear due to friction. Therefore, a lubricant is generally included in the binder. In the case of pumps, the pump packing must leak to perform properly. Pump packings serve to control leakage, not to prevent it. This slight leakage along the shaft provides proper lubrication to the packing. Pump packings have a lubricant which acts as a primary sealant for startup and break-in phases, during which time the lubricant reduces friction. However, once the pump is on line, external lubrication must be supplied to the packing to keep it running properly and ensure the longest life possible. If not, the lubricant in the packing will bleed out due to heat generation causing the packing to fail.

A valve is packed differently than a pump. In contrast to a pump packing which must leak, a valve packing must not leak. Pressure and temperature on a valve stem packing is normally much higher than on a pump packing. To eliminate the possibility of the lubricant bleeding out of the valve packing, a minor amount of impregnation is put into the packing. Valve stem packings must provide a dense structure that will not permit movement of the fluid through the body of the packing itself, thus acting more like a gasket.

SUBSTITUTES

Many different gasket and packing substitute materials are presently in use. One manufacture[8] lists over 160 asbestos-free materials from which gaskets and packings are fabricated. The particular material most suitable for a specific application is dependent on the application.

Two types of substitute products exist for asbestos gaskets and packings: (a) fiber-for-fiber replacements, and (b) a completely different substitute material. The fiber-for-fiber replacements include: silica, carbon, Kevlar®, ceramic and Teflon® fibers. Two substitute materials specifically developed as gasket materials are Gylon® and Nu-Board.

In general, compressed asbestos sheet gasketing can be replaced with substitute materials at this time with little added expense to the customer unless the application is over 260°C. Graphite and sheet metal gaskets can replace asbestos over 260°C but their cost will constitute a major expenditure for plant maintenance.

For a fiber-for-fiber replacement, the cost of packings and gaskets is proportional to the cost of fibers as the manufacturing processes are identical. Teflon fiber is approximately 7-10 times the cost of asbestos. Graphite (carbon) fibers cost approximately twice as much as asbestos and ceramic fiber prices vary greatly, from approximately 9-32 times that of asbestos.[9] Gylon® ranges from 4-7 times the cost of compressed asbestos sheet, and Kevlar® 29 is also in this range of 5.5 to 6 times the cost of asbestos.[10,11] Nu-Board costs consistently less than asbestos sheet at approximately one-half to three-quarters that of asbestos.[12]

Of note here is that in many cases, the cost of the gasket or packing is insignificant compared to the cost of its installation.[13] Consequently, it is often more cost effective to install a higher quality, higher cost material rather than the lower cost, lower quality material. Lost production while equipment is down due to gasket and packing replacement must also be included in the cost of the replacement.

Specific to packings, it appears that substitute materials are both economically and physically viable alternatives to asbestos in every application. Since substitute materials result in less abrasion on rotating shafts, improved heat dissipation and superior life characteristics, lower operating and maintenance costs are experienced. As a result, the newer synthetic packings are cost competitive with asbestos packings.

MANUFACTURING

Primary Manufacture

There are several methods of gasket production currently in use. A typical process layout is presented schematically in Figure 21.

Raw ingredients including asbestos fiber, elastomeric binder and a solvent are preweighed and added to a mixer. In some cases, the compressed raw asbestos is dumped into a fluffer for fiber opening before the mix step. The mixture is then blended on a batch basis until a dispersed agglomerated mass is obtained. Mixing may be a dry or wet operation, according to the product requirements, and multiple production lines may be employed. The mixture feeds a sheeting machine consisting of two steel, horizontal revolving cylinders placed at a preadjusted clearance. The smaller cylinder or roll presses the mixture onto the larger roll, which is heated to drive off the solvent and compact the sheet. The large roll typically is 1.02 meters in diameter by 3.3 meters in length and produces a sheet 3.05 meters square. This calendered gasket sheet is then cut to size and packaged. This sheet may be stamped into products on site, or as is more common, sold to secondary manufacturers for further processing or to distributors for the maintenance market. The secondary manufacturers, such as gasket cutters, generally form gaskets from sheets by die cutting while the maintenance user cuts the sheet manually. Impregnated sheet scrap cannot be recycled and must be discarded.

Asbestos-based packing is manufactured by a variety of processes. These are represented schematically in Figure 22. The most common process is to impregnate dry yarn with lubricant, thereby coating the fibers. The impreg-

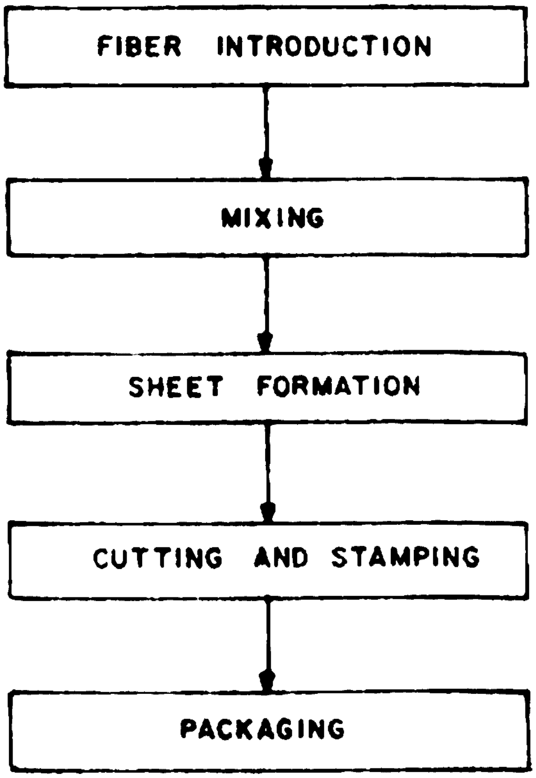


Figure 21. Asbestos gasket process operations.

Source: GCA/Technology Division

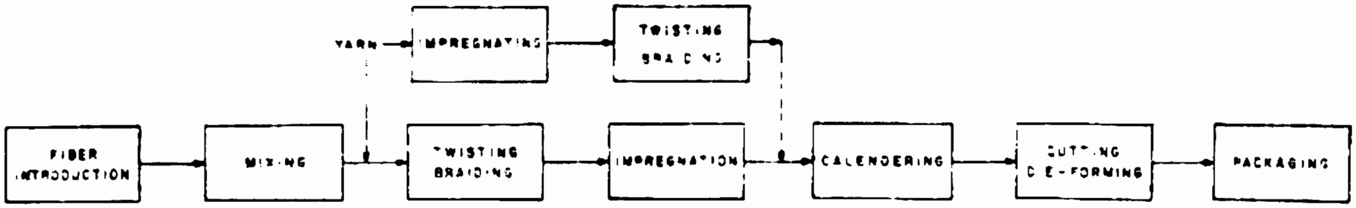


Figure 22. Asbestos packing process flow diagram.

Source: GCA/Technology Division

nated yarns are then braided into a continuous length of packing which is then calendered to a specific size and cross-sectional shape. It may then be coiled, boxed, and sold to the maintenance trade or be pressed into required shapes. The formed product may then be coated with graphite or other materials. Fiber or yarn may also be used as reinforcement to elastomers such as rubber and molded to desired cross-sectional shapes. A second type of packing production involves extruding a mixture of fiber, binder, and lubricants, and then braiding lubricated asbestos yarns over the extrusion. With either process, the final step in production is packing and shipment. Prime gasket sheets and packing are fabricated by a limited number of manufacturers. Most final cutting and forming operations are done by a large number of secondary fabricators. Asbestos-bearing waste is produced by both primary and secondary fabricators.

Secondary Manufacture

Although primary products such as compressed sheet and impregnated yarn are made by the primary manufacturers, much of the material is packaged and resold by a large number of specialty companies. These secondary manufacturers typically rework the gasket sheets and packing yarn into desired shapes and may sheath them in metal, plastic, or cloth or reinforce them with wire insertions. Due to the wide variety of gasket and packing sizes, shapes, sheathing materials and asbestos compositions available, no distinct all inclusive product list can be made. Similarly, the number of companies involved in secondary fabrication is impossible to estimate, although one 1975 estimate suggested that more than 200 such operations exist.*

Manufacturing Plants

Primary gasket and packing manufacturers and their plant locations are presented in Table 44. Actual annual asbestos consumption of each plant was unavailable. The following five manufacturers are currently marketing or developing asbestos substitute gasket and packing products:

- Garlock Inc.[27]
- Greene, Tweed and Company[28]
- F.D. Farnham Company[29]
- Boise Cascade, Specialty Paperboard Division[30]
- Janos Industrial Insulation Corp.[31]

Production Volumes--

In 1980, approximately 12,300 metric tons (MT), or 13,530 short tons of asbestos were used in the United States to produce gaskets and packings.[1] Of this amount, 12,200 metric tons was chrysotile and the remaining amount was crocidolite.

---

*A listing of 200 gaskets and packing manufacturing companies may be found in the 1980 Thomas Register.

TABLE 44. U.S. ASBESTOS GASKET AND PACKING MANUFACTURERS[2,14,15,17-26]

Name[a]	Location
Amatex Corporation[b]	Norristown, PA
Anchor Packing	Manheim, PA
Armstrong Cork Co.[17]	Fulton, NY
Braiding and Packing Works of America	Brooklyn, NY
A. W. Chesterton	Everett, MA
Crane Packing	Morton Grove, IL
Detroit Gasket & Mfg. Co.[18]	Detroit, MI
F. D. Farnum	Necedah, WI
Felt Products Mfg. Co.	Skokie, IL
Fitzgerald Gasket[19]	Torrington, CT
GAF[20]	Erie, PA
Garlock, Inc.	Charlotte, NC
Greene, Tweed and Company	North Wales, PA
Hollingsworth and Vose[21]	East Walpole, MA
Janak, Inc.[22]	Weatherford, TX
Johns Manville	Manville, NJ Waukeegan, IL
Lamont Metal Gasket Co. Inc.[23]	Houston, TX New Orleans, LA
McCord Corporation	Wyandotte, MI
Nicolet Industries	Ambler, PA
Parker Seal Gaskets[24]	North Brunswick, NJ
Raybestos-Manhattan, Inc.	Stratford, CT
Richardson Corp., Hercules Division	Alden, NY
Sacomo Packing Co.	San Francisco, CA
Sacomo - Sierra[25]	Carson City, NV
SEPCO	Birmingham, PA
Standco Rubber Gaskets[26]	Houston, TX

[a] Most of these companies were originally noted in the references listed, then verified by telephone contact by GCA personnel; locations for a few were verified by the 1980 Thomas Register.

[b] Manufacture asbestos-containing material that eventually goes into gaskets and packings.[16]

ASBESTOS RELEASE

Input/Output

Figure 23 shows estimated process disposal and emissions for the gaskets and packing manufacturing industry based on Levine's[32] 1974 estimates projected to 1980 U.S. Bureau of Mines[1] consumption figures. Of the 12,305.7 metric tons entering the process as raw asbestos fiber, approximately 11,992 metric tons are incorporated into the product and 307 metric tons are sent to disposal as vacuum cleaner and baghouse dust and product scrap. An estimated 6.1 tons escape through a control device (typically a baghouse). Levine's estimates are based on gross assumptions with a reported uncertainty of at least an order of magnitude. Meylan[2] reports emissions of 1 to 3 orders of magnitude less. Atmospheric emissions from disposal, based on GCA estimates, are shown to be approximately 0.6 metric tons. This estimate is loosely based on Levine's[32] data, and takes into account the amended asbestos NESHAPS regulations adopted in 1975 regarding the disposal of asbestos.

During Manufacture

Workplace Exposure--

The initial airborne emissions from the mixing process are discussed in Emissions to Air. Once the raw asbestos fiber is mixed with binders and solvents it is encased and presents less of an environmental problem. The main potential fiber release areas are those that precede this mixing operation. As with other industrial categories, raw asbestos fiber is received at the major fabricating facilities in 23 to 45.5-kilogram bags, stacked on pallets. The bags are transported to storage areas by fork-lift truck to await further processing. Accidental spills in this area can cause potentially large, though intermittent, ambient fiber releases. The bags of fiber are next transported to the fiber introduction area where the bags are opened manually and the contents dumped into mixing tanks. These stations are hooded and vented to baghouse collection systems to comply with OSHA worker exposure limits. The mouth of the mixing tanks is also equipped with enclosures vented to baghouses to prevent large workplace releases of raw asbestos fiber. Data on emissions at different stages of the manufacturing process are presented in Table 45.

TABLE 45. EXISTING FIBER[a] COUNTS[33]

Operation	TWA range (fibers/cc)
Receiving and storage[b]	0.5-2.5
Fiber introduction	0.5-2.5
Mixing	0.014-1.0
Braiding and twisting	-
Sheet formation	-
Cutting	-
Packaging	-

[a] Fibers greater than 5 um anaylzed by optical microscopy.

[b] Fiber count data was taken at similar operations in other industrial categories.

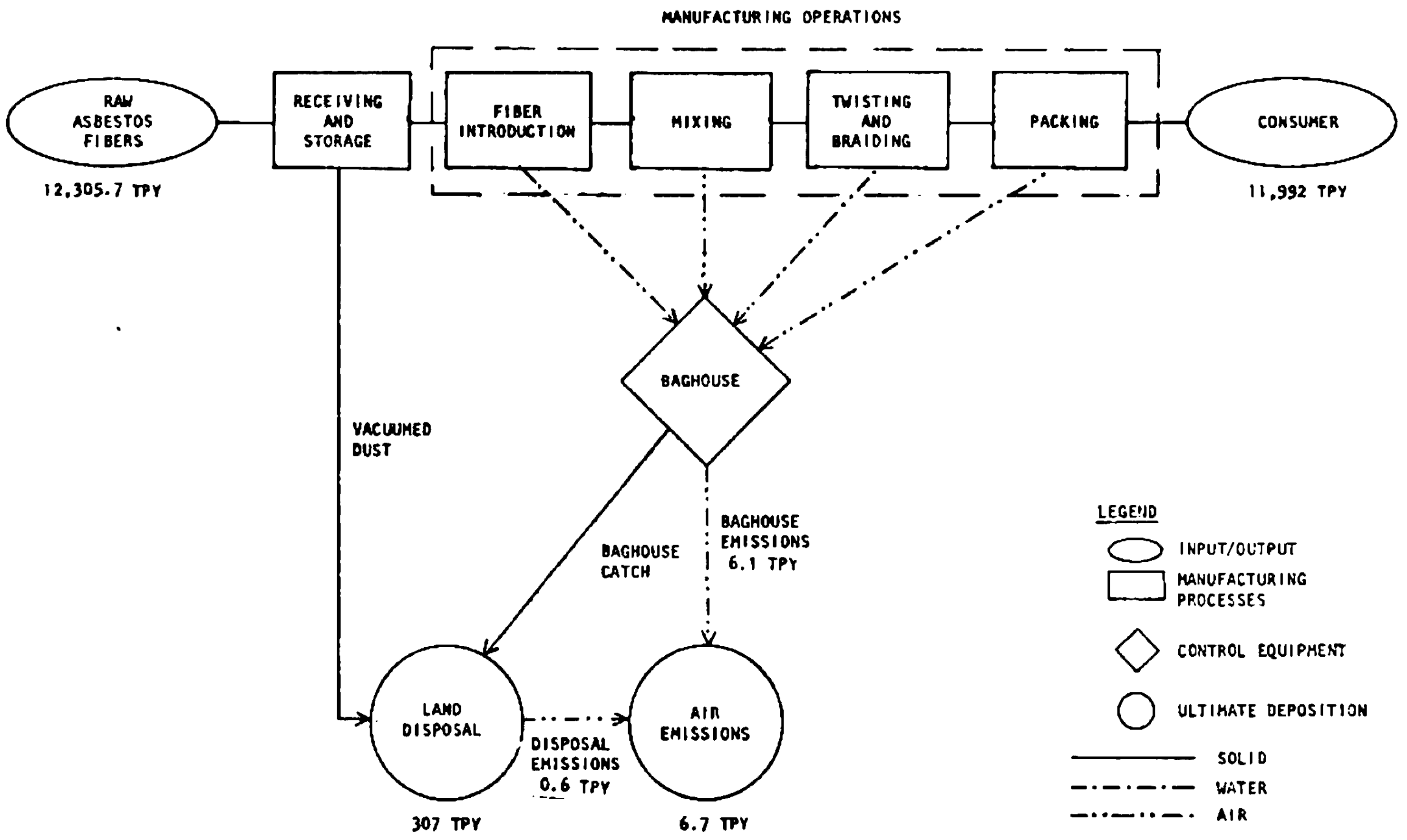


Figure 23. Disposal and emissions of asbestos from the packing and gaskets industry (metric tons).

As the asbestos fibers are thought to be bound in the finished gasket sheet and braided packing, only minimal fiber emissions would be expected in secondary fabrication and product consumption, and none were reported.

There have been no actual measurements of the asbestos fiber concentration in the vacinity of a gasket and packing manufacturer. However, Suta and Levine[34] estimated concentrations near asbestos industrial facilities using mathematically derived dispersion curves of assumed plant emissions. In the case of gaskets and packings, it was estimated that a population within 5 km of a manufacturing plant would be exposed to median atmospheric asbestos concentrations of 24.0 and 4.4 ng/m^3 for urban and rural facilities respectively. Comparing this data with the median U.S. atmospheric asbestos fiber concentration (20 ng/m^3), it appears that gaskets and packing facilities contribute little to nonoccupational exposure. However, actual ambient monitoring in the vicinity of a gaskets and packing facility is necessary to confirm Suta and Levine's estimates.

Emissions to Air--

There are two major sources of airborne asbestos emissions from gasket and packing production. The first is emissions that are not captured by process controlling baghouses. While baghouses are highly efficient collectors for controlling asbestos fibers (99.99 + percent), Levine[32] nonetheless estimated emissions from these devices to be 6.1 metric tons per year. Meylan's[2] estimate is substantially lower; less than one-third of 1 ton. This discrepancy can be attributed to differing estimates of the number of baghouse controlled process air streams. The second source is emissions from solvent recovery operations typically installed at each facility. These total 0.09 to 0.18 kg/mt of finished product[35] or 10 to 20 m.t. per year. These solvent recovery emissions may be discharged to wastewater streams if the individual facility uses a wet dust collection system. Additional, nonpoint sources of asbestos fiber emissions include roof-top vents in the warehouse, and fiber introduction and mixing areas of the plants.

Release to Water

Water is not used in the direct manufacture of gaskets and packing. Sheet gasket production may involve cooling and solvent recovery operations that generate wastewater streams; however, such plants are not common. Asbestos fiber release to receiving waters is therefore negligible. The infrequent washing of warehouse floors containing residual asbestos from accidental spills is a potential source of waterborne asbestos although the annual amount of fiber released would be minimal.

Release to Land

As with the other industrial categories, the vast majority of asbestos discharged to the environment from the production and consumption of gaskets and packing is in the form of solid waste. As indicated in Figure 23, 98.0 percent of all asbestos disposed or emitted from this product group is solid waste. This waste is in the form of asbestos fibers collected in baghouse control devices and scrap from production and consumption in which the asbestos is contained in a binder matrix. Meylan[2] has estimated the amount of asbestos fiber annually collected in gasket and packing plant baghouses to be 35 tons. Based on 1980 consumption data, an estimated 13.8 tons of baghouse waste was generated. This material represents 4.5 percent of all solid waste generated by the production of gaskets and packings. Waste collected by the baghouses presents the greatest environmental hazard as it is in fiber form, and could be discharged to the atmosphere if not properly handled and landfilled.

The remainder of the manufacturing solid waste is scrap generated from stamping of individual gasket and packing pieces. Since the scrap cannot be reused or recycled once plastic binder has been added to the asbestos, primary and more often secondary manufacturers dispose of it to landfills, incinerators, etc. Similar bound asbestos is disposed of by product users. Various sources estimate that between 63 and 80 percent of all asbestos gaskets and packing produced in a given year are released to the environment in the form of used product waste by gasket and packing consumers.[2,32] While the asbestos contained in this waste is generally encased, its ultimate disposal has not been fully documented, as there are thousands of users of these products.

During Use

The consumer use of gasket and packing material will generate waterborne asbestos. This asbestos is primarily released when packing material wears and enters process water systems. The specific release points have not been widely investigated and the 25-ton emission estimate by Levine[32] is an order of magnitude estimate. As gasket material, asbestos is fully bound in a binder matrix, no water discharge is expected from the consumption and final disposal of this product.

During Disposal

The Release to Land section above has already discussed most of the potential environmental concerns associated with the disposal of asbestos-containing gasket and packing waste. Meylan[2] estimated that between 0.5 to 1.0 percent of gasket and packing production is discarded as waste material. This material, excluding control device waste, would primarily consist of trimmings and cutting. Because most of the gaskets and packing material is impregnated with some organic binder, this material cannot be recycled. This condition is actually beneficial with respect to disposal because the asbestos fibers are bound within the product matrix and are not likely to be released to the environment during disposal. As indicated previously, 25 percent of gaskets and 90 percent of packing material do not have a useful life span beyond one year.

CONCLUSION

Fiber release from asbestos gasket and packing manufacturing facilities results from emissions that are not captured by process controlling baghouses and from solvent recovery operations. It has been estimated that baghouse emissions to the atmosphere amount to only 0.005 percent of all asbestos used by the industry,[2] while emissions from solvent recovery operations amount to 10 to 20 m.t. per year or 0.03 to 0.06 percent of industry asbestos consumption. Emissions from solvent recovery may be discharged to wastewater streams if companies utilize wet dust control systems.

One of the greatest environmental hazards associated with the gasket and packing industry is the potential for asbestos fiber collected in baghouses to be discharged to the atmosphere if not properly handled and landfilled. Wetting methods and bagging procedures by designated personnel using good work practices are essential in eliminating dust emissions resulting from waste handling. Fiber releases from scrap waste is thought to be insignificant since the asbestos is bound in a binder.

Based on the Bureau of Mines statistics; which are approximations, the amount of asbestos consumed by the gaskets and packings industry has declined 60 percent between 1978 and 1980. This decline may be attributed to a turndown in the economy and an increase in the availability and use of asbestos substitutes. Currently, in packing materials, synthetic fibers are the preferred choice over asbestos in almost every application. Likewise, in gasket applications under 260°C, there are a variety of substitutes which can replace asbestos with little added expense to the user. However, in gasket applications over 260°C, asbestos appears to have advantages (principally lower costs) over substitute materials. Graphite and metal gaskets can replace asbestos over 260°C but their costs are somewhat prohibitive. There may be many substitute fibers available that have yet to be tried because of the historically low cost and availability of asbestos.

REFERENCES

1. Clifton, R. A. Asbestos. 1980 Minerals Yearbook, U.S. Bureau of Mines. Washington, D.C.

2. Meylan, W. M., et al. Chemical Market Input/Output Analysis of Selected Chemical Substances to Assess Sources of Environmental Contamination: Task III - Asbestos. EPA-560/6-78-005. August 1978.

3. Johns-Manville Corporation. Sealing Components, Comprehensive Guide to Mechanical Packings, Ropes & Tapes. PK-401. Ken-Caryl Ranch, Denver, Colorado. April 1978. 65 pages.

4. Bikales, N. M. Executive editor. Encyclopedia of Polymer Science and Technology, Plastics, Resins, Rubbers, Fibers. Volume 7. John Wiley and Sons, N.Y. 1967.

5. Johns-Manville Corporation. Sealing Components, All You Need To Know About Gasket Materials. PK-132. Ken-Caryl Ranch, Denver, Colorado. November 1979. 17 pages.

6. Armstrong, Industry Products Division Accobest®, Accopac®, Armstrong Gasket Material Specifications. IP-926-175x. Lancaster, Pennsylvania. 5 pages.

7. The Chemical Rubber Co., Handbook of Tables for Applied Engineering Science. Cleveland, Ohio. March 1970. Page 122.

8. Excelsior, Inc., Advertising List of Raw Materials Publication Number 49758. p.1. Rockford, Illinois.

9. Armco. Hitco Materials Division. Hitco Aerospace Materials. LHT-MD-3278 3M TC 9-78. Gardena, California. September 1978. 5 pages.

10. Colt Industries, Garlock Inc. Mechanical Packing Division, Industrial Packing. Gylon. GSK-292. Palmyra, New York. January 1980.

11. Chiostergi, R., Marketing Manaber, E. E. DuPont de Nemours & Co. Inc., Wilmington, Delaware, (302) 999-3951, Personal Communication with Mr. Henderson, GCA/Technology Division, February 1, 1980. Notebook No. 07, Phone call No. 20.

12. Telecon. Connolly, T. Janos Industrial Insulation Corp., Moonachie, N.J. with T. Curtin, GCA/Technology Division. February 27, 1980. Notebook No. 6, Phone call No. 42.

13. Swanson, R. C., Sales Representative, Colt Industries. Garlock Inc. Mechanical Packing Division, Charlotte, N.C. Meeting with Mr. T. Curtin, GCA Corporation, February 21, 1980.

14. Wright, M. D., et al. Asbestos Dust Technological Feasibility Assessment and Economic Analysis of the Proposed Federal Occupational Standard: Part I. U.S. Department of Labor, OSHA. September 1978 (Draft).

15. Arthur D. Little of Canada and Sores, Inc. Characterization of the U.S. Asbestos Paper Markets. Report to the Government Du Quebec, Minstere De L'Industrie Et Du Commerce. May 1976.

16. Telecon. Tony Rokos, Amatex, with Anne Duffy, GCA Corporation, GCA/ Technology Division, May 4, 1981, Call No. 36.

17. Telecon. Mr. Ambursal, Armstrong Cork Co., Lancaster, PA, (717) 397-0611, with Anne Duffy, GCA Corporation, GCA/Technology Division, April 16, 1981, Call No. 20.

18. Telecon. Sales Representative, Detroit Gasket and Mfg. Co., Detroit, MI, (313) 968-2200, with Anne Duffy, GCA Corporation, GCA/Technology Division, April 16, 1981, Call No. 21.

19. Telecon. Company Representative. Fitzgerald Gasket, Torrington, CT, (203) 482-9366, with Anne Duffy, GCA Corporation, GCA/Technology Division, May 4, 1981, Call No. 37.

20. Telecon. Harvey Loud's Office, GAF Corp., New York, NY, (212) 621-5000, with Anne Duffy, GCA Corporation, GCA/Technology Division, April 13, 1981, Call No. 1.

21. Telecon. Mr. McDoughall, Hollingsworth and Vose, East Walpole, MA, (617) 668-0295, with Anne Duffy, GCA Corporation, GCA/Technology Division, April 16, 1981, Call No. 22.

22. Telecon. Company Representative. Janak Inc., Weatherford, TX (817) 549-8771, with Anne Duffy, GCA Corporation, GCA/Technology Division, May, 4, 1981, Call No. 38.

23. Telecon. Raymond Croucheck, Lamont Metal Gasket Co. Inc., Houston, TX, (713) 222-0287, wtih Anne Duffy, GCA Corporation, GCA/Technology Division, May 4, 1981, Call No. 39.

24. Telecon. Company Representative. Parker Seal Gaskets, North Brunswick, NJ, (201) 247-6800, with Anne Duffy, GCA Corporation, GCA/Technology Division, May 4, 1981, Call No. 40.

25. Telecon. Company Representative, Sacomo-Sierra, Carson City, NV, (702) 882-7560, with Anne Duffy, GCA Corporation, GCA/Technology Division, April 17, 1981, Call No. 23.

26. Telecon. Company Representative. Standco Rubber Gaskets, Houston, TX, (713) 944-3160, with Anne Duffy, GCA Corporation, GCA/Technology Division, May 4, 1981, Call No. 42.

27. Swanson, R. C., Sales Representative, Colt Industries, Garlock Inc. Mechanical Packing Division, Charlotte, N.C. Meeting with T. Curtin, GCA Corporation, February 21, 1980.

28. Koehler, S., Product Manager, Greene, Tweed & Co., North Wales Pennsylvania, (215) 256-9521, Personal Communication with T. Curtin, GCA/Technology Division, February 22, 1980. Notebook No. 06, Phone call No. 40.

29. Pafsarella, M., Laboratory Director, F. D. Farnham Co., Necadah, Wisconsin, (608) 565-2241. Personal Communication with Mr. Curtin, GCA/Technology Division, February 11, 1980, Notebook No. 06, Phone call No. 022.

30. Call, M. Product Development Manager, Boise Cascade Specialty Paperboard Division, Beaver Falls, New York, (315) 346-6111. Personal Communication with Mr. Curtin, GCA/Technology Division.

31. Letter and attachments from Connolly, T. J., Janos Industrial Insulation Corp., to T. Curtin, GCA/Technolgoy Division, February 21, 1980, information on asbestos substitutes.

32. Levine, R., ed. Asbestos: An Information Resource. May 1978.

33. Weston, Roy F. Environmental Consultants. Technological Feasibility and Economic Impact of OSHA Proposed Revision to the Asbestos Standard (Construction Excluded). Asbestos Information Association/North America. March 26, 1976.

34. Suta, B. E., Levine, R. J. Non-Occupational Asbestos Emissions and Exposures. Asbestos, Properties, Applications and Hazards. Volume 1. John Wiley and Sons, New York, N.Y. 1979.

35. Gregg, R. T. Development Document of the Effluent Limitations Guidelines and New Source Performance Standards for the Textile, Friction Materials and Sealing Devices Segment of the Asbestos Manufacturing Point Source Category. U.S. National Technical Information Service. PB-240-860. December 1974.

SECTION 10

SEALANTS

INTRODUCTION

Various types of paints and protective coatings containing asbestos fibers are considered under the category "sealants." Asbestos is used as a filler and reinforcement agent for asphalt and tar bases to improve strength and corrosion resistance as well as serving to add other important qualities to the products, such as fire resistance or sound deadening attributes. Products considered in this category are many and varied, ranging from sealants used in waterproofing concrete foundations and various other structures such as mobile homes, to chimney stack paints. Many different products are or have been produced including automobile undercoatings, wood block and concrete floor mastics, tennis court coverings, spackling and drywall joint compounds, texture paints, and protective coatings for underground pipelines. The basic batch or semicontinuous process used in manufacturing is shared across the board for these products, with raw material input being the variable in determining the end product desired.

Information gathered for this report was derived from a combination of efforts, including an extensive literature search, on-site plant visits, and telephone contact, both with industry and other representatives.

PRODUCT DESCRIPTION

Composition

Asbestos roofing products use finest grade 7 chrysotile asbestos 99 percent of the time. Coatings and paints also use chrysotile asbestos, with over 95 percent consisting of grade 7. Table 46 shows the distribution of asbestos by type and grade. About 90 percent of the milled asbestos is imported from Quebec.[2]

Bituminous coatings considered here contain 10 to 12 percent asbestos, with 50 percent of their composition being volatile petroleum solvents.[2] The remainder consists of other ingredients, such as rust proofing chemicals, pigments, heat reflecting metallic paints, and miscellaneous fillers. Additional insulation materials, such as cork, emulsifiers, and resins may also be used. These solvents are added to reduce viscosity, especially in spray applications and emulsions. The asbestos fibers are thought to be completely bound by all of these additives in the final product.

TABLE 46. DISTRIBUTION OF ASBESTOS MINERALS USED FOR COATINGS, PAINTS, AND SEALANTS (1980)[1]

Asbestos type and grade	Quantity (metric tons)
Chrysotile	
Grade 4	100
Grade 6	100
Grade 7	10,700
Total Asbestos metric tons/yr	10,900

Uses and Applications

Asbestos-containing sealants are used in a wide variety of applications by everyone from homeowners to private roofers to large construction companies. Roofing applications represent the largest use. Otherwise, coatings may be applied both as light sealants or as heavier coatings, depending upon asbestos content and the number of coats applied. Mixes are applied to surfaces by brush, spray gun, roller, or trowel. Product uses are many and varied. Patching compounds represent the roofing applications, while sealants can also be used as protective coatings for underground pipelines. Concrete foundations, side walls, tanks, and structures such as cooling towers in nuclear power plants and mobile homes may all use asbestos-containing sealants for their moisture/waterproofing attributes. Anticondensation asbestos coatings are made for low temperature refrigeration service. Products exposed to seawater spray, salt solutions, organic acids, mineral acids, or petroleum products may use asbestos coatings for resistance to corrosion.

Asbestos is also used in the automotive market for automobile undercoatings because it acts as a sound deadener in addition to its other properties. Wood block and concrete floor mastics may contain asbestos, as well as flashing and tile cements used in construction. In addition, many other building construction needs such as spackling (for patching and repairing plastered walls) and drywall joint compounds (used for finishing gypsum wallboard walls) have also been met with asbestos-containing mixtures. In 1977, regulations were drawn up to prohibit asbestos use in the manufacture of these products. However, asbestos is still present in many buildings where these materials were used in the past.

Special Qualities

Asbestos fibers are present in many of the products mentioned due to inherent properties that, at present, asbestos alone exhibits. Asbestos fibers improve and stabilize the strength of the product, increase the products' resistance to corrosion and rot and gives insulation and fire resistance. In addition, asbestos has the high tensile strength necessary for reinforcing asphalt and cement matrices, it maintains the dimension of the product, and it avoids the disintegration that may occur with the use of alternative organic reinforcement materials. The effects of temperature changes on sealants may be controlled with asbestos, and the tendency of the binder to flow or crack with changes in temperature is reduced. Asbestos provides increased resistance to weathering, oxidation, and other wear factors, as well as enhancing thixotropic characteristics, and assists in the deadening of sound. Although other materials exist that may possess one or more of these qualities, none has been found that suitably combines all of the essential properties that asbestos fulfills.

Roofing Sealants--

Asbestos as an ingredient in roofing sealants is unique because of its affinity for asphalt, fiber fineness, and its strength. Asbestos controls the viscosity of the coatings allowing them to be applied on nonhorizontal surfaces without the flow of asphalt which would result in the loss of waterproofing abilities. The tensile strength of asbestos is higher than that of other fibers resulting in a stable product which resists weathering and adheres well to protected surfaces.

Automobile and Truck Undercoating--

The properties of asbestos that are important for automobile and truck undercoating products are high thermal resistance, affinity for asphalt to control viscosity, high fiber density, strength, and durability. The affinity for asphalt is required to ensure complete encapsulation of fibers. Small fiber dimensions result in a high density product with soundproofing abilities. High tensile strength is needed to hold the product together and thermal resistance is required to retain this strength at the elevated temperatures experienced. Control of viscosity is required to retain this strength at the elevated temperatures and prevent unwanted flow of the product resulting in loss of waterproofing abilities.

SUBSTITUTES

The general consensus of the asbestos industry is that, for most sealant products, no viable substitutes for asbestos exist at this time. An acceptable substitute must be:

- Noncombustible
- Resistant to decay, many acids, and vermin
- Made up of long, flexible fibers
- Strong enough to reinforce other binders
- Unaffected by temperatures up to 500°C (930°F)
- Economic

There are no substitutes available which possess all of the above, but for applications where only several of the characteristics are necessary, a substitute may be available.

Several companies have investigated the use of alternative fibers such as fiberglass, polyethylene, polypropylene, polyesters, acrylics, cotton, and other threads and fibers for use in roofing coatings and cement, but none has proven to be an acceptable substitute for asbestos.[3-6] A major problem is that none of the above become wetted by the asphalt. They "ball-up" when applied with a trowel.[3] Fiberglass provides adequate reinforcement but does not contribute to the viscosity of the product and lacks chemical affinity for asphalt. A number of proprietary materials are presently being investigated but more specific information is not available in most cases. All commercially available fibers are more expensive than asbestos. Grade 7 chrysotile asbestos costs between 0.13 and 0.26 $/kg whereas fiberglass, polypropylene, cellulose, cotton and a proprietary fiber used by Tremco Inc. range from 0.44 to 2.97 $/kg.[1,5] The substitution of an alternative fiber for asbestos may require a manufacturing process change which would involve additional cost.

No suitable substitute is being manufactured to replace asbestos in automobile and truck undercoating uses. Zinc coating can be used to provide resistance to rusting but, by itself, is not sound deadening.[3] Zinc coating is often used in combination with asphalt/asbestos undercoating. A representative of Chrysler Corporation suggests that fiberglass, fibrous alumina and magnesium silicate fiber might be used as substitutes although they cost 4 to 30 times as much as Grade 7 chrysotile. These materials do not possess affinity for asphalt or the ability to control viscosity which make asbestos unmatched for use in undercoating products.[7]

Asbestos is used in nonasphalt-based coatings to provide resistance from alkali, acids, water, and weather. Table 47 lists substitutes for these applications.

A representative of Dudick Corrosion-Proof Manufacturing, Inc., states that they have a new proprietary formula for acid and alkali resistant tank linings.[9] However, at this time, no specific information on this product has been made available. Electro Chemical Engineering and Manufacturing Company has tried high temperature glass as a substitute for asbestos in asphalt mastics. It did not prove to have the necessary affinity for asphalt and therefore could not be sprayed to produce a desirable pattern.[10]

Major texture paints manufacturers (Bondex International and The Synkoloid Company) indicate that asbestos is no longer used in texture paints.[11,12] This has been confirmed by several minor manufacturers and distributors. The elimination of asbestos from texture paints followed the ban issued by the Consumer Product Safety Commission on the use of asbestos in the manufacture of consumer patching compounds. Several companies which manufacture the patching compounds also produce texture paints.

TABLE 47. PHYSICAL AND RESISTANT CHARACTERISTICS OF COATING AND SEALANT MATERIALS.[8]

Name	Resistant characteristics				Physical characteristics
	Alkali	Acid	Water	Weather	
Talc	F	G	E	E	Fibrous-platelike
Asbestos	F	G	E	E	Fibrous
Barite	G	G	G	G	Cubical, heavy
Diatomite	P	E	E	E	Porous
Silica	P	E	E	E	Hard, sharp crystals
Clay	F	G	F	G	Platelike
Mica	G	G	G	G	Platelike, used to reduce moisture vapor transfer

Key: P = Poor G = Good
F = Fair E = Excellent

Properties that are required for an asbestos substitute are resistance to vermin, heat, ozone, and ultraviolet and infrared radiation.[13] The substitute must also be available in various fiber dimensions to produce differing textures. Possible substitutes include fiberglass, rayon, nylon, polypropylene, polyester, and hemp fiber. Other fillers which can be used are clays, diatomite, talc, perlite, silica, mica, barite, calcium carbonate, bentonite and others. None possess the combination of properties attributable to asbestos. The organics react with infrared, ultraviolet and heat radiation and ozone; hemp is often attacked by vermin, and the inorganics do not possess the fibrous structure necessary to bridge cracks. Texture is now often produced by worker's tools.[14] Some nonasbestos products cost no more than asbestos products with prices of substitute fibers ranging from 0.11 $/kg (versus 0.13 to 0.26 $/kg for asbestos) up to nylon at 1.32 $/kg.

MANUFACTURING

Small manufacturing plants usually have one production line for all sealants produced, whereas larger plants have a wide product mix with several production lines oriented to a specific product. Production facilities for coating, painting, and sealant products are the same as for roofing coatings except that they are usually designed for a significantly lower market requirement. Consequently, coating operations will usually operate on a part-time basis, producing roofing coating products as well as other coatings containing no asbestos. For instance, one major manufacturer of roof coating emulsions and joint insulation compounds indicates that asbestos emulsions for roof coatings are made 5 days per week in a one- or two-shift operation.[15] Other facilities are used less frequently to manufacture joint insulation. Because of seasonal fluctuations in demand, the plant generally operates one shift from November through March and two shifts otherwise.[15]

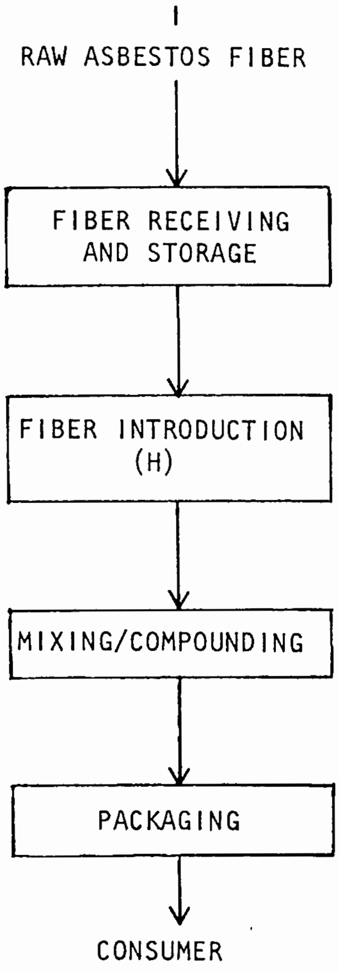
Primary Manufacture

Sealants are produced by batch processes with a simple, general production cycle. Basically, the fiber is introduced, fluffed, put in a batch mixing tank, mixed with asphalt or tar and solvents or other additives as required for an even dispersion, pumped to packaging (containerizing) operations, and finally shipped out to market. Figure 24 is a simple process flow diagram for sealant manufacture. A more detailed description follows.

First, pallets of bagged asbestos are moved from a shipping or storage area to a staging area where they are weighed according to specific amounts needed for each product. The bags may be manually slit or a machine may be utilized to help minimize worker exposure. The asbestos is then dumped either directly into a hopper or into a fluffing machine while the shipping bags, which contain some residual asbestos fiber, are sealed in clean plastic or paper containers for ultimate disposal at a landfill. This machine is used to break down the compressed fibers, causing them to become open and free, enabling dispersion and more complete encapsulation during asphalt mixing. Typically, fluffed asbestos fiber is transferred to hoppers or directly to a batch mixing tank.[17] Fiber transfer at this stage may be pneumatic, mechanical (conveyors), or manual. Pneumatic transfer systems are enclosed, with bag filters being used for the exhaust air. Generally, conveyor systems are also enclosed. Manual transfer may be used in small operations or for specialized, low-volume requirements.

The next step is to mix the fluffed fiber and other dry ingredients with the asphalt (and solvents as required) in a batch tank. Mixing takes place until the material is evenly dispersed. Shortly after mixing, the asbestos fiber is bound by the asphalt and upon completion of the mixing, the asbestos is considered completely bound in the asphalt with little chance of fiber dust exposure.[17] As a batch is finished, the material is pumped to the packaging (containerizing) operation and placed in containers whose size varies with the product. The predominant packaging for coatings is 5-gallon metal pails with sealed lids. Special orders may use drum containers. Bulk shipments in tank cars may take place, but are infrequent.

The batch sizes produced may vary from several hundred gallons for small manufacturers with one production line to several thousand gallons for larger manufacturers who are able to have a wide product mix and several production lines in different locations (partitioned work areas or separate buildings) oriented to a specific product.[17] The batch sizes vary with size of company, type of product, method of containerization, type of existing equipment, and size of order. Sealant products are shipped out ready for distribution and use; therefore, there are no secondary producers considered here.



(H) - Indicates hooded operations

Figure 24. Process flow diagram for the manufacture of paints, coating, and sealants.[16]

Manufacturing Plants

There are six major manufacturers of asbestos sealant products in the U.S with many different plant locations, as shown in Table 48. Most of the production involves roofing products. In addition, 27 major companies sell asbestos paint products, and there are about 100 more suppliers of asphalt paint, which may add asbestos to their products without being classified as asbestos paint vendors.[19] Many suppliers may only mix the paints, while others pack and resell the mixed products. There are also numerous small suppliers who mix smaller quantities of asbestos coatings for limited local markets. Roofing compound figures are difficult to assess as they are often buried within other roofing product totals. It is estimated that roof coatings are produced at a maximum figure of 3 million gallons per year.[2]

TABLE 48. NATIONAL MANUFACTURERS OF ASBESTOS SEALANT PRODUCTS[2,18]

Manufacturer	Plant location	Product
Celotex Corporation (A Division of Jim Walters Corporation)	Lockland, OH	Roofing products
	Houston, TX	Roofing products
	Memphis, TN	Roofing products
GAF Corporation	Millis, MA	Roofing products
	S. Bound Brook, NJ	Roofing products
Gibson Homans Co.	Cleveland, OH†	Roofing products
Johns-Manville	Waukegan, IL	Roofing products
	Manville, NJ	Roofing products
	Savannah, GA	Roofing products
	Marrero, LA	Roofing products
	Los Angeles, CA	Roofing products
	Fort Worth, TX	Roofing products
	Pittsburg, PA	Roofing products
Koppers	Youngstown, OH	Roofing products
	Wickliffe, OH	Roofing products
Monsey Products Co.*	East Rutherford, NJ	Roofing products
	Garland, TX	Roofing products
	Kimberton, PA	Roofing products
	Rock Hill, SC	Roofing products
	Troy, NY	Roofing products

*Telecon with manufacturer.

†Corporate headquarters; other branches throughout the U.S.

Production Volumes

Sealant manufacturing consumed approximately 10,900 metric tons of asbestos or 3.0 percent of all asbestos used in the United States in 1980, according to the Bureau of Mines.[1] No census information regarding the value of products is available. The value of asbestos consumed in 1980, calculated from Bureau of Mines consumption data and current asbestos prices, is $2.13 million. An expenditure of $2.13 million represents 1.1 percent of total annual sales for sealants which amount to approximately $200 million.

ASBESTOS RELEASE

Input/Output

Figure 25 shows estimated process and disposal emissions for the asbestos sealants manufacturing industry based on Levine's[20] 1974 estimates projected to 1980 U.S. Bureau of Mines[1] consumption figures. Of the 10,900 metric tons entering the process as raw asbestos fiber, approximately 10,790 m.t. are incorporated into the product and 109 metric tons are disposed as vacuum cleaner and baghouse dust. An estimated 0.6 metric tons escape through a control device (typically a baghouse). Levine's atmospheric emissions estimates are based on gross assumptions with a reported uncertainty of at least an order of magnitude. Atmospheric emissions from disposal, based on GCA estimates are shown to be 0.5 metric tons. This estimate is loosely based on Levine's[20] 1974 data, and takes into account the amended asbestos NESHAPs regulations adopted in 1975 regarding the disposal of asbestos.

During Manufacture

In the fiber receiving and storage area asbestos is received by truck or railroad car in 23, 32, and 45 kilogram polyethylene bags. Accidental spillage is the greatest potential cause of fiber release in this area. Spills generally occur when asbestos is being transported into and out of storage. In an effort to minimize emissions, bags of asbestos are often received on shrink-wrapped pallets. It is also a standard practice to tape ripped or torn bags and immediately vacuum any spilled fiber. Respirators are worn by workers wherever loose asbestos fiber is handled. Aside from receiving and storage, release of asbestos to the environment during the manufacture of sealant products normally consists solely of fiber released from initial bag opening and dumping operations. In most of the newer plants these operations are hooded and vented to baghouse filters. Pollution control equipment is lacking in some of the older and smaller plants and dust capture hoods are exhausted to the atmosphere. One plant, visited by GCA personnel, was equipped with no pollution control equipment other than an automatic bag opener. The bag opening and mixing processes were hooded, but were vented directly to the atmosphere. Baghouses, cyclones, and wet scrubbers were all absent from the plant operations.[15] After fiber introduction it is believed that no control equipment is either installed or, perhaps, required from the mixing area right through to the end of the manufacturing process.[17]

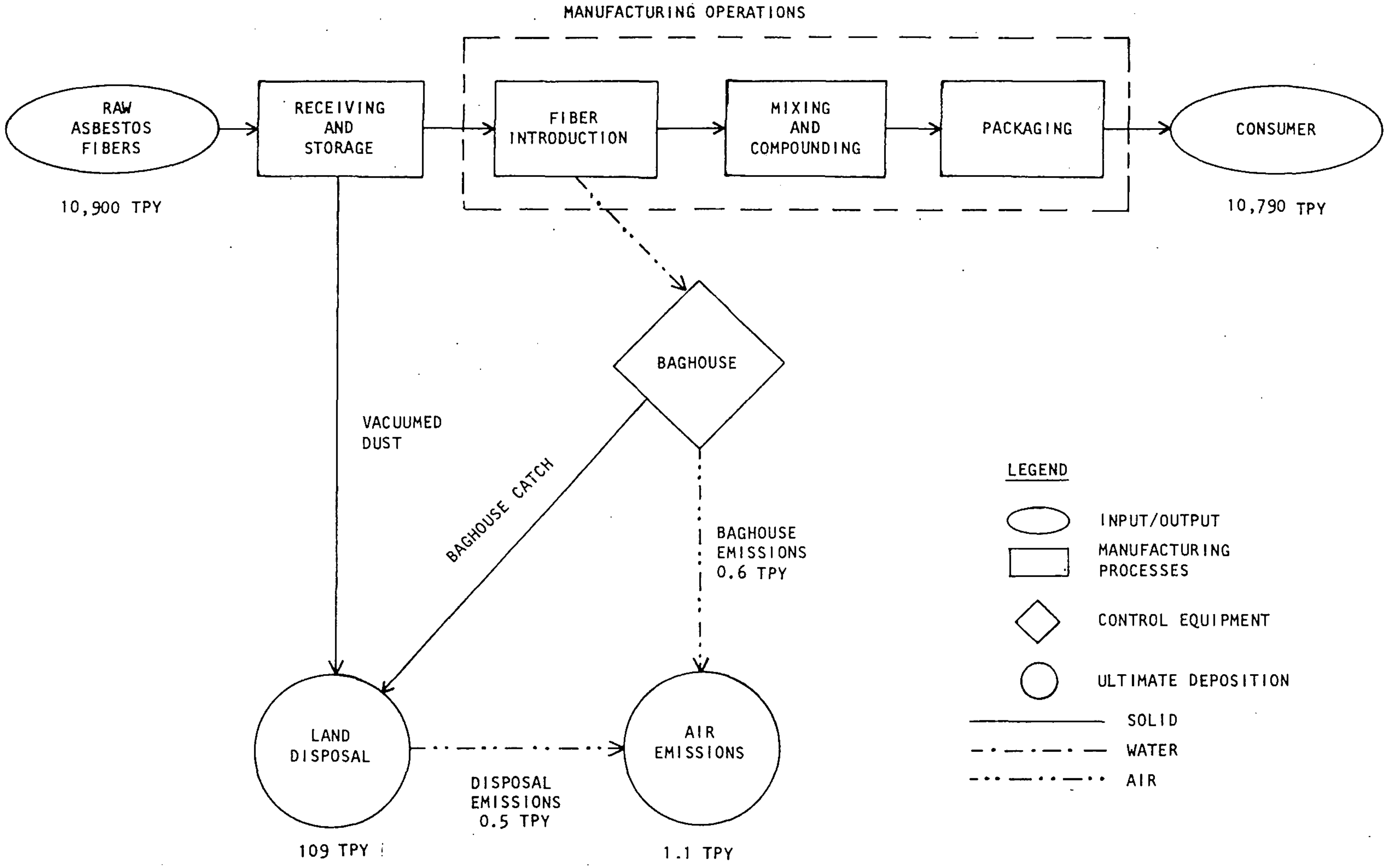


Figure 25. Input/output estimates for the asbestos sealants industry (metric tons).

Emissions To Air

Assuming that baghouses with particulate removal efficiencies of 99.99 percent[21] are used to control asbestos release during fiber introduction and that 10,900 metric tons of asbestos were consumed in 1980, annual fiber release would amount to 1.1 tons. This estimate concurs with that made by Meylan.[2] Following Levine's[20] methodology, however, only 0.3 tons would be emitted. The range of 0.3 to 1.1 tons reflects differences in calculating assumptions. This range allows for differences between manufacturing methods and the amount of particulate control. The dust from bag filters and uncontrolled vents is the only release in which fibers are in free-fiber form, as the other effluents produced during manufacture such as washing, floor spills, and wastage of the bitumastic product, contain asbestos fibers which have been bound in the binder.

Fiber concentration data collected in 1976 for 12 processing steps indicate that only four of the locations would meet the 2.0 fiber/cc TWA standard, with one exceeding 5 fiber/cc.*[17] Table 49 presents the results of the study which revealed typical exposure levels of 2.5 fibers/cc in the fiber introduction step, where the highest readings occurred. None of the reporting manufacturers met the 0.5 fiber/cc 8-hour TWA proposed standard. Sealants display low levels of asbestos fibers in the primary production stages, also no machining or cutting processes are needed in sealant production.

Release To Water

No significant asbestos-laden water effluents are generated during the manufacture of sealants.[2] Water is not used directly in the product manufacturing process. The infrequent washing of warehouse and production area floors containing residual asbestos from accidental spills is a potential source of waterborne asbestos although the annual amount of fiber release would be minimal.

Release To Land

Asbestos-containing solid wastes generated during the manufacture of sealants include control device and housekeeping wastes, empty asbestos wrappers, and scrap product. Control device and housekeeping wastes, estimated to be 109 metric tons based on 1980 consumption figures, are commonly sealed in disposable containers and hauled to a landfill. Empty asbestos wrappers are disposed of in a similar manner. It has been estimated that several thousand emptied asbestos bags are disposed of by a single coating manufacturer annually.[17]

---

*More recent data, showing that fiber levels at all stations are at or below the 8-hour TWA asbestos standard, are generally not publicly available.

TABLE 49. TIME-WEIGHED AVERAGE FIBER COUNTS[a]-PAINTS, COATINGS, AND SEALANTS[17b]

Process step	Fiber count with existing control technology		Fiber count with best available technology[c]
	Typical Fibers/cc	Range Fibers/cc	Fibers/cc
1 Receiving & storage	1.0	0.25 to 2.5	0.5 to 1.0
2 Fiber introduction	2.5	1.5 to 8.0	1.5
3 Mixing, compounding	-	-	-
4 Packaging	-	-	-

[a] NIOSH Method, counting fibers 5 μm or longer by optical microscopy.

[b] Data Base: Data collected from plants consuming 30 percent of the asbestos used in the manufacture of Paints, Coatings, and Sealants.

[c] Projected fiber counts are estimates of average exposure after implementing BAT. Variations of these values are expected depending upon individual installation.

Sealant manufacturers do not generate significant amounts of scrap.[2] Given the high costs of raw materials and the relative ease with which off-specification products can be reworked for sale, these types of operations do not produce much in the way of manufacturing wastes. Scrap that must be disposed of would pose minimal environmental concern because the asbestos fibers are bound within the product matrix.

During Use

Release of asbestos fibers during use of the sealant products will occur from the following sources:

1. Wastes during application
2. Losses from in service weathering, wear, corrosion, etc.
3. Scrap from maintenance, replacement, and final demolition of the structure or equipment.

In nearly all of these losses, the asbestos fibers should be completely encased in the bituminous binder. Consequently, only small quantities of free fiber as airborne material are likely to be released.

The removal of texture paints containing asbestos from the substance to which they were applied is one area of concern in regard to release of free fibers. Inhalable asbestos fibers may be released during paint removal by sanding or some other similar activity.[2] Textured paints are likely to present the greatest potential problem here as they are probably the only application where sanding is used for removal. However, no monitoring data is available that could more accurately quantify free-fiber releases from coatings or paints.

Likewise, there is also a lack of monitoring data available to indicate the amount of asbestos released from roofing materials during use. For installed products, this release would come essentially from scrapping worn out material to which roofing compounds had been applied. The eventual fate of such material is in landfills or trash dumps. The potential fiber release for this use requires more study before an accurate accounting can be reached. The amount of fiber release from weathering processes acting on roofing materials would, again, require monitoring, for perhaps extended duration.

Waste released as spillage, wastings, and scraps during application of coating and paint compounds accounts for an average of 1 percent of their annual consumption.[17] Scraps left in their container pails as well as a portion of spillage is disposed of in landfills, while other spillage and washings may instead be diverted to municipal or plant sewer systems. Asbestos fibers contained in this waste would eventually settle as deposits in the disposal system used.[2] About 200 m.t. of asbestos are thought to be deposited annually in this manner.

During Disposal

Usual maintenance and replacement rates for industrial equipment account for a loss of asbestos representing about 2,500 metric tons or 25 percent of the annual consumption.[2] Loss of asbestos fibers also occurs when the bituminous binder in coating and paint compounds becomes oxidized, cracked, or actually peels off the substance it was originally applied to. Rain, spray, corrosion, wear, or water condensation may flush off large pieces of such material, delivering them to floors, the ground surface, or other surrounding areas. The particles may in time show up in the ground water supply, or be routed to process or municipal sewers or drainage systems, where again, they end up as deposits of asbestos fibers in the settling areas of the systems.

The fate of the asbestos in coating and paint compounds that would usually be scrapped during replacement and demolition of the equipment to which they are applied, varies with the product. Steel equipment, structures, piping, and other metallic materials with asbestos coatings are usually fed to scrap yards and recovery furnaces where the asbestos ends up in the slag produced by such operations. Asbestos fibers from demolished concrete and other nonrecoverable materials usually end up in landfill dumps or incineration operations.[2] Asbestos could possibly be released in the combustion gases or the ashes of the incineration process if temperatures were not controlled. Scrubbers can control the loss from combustion gases, transferring it to a wet waste product to be dealt with. If the asbestos in the product is not destroyed during incineration, it could be released instead in the ashes, which are sometimes used in fertilization applications or in making cement blocks.[2]

The total quantity of asbestos released as scrap approximates the balance of annual consumption after a 1-percent reduction is taken for losses in application, 1 to 2 percent consumed for expanding uses, and 25 percent for maintenance uses. This amounts to about 70 percent or 7950 m.t. per year. Approximately 5675 m.t. of this goes to landfill dumps, and the balance (2275 m.t.) goes to scrap recovery furnaces.[2] A summary of these various destinations of asbestos fibers is included in Table 50. These figures are based on the 1980 consumption rate. This does not allow for the backlog that may prevail from earlier consumption at even higher rates. Not only will these past high consumption rates tend to increase the scrap rate for the near future, they will also increase the overall deposition of asbestos in our living environment.

CONCLUSION

Neither the U.S. Bureau of Mines nor the U.S. Bureau of Census reports contain data by which consumption trends for asbestos sealant products can be estimated. Previous discussions with suppliers and consumers of such products indicate that they differ considerably in their predictions with respect to future applications of asbestos in these products.[2] As mentioned, some suppliers have already stopped using asbestos as a result of the recent OSHA regulations. Others, however, use it at essentially the same or even higher rates. An extensive reduction in use has taken place to arrive at the current level, but it is expected that this level will hold due to the fact that in nearly all coating applications, the asbestos is completely encased. It is even predicted that new uses and products will appear in this category as the use of short fiber California asbestos is implemented in the manufacturing process.[2] As for specific roofing products, industry spokespersons indicate that asbestos coatings are undergoing static growth, and this area may be one in which there are small decreases.

Looking at industry considerations, there are several conditions that need to be met to help improve the present situation. Improved packaging methods for bulk asbestos shipments are pointed out as having high priority.[17] Such items as recyclable bulk containers, enclosed pallets to shield bags from physical damage and reinforced bags are needed. Automatic bag-opening machines would eliminate manual operation, which is where the majority of fiber introduction takes place. If it can be assured that such activities as bag opening operations can be performed in new ways with minimal fiber release to the plant environment.

TABLE 50. APPROXIMATION OF ASBESTOS RLEASED TO ENVIRONMENT FROM COATING AND PAINTING COMPOUND APPLICATIONS[2]

Source	Disposition	Metric tons per year
Waste during application	To sewer system or landfills	115
Losses from water, weathering, and service	To sewer system or ground waters	2,835
Scrap from replacement and demolition	To scrap metal recovery furnaces	2,275
	To landfill and incineration	5,675
	Total release	10,900[a]

[a] Nearly all of the asbestos released in the above figures is bound versus free-fiber form.

REFERENCES

1. Clifton, R. A. Asbestos. 1980 Minerals Yearbook. U.S. Bureau of Mines, Washington, D.C.

2. Meylan, W. M., et al. Chemical Market Input/Output Analysis of Selected Chemical Substances to Assess Sources of Environmental Contamination: Task III - Asbestos. EPA 560/6-78-005. August 1978.

3. Telecon. N. R. Fernandez, Celotex Corp., with David Cook, GCA. January 29, 1980. Asbestos in roofing materials.

4. Telecon. Edmund Fenner, Johns-Manville, with David Cook, GCA. January 15, 1980. Asbestos in various sealant products.

5. Telecon. Ken Brzozowski, TREMCO, Inc., with David Cook, GCA. January 18, 1980. Substitute fibers for roofing products.

6. Telecon. Fred Mallay, Consolidated Protective Coatings Corp., with David Cook, GCA. January 18, 1980. Substitutes for roofing products.

7. Telecon. Jack H. Engel, Chrysler Corp., with David Cook, GCA. January 17, 1980. Asbestos in automobile undercoatings.

8. M. Grayson, and D. Eckroth. Encyclopedia of Chemical Technology, Third Edition, Volume 6. Wiley-Interscience. New York, N.Y. 1978. p. 461.

9. Telecon. T. Dudick, Dudick Corrosion-Proof Manufacturing, Inc., with David Cook, GCA. January 18, 1980. Acid and alkali resistant coatings.

10. Telecon. Ken Heffner, Electro Chemical Engineering and Manufacturing Co., with David Cook, GCA. January 18, 1980. Asbestos containing mastics.

11. Telecon. Jack Fleming, Bondex International, with David Cook, GCA. January 16, 1980. Texture paints.

12. Telecon. Pass, Williams, Synkoloid Co. with David Cook, GCA. January 16, 1980. Texture paints.

13. Telecon. Charles Spector, Everseal Manufacturing Co., Inc., with David Cook, GCA. January 17, 1980. Texture paints.

14. Telecon. Harry Schwartz, Baltimore Paint and Coatings Group of Dutch Boy Paints with David Cook, GCA. January 22, 1980. Texture paints.

15. LaShoto, Paul W. Trip Report on visit to Celotex Corp., Lockland, OH. August 1, 1979.

16. Gregg, R. T. Development Document of Effluent Limitations Guidelines and New Source Performance Standards for the Textile, Friction Materials and Sealing Devices Segment of the Asbestos Manufacturing Point Source Category. U.S. National Technical Information Service, PB-240-860. December 1974.

17. Weston, Roy F. Environmental Consultants. Technological Feasibility and Economic Impact of OSHA Proposed Revision to the Asbestos Standard (Construction Excluded). Asbestos Information Association/North America. March 26, 1976.

18. W. E. Davis and Assoc. (Leawood, KS). National Inventory of Sources and Emissions: Asbestos - 1968. U.S. Environmental Protection Agency Office of Air and Water Programs OAQPS, Research Triangle Park, NC. APTD-70, February 1980.

19. 1975 Thomas Register.

20. Levine, R., Ed. Asbestos: An Information Resource. May 1978.

21. Harwood, C. F. et al. Asbestos Emissions from Baghouse Controlled Sources. American Industrial Hygiene Association Journal. August 1975, pp. 595-603.

SECTION 11

ASBESTOS-REINFORCED PLASTICS

INTRODUCTION

Asbestos fibers, when added to polymeric materials, modify the physical and chemical characteristics of the composite. Fibers, in general, function as both fillers and reinforcing agents. The advantages of using asbestos derive from the fact that asbestos combines the advantages of both a mineral and a fibrous binder carrier with reinforcing action.

Asbestos fibers have been used in combination with plastics since the 1920's when asphalt floor tiles were first introduced. For most of the history of asbestos plastics, the largest quantity of asbestos fiber employed consisted of the shorter grades that functioned primarily as fillers rather than reinforcing fibers. This is still true today. However, recent research efforts have been directed toward using longer grade, reinforcing asbestos fibers.

The plastic materials manufacturers using bulk or "loose" asbestos fiber, typically in molding compounds, are the subject of this section. Industries which utilize asbestos in conjunction with plastics and other ingredients such as floor tile, friction materials, and gasketing, are discussed in other sections of this report. Also, in defining the scope of products to be discussed in this section, any asbestos plastic material that employs asbestos fiber in a preprocessed form such as paper, mat, felt, roving or cloth has been considered a secondary product for other asbestos industry segments such as paper and textiles and is therefore addressed in other sections of this report.

The material presented in this section is a summary of existing published data augmented with information obtained by telephone questionnaires and from observations and discussions with manufacturing personnel at operating facilities producing asbestos-reinforced plastics. Information was collected while visiting two facilities producing asbestos-reinforced plastics. Although an attempt was made to obtain extensive fiber release data, limited quantitative data were available.

PRODUCT DESCRIPTION

Composition--

Bulk fiber is the most widely used form of asbestos in combination with plastics. A breakdown of the various asbestos types and grades used in bulk by primary plastics manufacturers in 1980 is given in Table 51. Chrysotile is used in the largest quantities in plastics for molding compounds with lesser amounts of crocidolite. Chrysotile classified according to the Quebec Asbestos Mining Association (QAMA) test in grades 1 through 5 is normally used for its reinforcing properties. Grade 7 chrysotile fibers are used for their thixotropic characteristics (to control flow), heat resistance, dimensional stability and low cost. The crocidolite variety of asbestos is utilized for specialty purposes where corrosion resistance is important.

TABLE 51. ASBESTOS USE BY TYPE AND GRADE IN 1980[1]

Asbestos type		Consumption (metric tons)
Chrysotile grade	1 and 2	200
	5	400
	7	800
Crocidolite		100
Total		1500

Because of desirable properties such as thermal and mechanical enhancement and dimensional stability, asbestos fibers have traditionally been used in a wide variety of plastic resins--including phenolic, vinyl, epoxy, unsaturated polyester, urea diallyl phthalate, polypropylene, nylon and thermoplastic polyester (PBT).[2] Table 52 presents some of the effects of asbestos on physical properties of plastics.

TABLE 52. TYPICAL CHANGES IN RESIN PROPERTIES WITH ASBESTOS REINFORCEMENT[3,a]

	% change				
Material	Flexural modulus	Flexural strength	Tensile strength	Impact notched izod	HDT (°F)
ABS	+130	-20	-5	-60	+16
Nylon 6	+170	+100	+85	+20	+200
Phenolic	+120	+50	-	+5	-
Polyethylene	+320	+30	+20	0	+72
Polyphenylene sulfide	+60	+100	+10	+100	+35
Polypropylene	+360	-	-4	+125	+25
Polystyrene	+110	+50	+20	-40	+18

[a] Optimum reinforcement usually requires 20 to 40 percent short fiber asbestos.

Uses and Applications--

Despite a recent trend to use substitute materials, asbestos-reinforced plastic molding compounds are used in a variety of applications including the electrical, electronic, automotive, and printing industries. For example, the Rogers Corporation, a large manufacturer of phenolic molding compounds, uses asbestos in the following products: asbestos-reinforced board material used in the printing industry as a matrix from which multiple rubber or plastic printing plates can be molded; automotive transmission reactors which are employed to direct the flow of transmission fluid; commutators for electrical motors, switches and circuit breakers.[4] General Motors, a major consumer of reinforced plastics, uses Rogers Corporation asbestos-reinforced molded commutators used in fan drive motors installed in its new 1980 front wheel drive (X-model) compacts.[4]

Special Qualities--

Asbestos fibers are used to reinforce both thermosetting polymers such as phenolic and modified phenolic resins, epoxy resins, silicones, polyesters and diallyl phthalate polymers, and thermoplastic polymers such as vinyl resins, polypropylene, and fluorocarbon polymers.

Asbestos is particularly useful in molding compounds because, in addition to its reinforcing properties, it will impart very good surface finish, toughness, resistance to heat and fire, and less shrinkage and warpage than other fibers.[5] Also, the addition of asbestos improves the handleability of the product during processing. For example, putty-like compounds become much less sticky.

The advantages of using asbestos instead of inorganic or organic fillers (rock dust, wood floor, cellulose products, etc.) derive from the fact that asbestos has both the advantage of a mineral and a fibrous binder carrier with reinforcing action, and these favorable characteristics are revealed in the corresponding properties of the asbestos molded articles. When unprocessed asbestos fibers are employed, the properties of the molded articles reflect the length of the fibers, the degree to which the bundles of fibers have been opened, and the degree of purity of the fibers.[6]

SUBSTITUTES

A wide variety of alternatives to asbestos fibers are available as reinforcements and fillers in plastics. Manufacturers have developed alternatives for a majority of products previously reinforced with asbestos in which the physical properties of the substitute product are close to or may even exceed the asbestos product they replace. New fiber technology has been developed which has boosted physical properties of substitutes such that they are comparable to asbestos. In addition, manufacturers have blended various fillers and reinforcing materials to achieve required properties. Although there are still some specialty products where no feasible asbestos substitutes have been found, in general, reinforced plastics appear to have progressed towards the replacement of asbestos. A summary description of substitute materials is provided in Table 53.

TABLE 53. ASBESTOS SUBSTITUTE MATERIALS[7,8]

Substitute material	Performance and comments
Fibrous glass	May be used for higher temperature applications; new glass fiber technology enhances the physical properties of the material; problems with abrasiveness of glass wearing out processing equipment; process change probable.
Clay	Used as filler, no reinforcement; new clay base compositions are reported to maintain the acceptable balance of heat resistance and impact strength.
Talc	Loss of strength but can compensate by making thicker walled product; presently used as an asbestos substitute; limited to 450°F applications.
Mica	Adds dimensional stability and increases strength of plastics; high aspect-ratio mica purported to provide middle ground in cost performance between inorganic particulate fillers and fiber reinforcement; blended with higher priced substitute materials.
Carbon fibers	For high strength applications; increases acid resistance in phenolics; also used as filler for thermoset plastics; high heat resistance; specialty applications only.
Aramid fibers	Use in specialty plastic reinforcements; too expensive for asbestos replacement in phenolic molding compounds; can be blended with less expensive materials.
Polyethylene fibers	Still in development stage; high modulus but poor heat resistance properties.
Calcium sulfate	Provides improved output rates, allows high loadings, and results in low densities; high heat resistance; no reinforcing properties.
Wollastonite	Asbestos replacement in phenolics. Has been classified as merely a nuisance dust.
Processed mineral fiber	Asbestos replacement in phenolics and epoxy gel coats.

MANUFACTURING

The manufacture of asbestos-reinforced plastic products can be divided into two segments. A small number of primary manufacturers (currently there are only five manufacturers of asbestos molding compounds--see Table 54) produce molding compounds in pellet or flake form, package it, and sell this granulated material to up to perhaps 5,000 separate secondary manufacturers where the final product is shaped and finished. The primary manufacturing steps typically consist of (1) fiber receiving and storage, (2) fiber introduction, (3) dry blending, (4) resin formation, and (5) packaging and shipping. The secondary manufacturing steps usually are at a facility remote from the primary processing and consist of (1) resin receiving and storage, (2) resin introduction, (3) forming, (4) curing, (5) finishing, and (6) product packaging and shipping to consumers. The major secondary manufacturers of asbestos-reinforced plastic molding compounds produce products for the electrical, electronic, automotive and printing industries. It is the opinion of some manufacturers that the combination of high strength, corrosion resistance, high temperature performance, and low price provided by asbestos cannot be sacrificed.

TABLE 54. PRIMARY MANUFACTURERS OF PHENOLIC MOLDING COMPOUNDS[13,7,9,a]

Plant name	Location
Plaslok Corp.	Buffalo, NY
Plastics Engineering	Sheboygan, WI
Reichold Chemicals	Elizabeth, NJ
Resinoid Engineering	Skokie, IL LaPorte, IN Newark, OH
Rogers Corporation	Manchester, CT

[a] Augmented by GCA telephone contact.

Primary Manufacturing

Figure 26 illustrates the general process flow for the primary and secondary manufacture of asbestos-reinforced plastics.

Asbestos fiber is typically transported in a dry state by railcar or truck and is contained in palletized paper or plastic bags. A recent trend has been towards employing shrink-wrapped pallets which is now a customer option. At the plant, this material is unloaded either manually or by powered fork-lift trucks and transported to a raw-fiber warehouse for intermediate storage. At most facilities housekeeping practices such as taping broken bags and vacuuming the trucks or railcars prior to unloading are employed. The asbestos fiber is usually not isolated but stored in the same open warehouse with other materials such as dry resin and fillers. The warehouse air may or may not be exhausted to a particulate collection device.

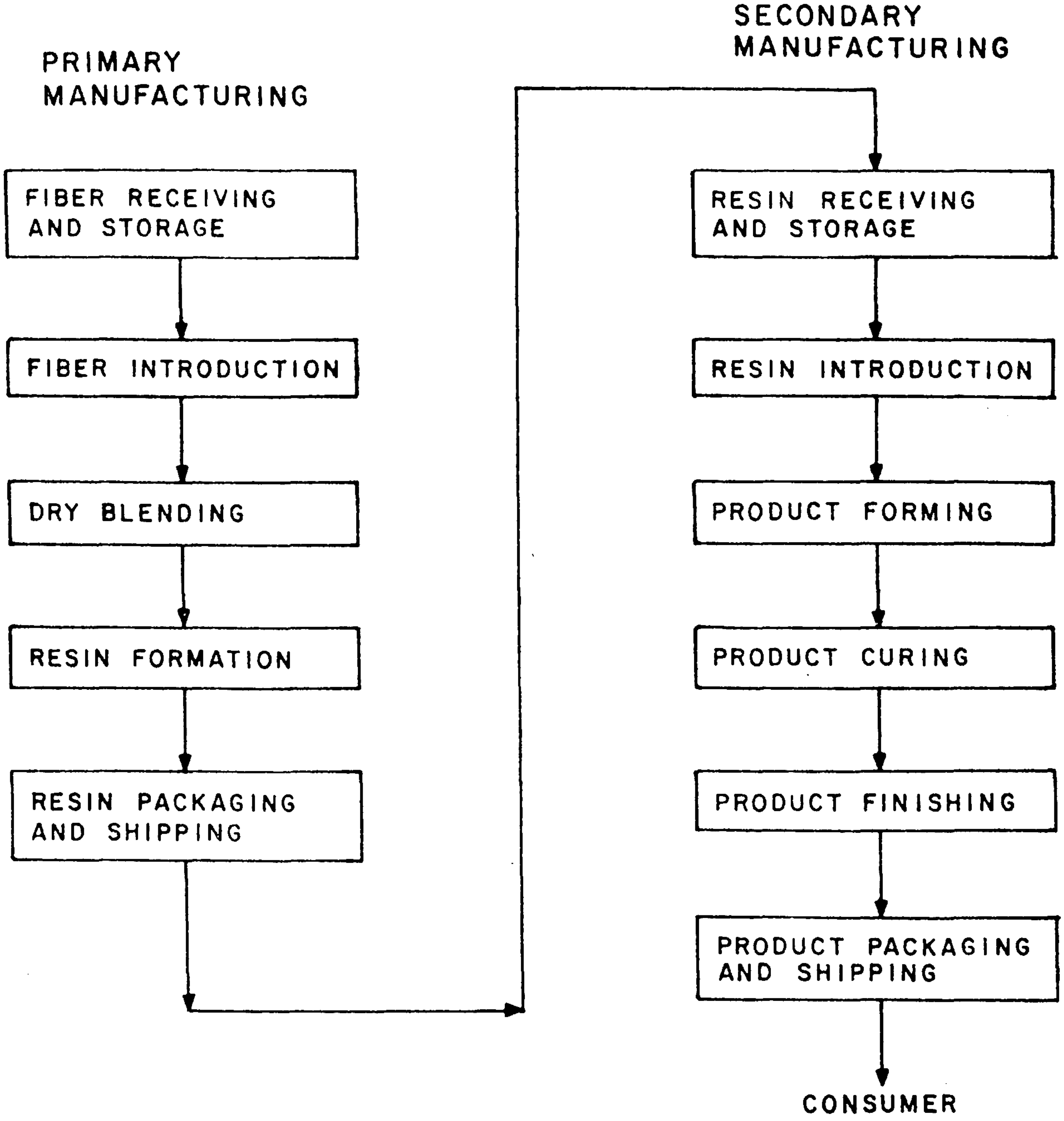


Figure 26. General process flow for manufacture of asbestos-reinforced plastic.[9]

The raw fibers are transported on pallets by fork-lift trucks to staging areas within the plant near the fiber introduction work stations. The asbestos fibers are introduced to a dry blending step which involves mixing the dry ingredients necessary to compound the material. Dry blending is needed to achieve a homogeneous mixture of the ingredients which include asbestos fiber, catalysts, additives, resins, and polymers. A wide variety of equipment is used throughout the industry to ensure a low-shear, well-mixed blend.

Asbestos fibers may be introduced into the process in a number of ways. At smaller facilities, preweighed asbestos is conveyed to a storage hopper prior to charging to the dry blending equipment. Alternatively, asbestos may be charged directly into the blending machinery without intermediate storage or handling. To protect the dry ingredients from excessive abrasion, mechanical agitation is minimized during blending.

At larger facilities, the blending step may be preceded by a beater operation where raw fibers are broken up and sized. Since the beating process is vigorous, pulpable bags can be used.[10] After conditioning, the asbestos fibers are transported to the product mixers pneumatically or in sealed containers.

Dust control measures during fiber introduction and blending include local exhaust hooding, evacuated enclosures, and vacuum lines. All of these devices typically vent through enclosed ductwork to cyclones or fabric filters. Fabric filters are known to have particulate removal efficiencies of 99 percent.

Asbestos shipping wrappers that are not charged into the mixer along with the fibers are placed in bulk sacks affixed with asbestos warning labels. When full, the sacks are sealed and taken to a landfill. Housekeeping practices around the fiber introduction area include central vacuum cleaning systems and mechanical floor sweepers.[11]

After the individual ingredients have been thoroughly mixed, the blend is transferred via sealed containers or vacuum conveyors to resin formation equipment. A variety of equipment may be involved, depending upon the end-product specifications. In general, the resin is formed by either of two processes: externally heated extrusion or internally heated (friction/shear) Banbury mixing. Both processes produce pellets, powders, or some similar product which is sometimes called a "preform." This resin is drummed and used in subsequent processes to form the end product. Some of the primary industries fabricate their own plastic products, but it is estimated that approximately 70 percent of the asbestos reinforced plastics are sold to secondary fabricators. Dust-control equipment in general use includes exhaust hoods vented to fabric filters and partial enclosures of process equipment. Housekeeping and maintenance include central vacuum cleaning systems and mobile floor sweeping/vacuuming equipment. In general, all the material collected by fabric filters and housekeeping systems is bagged, sealed, and tagged with special asbestos warning labels before being transferred to a landfill. At some facilities employing a beater operation, a portion of accumulated fines is wetted and recycled to the beaters.

Secondary Manufacturing

Subsequent processing of asbestos-reinforced plastics may be accomplished at a remote location or at the same facility where the primary manufacturing is performed.

At remote locations, drummed "preform" is received by railcar or truck and is transferred to a storage area by fork-lift truck. The drums are subsequently moved to the forming step. The forming step involves actual formation of an end product from the preformed resin by remelting the preform and submitting it to rolling, stamping, pressing, or molding. The processing equipment varies throughout the industry. Remelting serves to start the polymerization, cross-linking, and thermosetting reactions. Dust-control equipment includes exhaust hoods to fabric filters and partial enclosure of process equipment. Housekeeping practices include central vacuum cleaning systems and mobile floor sweeping/vacuuming equipment.

Following the molding process, the formed product is transferred to the curing step which involves control of cross-linking and thermosetting reactions to achieve specific strength and stiffness characteristics. This normally requires an enclosed area, furnished with a ventilating system. When the processes employ air-curing, hoods and local enclosures are provided. Housekeeping procedures are similar to those employed in other steps of dry processing.

After the product is cured, it is finished. This involves sawing, grinding, drilling, machining, etc. The degree of finishing and the type of process used depends upon the end use of the product. Asbestos dust is released when the plastic products are finished. Hand and portable tools are normally supplied with local exhaust systems vented through a central fabric filter unit. Larger, stationary machines employ local exhausts near the surface being finished and, in some cases, are supplemented with hoods over the finishing machine itself. All exhausts are vented to fabric filters. Housekeeping practices include central vacuum cleaning systems and mobile floor sweeping/vacuuming equipment.[11]

In general, all the material collected by fabric filters and housekeeping systems is bagged, sealed, and tagged with special asbestos warning labels before being transferred to a landfill.

It is extremely difficult to determine the entire scope of the secondary market for asbestos-reinforced plastics from primary molding compounds. There are industry estimates of some 3,000 secondary fabricators of reinforced plastics and perhaps 5,000 separate end users of the product. It is impossible to determine what percentage of these plastic fabricators presently use asbestos-reinforced plastics. It has been reported, however, that many secondary manufacturers have preferred not to process compounds containing asbestos fibers in their operations and have already converted to asbestos-free compounds.[12]

Manufacturing Plants

The most important primary manufacturers of phenolic molding compounds which currently produce asbestos-filled compounds are listed in Table 54.

Production Volumes

In 1978, 4,900 metric tons of asbestos fiber were consumed in the production of asbestos plastic molding compounds as classified by the Bureau of Mines.[14] In 1980, however, the Bureau of Mines reported that only 1,500 metric tons of asbestos were used in the production of plastics in the United States.[1] This 69 percent decline compared to a 42 percent decline in overall asbestos use reflects a dramatic trend toward the use of substitute fibers.

ASBESTOS RELEASE

Input-Output

Although Connecticut State personnel[15] measured significant atmospheric fiber concentrations in the vicinity of phenolic molding compound manufacturing operations, Levine[16] has estimated process-related air emissions from plastic manufacturing to be minimal. Figure 27 shows estimated process disposal and emissions for the plastics manufacturing industry based on Levine's[16] 1974 estimates projected to 1980 U.S. Bureau of Mines consumption figures. Of the 1,500 metric tons entering the process as raw asbestos fiber, approximately 1,462 metric tons are contained in the final product and 38 metric tons are sent to disposal as vacuum cleaner and baghouse dust and product scrap. It is estimated the asbestos fiber emission from control equipment (typically a baghouse) is minimal. Levine's atmospheric emission estimates are based on gross assumptions with a reported uncertainty of at least an order of magnitude. Meylan[9] reports emissions of 1 to 3 orders of magnitude less. GCA's estimate of atmospheric emissions from disposal is based on Levine's[16] data and takes into account the amended Asbestos NESHAP's regulations adopted in 1975 regarding the disposal of asbestos-containing wastes.[17]

During Manufacture

Workplace Exposure--

Based on data collected by the Asbestos Information Association from plants covering 55 percent of the asbestos-reinforced plastics industry, Table 55 has been compiled. The high exposures for receiving and storage are due to bag breakage during handling. The high exposures for fiber introduction are a result of a prevalence of manual bag opening, emptying, and handling for disposal.[11]

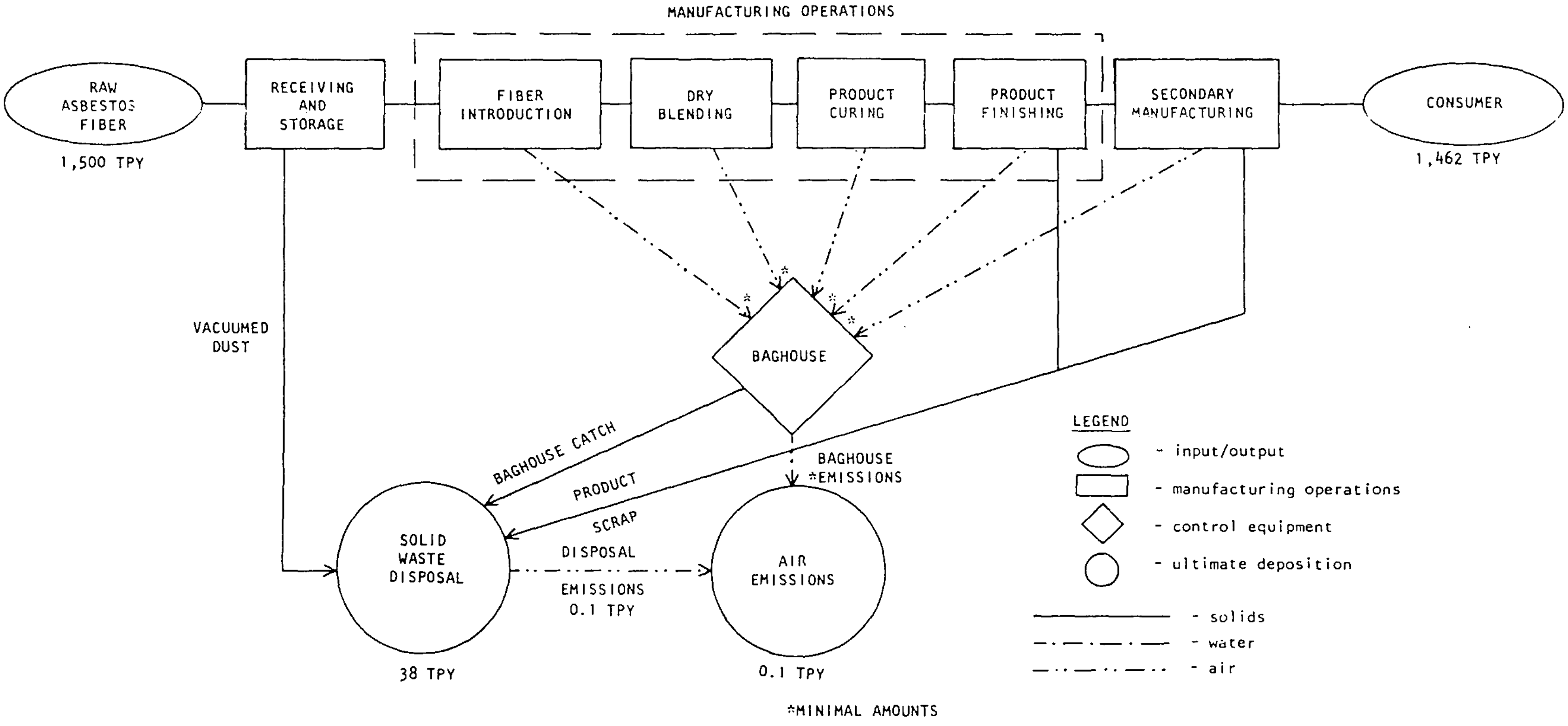


Figure 27. Process and disposal emissions from asbestos plastics industry (metric tons).

TABLE 55. TIME-WEIGHTED AVERAGE FIBER COUNTS[a] - ASBESTOS-REINFORCED PLASTICS[11]

Process step	Fiber count with existing control technology	
	Typical fibers/cc	Range fibers/cc
1. Fiber receiving and storage	1.0	0.25-2.5
2. Fiber introduction	2.0	0.5 -3.0
3. Dry blending	1.0	0.2 -1.5
4. Resin formation	0.75	0.5 -1.5
5. Kneading, rolling, etc.	1.0	0.25-1.5
6. Cure	0.75	0.2 -1.5
7. Finishing	1.0	0.5 -1.5

[a] NIOSH method, counting fibers >5 μm by phase contrast microscopy.

The asbestos dust exposure in other steps arises from the handling and introduction of the dry blended mixture and the dry preform. After remelting, the asbestos is bound in the polymer matrix.

Normally, only minor finishing is provided for the cured product. Thus, the amount of asbestos fiber released is less than in other asbestos industries. Additionally, the content of asbestos in the product is low compared to such products as asbestos-cement pipe or sheet. Therefore, for the same degree of finishing, a lower asbestos fiber release is expected as the content of asbestos in the product is decreased.[11]

From the exposure data given in Table 55 for fiber receiving and storage (0.25 to 2.5 f/cc), spillage from raw-fiber containers may add significantly to worker exposure levels and subsequent plant air emissions. Several currently available practices and techniques are used to avoid asbestos bag damage. The controls include the use of inflatable dunnage, lined railcars, shrink-wrapped pallets, and double-sealed bags. Taping of broken bags combined with prompt vacuuming of all spills also reduces asbestos dust emissions to the air in receiving and warehouse areas. The use of air pollution control equipment for existing warehouse exhaust is inappropriate due to the cost of designing for the typical large volumes of air. More controlled receiving and warehouse areas for asbestos with exhaust vented to pollution control equipment may be possible. Such modifications, however, might prove costly.

At most asbestos reinforced-plastic manufacturing plants, where preprocessed (opened and sized) fibers are purchased, the fiber-introduction step is accomplished largely by the use of evacuated (to a fabric filter), hooded dump stations with enclosed empty bag receptacles contiguous to the dumping hoods. Pulpable bags are not used since the dry blending step is accomplished by gentle agitation which would not break down the bag sufficiently. Due to the relatively high workplace exposure fiber count (0.5 to 3.0 f/cc), the fiber introduction step is one of the largest generators of airborne asbestos fibers in the primary asbestos-reinforced plastics industry. However, since the processing areas are usually hooded and vented to fabric filters, the dust emitted to the atmosphere is due to either the escape through the fabric filter or inefficiencies in the hood collection system.

During the dry blending and resin formation processes, most airborne asbestos fiber emissions are generated during transfer of the dry product. Localized ventilating systems exhausted to fabric filters and partially enclosed process equipment reduce the asbestos fiber emissions to the atmosphere. As in the fiber introduction step, the airborne dust emitted to the outside environment is due to either the escape through the fabric filter or inefficiencies in the hood capture system. The preform, which is the product from the resin formation step, is typically in pellet or flake form. Therefore, the potential for dust generation is present throughout the entire primary manufacturing sector. Since the preform is drummed for shipment to secondary manufacturers, vent systems and enclosed process equipment are employed in the packaging area to reduce airborne emissions.

Emissions to Air--

Data concerning asbestos air emissions from primary manufacturing of asbestos-reinforced plastics is very limited.[9] Ambient air asbestos levels in the vicinity of one primary manufacturer of phenolic molding compounds have been measured and these levels give an indication of plant emissions. The manufacturer in question uses approximately 150 m.t./month of chrysotile asbestos.[15] Thirty-day average ambient levels near the plant measured from 3 to 33 ng/m^3 of asbestos.[15] The highest reading, 33 ng/m^3, exceeded the proposed state (in which this manufacturer is located) air quality standard for asbestos of 30 ng/m^3 or 30,000 total asbestos $fibers/m^3$, 30-day average. All processes with a potential to emit asbestos fibers at the facility were well controlled, with hoods and baghouses used to minimize asbestos fiber release. The ambient monitoring data indicate that asbestos emissions from a phenolic molding manufacturer can be significant in the immediate vicinity of the facility, in spite of good control practices.

The principal sources of airborne asbestos fiber emissions in the primary and secondary reinforced plastics industry are the finishing operations. Once the asbestos fibers are encapsulated by the plastic resins, they can only become airborne if the fiber bundles are penetrated by a cutting tool such as a drill or a saw. Most hand and portable finishing tools and primary and secondary facilities are supplied with local exhaust systems connected to the central ventilation/collection system. These local exhaust systems can be designed to minimize any asbestos fiber release to the workplace and subsequently to the atmosphere. Therefore ambient emissions from plastics manufacturing would mainly be asbestos fibers which escape through the central fabric filters.[9] Based on 1980 asbestos consumption, these emissions are estimated to total less than 0.02 m.t. per year. This estimate is based on monitoring data of well-operated baghouses. It should be noted that faulty baghouse equipment can potentially increase emissions significantly.

Release to Water--

Water is not used directly in the manufacture of asbestos-reinforced plastics. Asbestos would be released in wastewaters from water-type air scrubbers used to clean exhaust from hooded processing steps. However, baghouse collectors are normally used for this function.

Release to Land--

The asbestos solid waste generated at primary manufacturing facilities is mostly from baghouse collections and housekeeping procedures or is contained in the emptied raw asbestos bags discarded in the fiber introduction step. Pellet and flake product scraps can normally be recycled. At one manufacturing plant where a beater operation is run, the accumulated fines from baghouses are wetted for reuse in the beater.[10] Some facilities recycle baghouse collections as a filler material. However, many plants find it more economical to dispose of baghouse and housekeeping collections along with empty raw asbestos bags in bulk sacks, specially marked with warning labels, prior to shipment to a landfill.

The amount of asbestos removed to landfills from primary manufacturing is difficult to determine. The disposal estimate presented in this section, 38 metric tons/year, includes both primary and secondary manufacturing although most of this scrap is from secondary producers. This total amounts to 2.5 percent of industry asbestos use. It was based on Levine's disposal estimates projected to 1980 asbestos consumption data. These data are more conservative than estimates published by Meylan, et al.[9] Meylan has estimated that solid waste generated at secondary manufacturing facilities in the form of product scraps and damaged products amounts to about 2 percent of annual use, while an additional 4 percent is collected in baghouses. This total of 6 percent scrap asbestos amounts to approximately 90 metric tons of solid asbestos waste based on 1980 industry asbestos consumption. Insufficient information exists relative to the amount of scrap generated, scrap asbestos content and current disposal practices at both primary and secondary plastics manufacturing facilities to determine which estimate is correct. Since the Levine estimate is more conservative in predicting overall asbestos emissions, it is the one presented here.

During Use

Fiber release is unlikely during the service life of an asbestos plastic product. Matrix bonding binds the fibers so that only friction, scraping, sanding, rubbing, or some other force which can break down the plastic matrix will result in free fiber release. Typical uses for asbestos reinforced plastic, such as in electrical equipment, would not subject the plastic to these forces.

During Disposal

In general, most of the diversified plastic products are not designed to have a service life greatly in excess of 10 years. Therefore, a sizeable percentage of production (perhaps 80 to 90 percent) is intended for replacement purposes.[9] The annual wasting of asbestos plastics may, therefore, be in the range of 1,300 m.t. These wastes will be discarded primarily at commercial landfills and auto junkyards (asbestos plastics have significant usage in automobiles). Because the asbestos fibers are encased in the plastic matrix, the replacement wasting of asbestos-reinforced plastics is not judged to cause any significant free-fiber release to the atmosphere.

CONCLUSIONS

Through the 1970s there has been a consistent decline in the use of asbestos for reinforced plastics. This decline in overall asbestos use reflects a dramatic trend toward the use of substitute fibers.[7,18] Manufacturers have reported that customers have demanded asbestos-free compounds.[13,19] Coupled with customer demand are the high costs of complying with environmental regulations. Installation of engineering controls and implementation of specific work practices have reduced the economic advantage of manufacturing asbestos-based plastic resins. The increased costs have had the greatest impact in industries where asbestos was being used mainly because it was inexpensive and where the properties imparted to the plastic by asbestos fibers were not critical to the usefulness of the product. The major manufacturers of reinforced plastics are either in the process, or have already phased out asbestos in their product lines. However, there are apparently some specialty product lines where no feasible asbestos substitute has been found. It may be that asbestos will remain a reinforcement material in specialty applications, if exposures can be controlled to within acceptable limits.

In general, the control of asbestos fiber emissions from manufacture of asbestos-reinforced plastics is accomplished about as well as can be reasonably expected with today's technology. The major sources of airborne emissions are at fiber receiving and storage and fiber introduction during primary manufacturing, at the finishing step during secondary manufacturing, and from reentrainment of improperly discarded solid waste at dumps and landfills. At the manufacturing facilities, most equipment is hooded and exhausted to fabric filters and residual dust is continuously removed by vacuuming during housekeeping. The problem at landfills is being alleviated by specially tagged containers holding asbestos and monitoring their disposal.

Solid waste is generated from baghouse and housekeeping collections and from product scraps. The latter is not a large problem in the primary industry segment because most scraps are recyclable. In the secondary industry segment, upwards of 38 tons of asbestos annually end up in product scraps which are removed to landfill. However, the asbestos in these scraps is bound tightly in the plastic matrix and free-fiber emissions would not be expected.

Asbestos fibers should not be released during the service life of asbestos-reinforced plastic molding compounds because the products are not typically subjected to friction, scraping, sanding, rubbing, or some other physical force that could break down the plastic matrix. The product life expectancy is usually short (less than 10 years). The wasted material is disposed primarily to commercial landfills and auto junkyards.

It can be concluded that most of the asbestos fibers used for reinforced-plastic molding compounds since their invention in the early 1920s have been discarded with waste products in dumps and landfills in a nonfriable form. It can also be concluded that asbestos used for plastics will hold a smaller and smaller fraction of the reinforced plastics market.

REFERENCES

1. Clifton, R. A. Asbestos. 1980 Minerals Yearbook. U.S. Bureau of Mines, Washington, D.C.

2. Naitove, M. Asbestos in Plastics: Looking for Alternatives. Paper presented at the National Workshop on Substitutes for Asbestos, Arlington, Va. July 14-16, 1980. U.S. EPA Report No. EAP-560/3-80-001. November 1980.

3. Byrne, Jr., R. E. Asbestos. Union Carbide Corp. brochure reprinted by permission from the Modern Plastics Encyclopedia, McGraw-Hill Inc.

4. Exner, P. Trip Report to Rogers Corporation, Manchester, Conn., GCA, October 30, 1979.

5. Oleesky, S. S., and J. G. Mohr. Handbook of Reinforced Plastics. Reinhold. 1964.

6. Berger, H. Asbestos with Plastics and Rubber. Chemical Publishing Co., Inc. New York, N.Y. 1966.

7. Wright, M., et al. Asbestos Dust Technological Feasibility Assessment and Economic Impact Analysis of the Proposed Federal Occupational Standard - Part I: Technological Feasibility Assessment and Economic Impact Analysis, prepared by Research Triangle Institute, for U.S. Department of Labor, OSHA, Washington, D.C. September 1978.

8. Telecon. Vincent R. Landi, Rogers Corporation with R. Bell, GCA Corporation/Technology Division. February 5, 1980.

9. Meylan, W. M., et al. Chemical Market Input/Output Analysis of Selected Chemical Substances to Assess Sources of Environmental Contamination: Task III - Asbestos. EPA 560/6-78-005. August 1978.

10. MacBride, R. R. Plastiscope 1. Modern Plastics. September 1976. p. 12.

11. Daly, A. R., et al. Technological Feasibility and Economic Impact of OSHA Proposed Revision of the Asbestos Standard (Construction Excluded). Asbestos Information Association/North America. March 26, 1976.

12. Swanson, R. C. Sales Representative, Colt Industries, Garlock Inc. Mechanical Packing Division. Charlotte, N.C. Meeting with Mr. T. Curtin, GCA Corporation, February 21, 1980.

13. The Asbestos Controversy Continues, Plastics Design Forum. November/December 1978.

14. Clifton, R. A. Asbestos in 1978, Mineral Industry Surveys. U.S. Bureau of Mines, Washington, D.C. August 22, 1979.

15. Bruckman, L., R. A. Rubino. Monitoring Asbestos Concentrations in Connecticut. Air Pollut Contr Assoc J. 28(12). 1978.

16. Levine, R., ed. Asbestos: An Information Resource. May 1978.

17. 40 CFR Part 61, Subpart B - National Emission Standards for Hazardous Air Pollutants - Asbestos.

18. Telecon. Sales Manager, General Electric Co., with R. Bell, GCA Corporation, February 1980.

19. A. S. W. More Muscle, Higher Heat: They Power a Phenolic Molding Compound 'Revival.' Modern Plastics. July 1979.

SECTION 12

TEXTILES

INTRODUCTION

Asbestos, the only mineral that can be processed into textiles using looms and other equipment commonly employed in the textile industry, is used to manufacture durable heat and acid resistant textiles. Final products take many forms, such as roving, lap, yarn, cord, cloth, tubing, wick and tape, and are used in many applications such as friction materials, industrial packings, electrical insulation, and thermal insulation. Asbestos has been used in fire and heat resistant textiles since antiquity. Modern commercial operations have been well established for over a hundred years.[1]

In 1980, approximately 1,900 metric tons of asbestos or about 0.5 percent of the total U.S. fiber consumption went into textiles.[2] This represents a decline of almost 67 percent from the amount processed into textiles in 1979.[3] The number of plants producing asbestos textiles has also declined over the last few years. Thirty-five plants produced asbestos textiles in 1968[4] and at least 13 plants produced asbestos textiles in 1972.[5] But as of 1976 only six plants owned by four firms are known to manufacture asbestos textiles.[6] In 1976, 65 percent of the nation's demand for asbestos textiles was supplied domestically, with imports accounting for the remainder.[7] It is assumed this percentage has not changed.

PRODUCT DESCRIPTION

Composition

Asbestos textiles are predominantly made from long, spinning grade chrysotile fibers. Grades 1, 2 and 3 are used, with grade 3 accounting for 90 percent of the asbestos fiber in textiles produced in 1980.[2] The different forms of asbestos textiles manufactured and the six major product categories in which they are used are presented in Table 56. The asbestos content of textiles ranges from 75 to 100 percent by weight.[8,9]

Asbestos yarn is composed primarily of asbestos fibers. Cotton, nylon, polyester, and wire are added for reinforcement in some applications of yarns. Asbestos yarns are made in all of the standard ASTM grades shown in Table 57.

TABLE 56. FORMS OF ASBESTOS TEXTILES USED IN ASBESTOS PRODUCTS

Fire resistant	Thermal insulation	Electrical insulation	Packings and gaskets	Friction materials	Specialty textiles
Yarn	Yarn	Yarn	Yarn	Yarn	Fiber
Thread	Cloth	Roving	Rope	Cloth	
Cloth	Cord	Tape	Wick		
	Rope	Thread	Cord		
	Tape	Felts	Cloth		
	Tubing	Cord	Tape		
		Lap			
		Tubing			

TABLE 57. ASBESTOS TEXTILE GRADES[10]

Grade[a]	Asbestos content by weight
Commercial	75% up to but not including 80%
Underwriters'	80% up to but not including 85%
Grade A	85% up to but not including 90%
Grade AA	90% up to but not including 95%
Grade AAA	95% up to but not including 99%
Grade AAAA	99% up to and including 100%

[a] Asbestos textile grades differ with each asbestos textile form.

Asbestos thread is produced in both plain (nonmetallic) and metallic (wire inserted) classes (A and B), the latter being noted for its great tensile strength and high thermal stability. Asbestos thread is generally furnished in Underwriters' grade.

Asbestos cloth is woven from five classes of asbestos yarns. The most widely used fabrics are woven from Class A (plain or nonmetallic) yarns and Class B (metallic or wire inserted) yarns. Other fabrics are made from Class C, D and E reinforced yarns. The different classes of asbestos cloth are listed below:

- Class A--Cloth constructed of asbestos yarns containing no reinforcing strands.
- Class B--Cloth constructed of asbestos yarns containing wire reinforcing strands.
- Class C--Cloth constructed of asbestos yarns containing organic reinforcing strands.
- Class D--Cloth constructed of asbestos yarns containing nonmetallic inorganic reinforcing strands.
- Class E--Cloth constructed of two or more of the yarns used in Classes A through D.

Asbestos cord is manufactured in all standard ASTM grades. The diameters of asbestos cord range from 0.15 cm (0.06 in.) to 0.97 cm (0.38 in.). Asbestos rope is available in commercial grade for most general uses and in Underwriters' AA, AAA, and AAAA grades depending on service requirements. Tape is manufactured mainly as plain or nonmetallic tape and as a wire inserted product; those used in thermal insulation are manufactured in all of the standard ASTM grades. Asbestos tubing also comes in all of these grades; roving is blended with cotton or other organic fibers, producing various degrees of density to meet specific requirements of the user. This is also applied in the five standard ASTM grades. Asbestos lap comes in two styles: one is a single ribbon-like formation of fibers and the other a paralleled assemblage of the first. It comes in A, AA, and AAA grades. Felts come in all grades and are available both with or without glass cloth reinforcement; they are produced in sheets, tapes, and rolls. Wick is usually of commercial grade but other grades can be supplied on order. In most cases the textiles are coated or bound with resins or elastomers before being worked into a final product. They can also be sprayed with a metal like aluminum to reflect heat. When braided to make packing and gaskets, the material may be impregnated with different compounds. For example, graphite is commonly used to impart better frictional and binding properties.

Uses and Applications

About two-thirds of all manufactured asbestos textile material is an intermediate product used in other industry categories such as friction materials, insulation, or gasketing. Long fibers are spun into yarn, cord, thread, cloth, roving, rope, tape, braid, and corded fibers which may subsequently be worked into protective clothing, insulation, filters, or diaphragms. The form the textile product takes is dependent upon its intended end use as presented below:

- Lap - electrical insulation
- Roving - insulation for heater cords, twisted to form yarn
- Yarn - woven into textiles
- Cord - seals, packings, insulation
- Cloth - curtains, blankets, safety clothing
- Tubing - sleeving for electrical conductors
- Wick - packing and seals
- Tape - electrical insulation

Asbestos fire-resistant materials are used in a variety of applications, including welding curtains, draperies, blankets, protective clothing, hot conveyor belts, furnace shields and molten metal splash protection aprons.[10] In addition, asbestos fire-resistant materials are used in the construction field as temporary blankets or curtains. Further, they are used in the military, fire-fighting and aerospace fields for protective clothing and in various rocket and missile parts. Ironing board covers and theater curtains also contain these materials.

Asbestos textiles are used as thermal insulation in pipe wraps for safety protection; stress relieving pads in welding operations; protective coverings for hot glassware utensils such as pincers and tongs; coverings for diesel engine exhaust lines; flue sleeves; and braided walls in the construction of steam hoses.[11]

Asbestos textiles are employed for the insulation of wires and cables, especially those which are designed for low voltage, high-current use under severe temperature conditions. They are also used for insulation of arcing barriers in switches, circuit breakers, heater cords, and motor windings, and as sleevings for electrical appliance leads and insulated conductors where fire protection and resistance to mechanical abrasion are needed.

Asbestos textiles are used for pump packings; all purpose shaft and valve stem packings' expansion joints; manhole gaskets; seals for boilers, ovens, and furnaces; flange gaskets; and gaskets for storage tanks, cookers, and dryers.

The applications of woven asbestos brake linings are mainly found in industrial band and drum brakes contained in cranes, lifts, excavators, winches, concrete mixers and mine equipment. Woven asbestos may be used as clutch facings for industrial band, plate and cone clutches in cranes, lifts, excavators and winches. Automotive brake pads can use a woven asbestos cloth which may be reinforced with brass wire or impregnated with phenolic resin, as is commonly used in clutches.[12]

Asbestos carded fiber is the main form of asbestos textiles that can be used in specialty products. Carded fiber is used mainly in liquid filters for such products as beer, wine, oils and chemicals; and in electrolytic diaphragms. It is also used as wiping pads for molten metal and as stuffing box packing.[10]

Special Qualities

Asbestos withstands high temperatures more effectively than any of the resins and organics with which it is bound. It remains unaffected by the combination of moisture and heat. Although asbestos will suffer thermal degradation and some loss of strength at elevated temperatures, fibers will not burn, splinter or disintegrate when in contact with flame. Strength retention for several grades of asbestos textiles at elevated temperatures is shown in Figure 28. Pure chrysotile is stable in continuous use at temperatures up to 480°C and can be used in higher temperature applications if exposure is discontinuous.[1] Asbestos fibers also restrict the thermal expansion of materials with which they have been combined and impart a high resistance to impact and abrasion to the final product.[13]

SUBSTITUTES

At a recently held conference concerned with the availability of substitutes for various asbestos products, a supplier of asbestos-free textiles stated, "... it is very safe to say that there is a replacement for every asbestos textile product right now."[14] Asbestos substitutes available for fire resistant applications include: fiberglass, ceramics, organics, graphite, carbon, quartz, cotton, and special wool blends. These products, when woven into cloth, can be substituted for asbestos in a majority of cases, displaying similar or even better properties. In general, replacement of asbestos must be made on an application-by-application basis, taking into considerations such factors as cost, performance, and service life. Table 58 presents the physical and chemical properties of available substitute materials for textile products.

At service temperatures below 204°C (400°F) or at higher temperatures with shorter exposure time, there appears to be little difficulty in selecting a suitable replacement. Even in high temperature applications above 204°C (400°F), there are a number of materials available that are designed to replace asbestos.[37] High temperature fiberglass, an alumino silicate (a ceramic-type material), and an aluminum borosilicate material sold under the name Zetex® all offer temperature resistance and fiber strength comparable to or exceeding that of asbestos.[16,38]

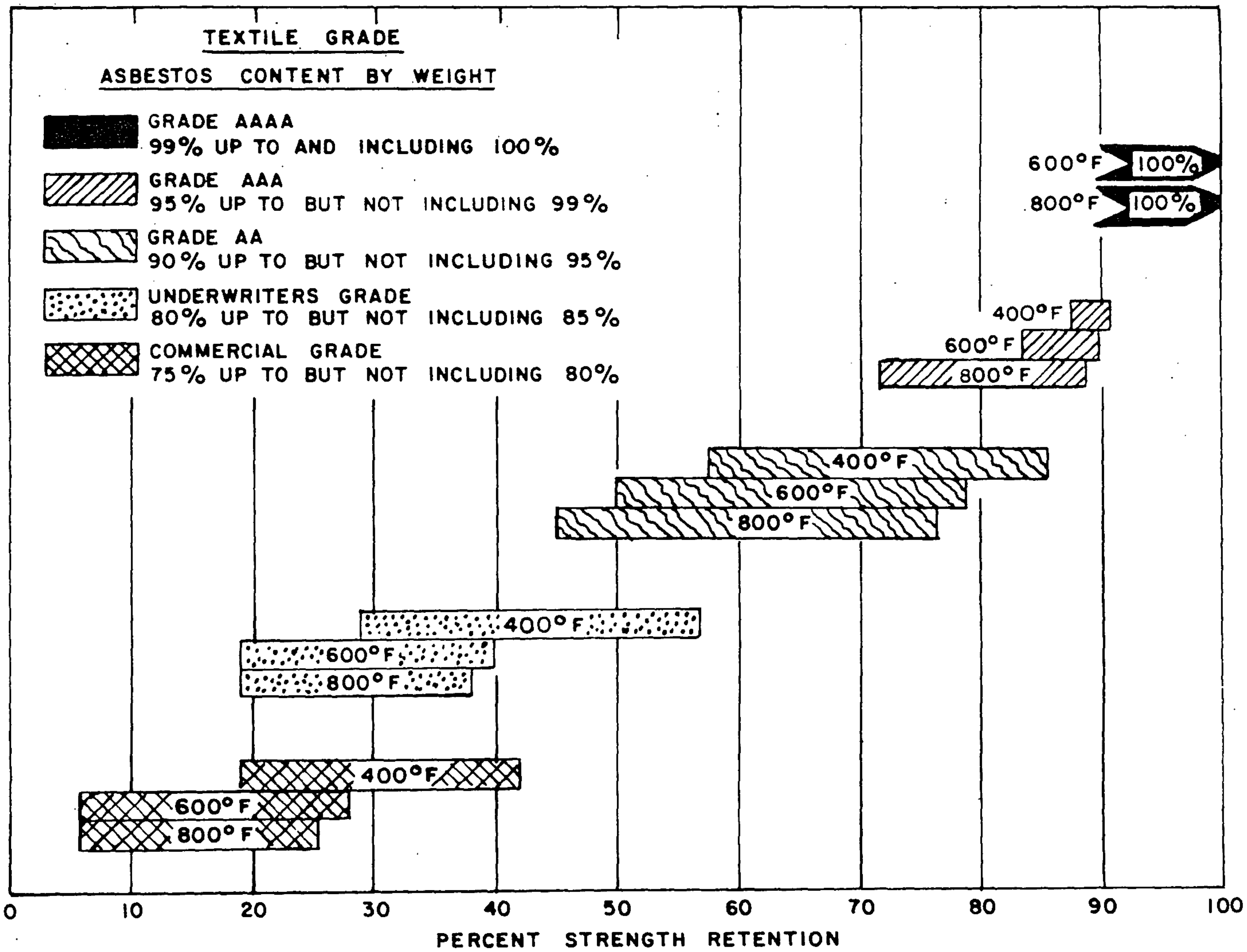


Figure 28. Strength retention of plain (nonmetallic) asbestos textiles after 24-hour exposure to temperatures of 400°, 600°, and 800°F (190; 280; 380°C respectively).[1]

TABLE 58. ASBESTOS AND SUBSTITUTE MATERIAL PROPERTY COMPARISON FOR TEXTILE PRODUCTS

Material (Manufacturer)	Product application	Properties			References
		Temperature resistance^a up to °C (°F)	Tensile strength^b kPa (psi)	Comments	
Asbestos	All applications requiring an incombustible high temperature fabric.	649^c (1200)^c	5.68×10^6 (824,000)	Low thermal conductivity; excellent radiation stability; good flexibility; excellent resistance to moisture and corrosion; excellent spinnability; contains a minimum of magnetic or conductive fibers.	11
Glass	All applications requiring an incombustible high temperature fabric.	538 (1000)	2.17×10^6 (315,000)	Density similar to asbestos; excellent handling characteristics; high dielectric strength; not as durable as asbestos; may produce some skin irritation; fiber diameter 0.066 mm (0.0026 inch).	6,11
Zetex™ (Newtex Industries, Inc.)	Fire-resistant materials; thermal and electrical insulation; packings and gaskets.	1538 (2800)	3.44×10^6 (500,000)	Excellent strength and durability; excellent dielectric strength; dimensional stability; excellent cutting, sewing and handling; abrasion-resistant; fiber size ~9 microns; lower (less than one-half) thermal conductivity than asbestos.	15,16
Ceramics	All applications requiring an incombustible high temperature fabric.	1427 (2600)	high	A high tensile strength silica - alumina fiber; flexible; abrasion-resistant	6
Nextel® 312 (3M Company)	Fire-resistant materials; thermal and electrical insulation, packings and gaskets.	1427 (2600)	1.72×10^6 (250,000)	High strength retention; low shrinkage; abrasion-resistant (after 4 hours at 816°C (1500°F), it retained 100 percent of its strength); good flexibility; some skin irritation; fiber size 10 to 12 microns in diameter.	17,18
Refrasil® (Hitco Materials)	Fire-resistant materials; thermal and electrical insulation; packings and gaskets.	928 (1800)	5.17×10^5 (75,000)	Good acid resistance; good dielectric properties; excellent resistant to thermal shock; high capacity to absorb moisture; lacks abrasion resistance, fiber diameter 8 to 12 microns.	19,20
Organics					
Nomex® (DuPont Co.)	Fire-resistant materials; thermal and electrical insulation packings and gaskets	371 (700)	6.89×10^5 (100,000)	Abrasion-resistant; flexible; radiation-resistant; chemical-resistant; washable; low shrinkage.	6,21,22
Kevlar® (DuPont Co.)	Fire-resistant materials; friction materials; cables.	204 (400)	2.76×10^6 (400,000)	High thermal stability; excellent chemical resistance; excellent cut resistance; low thermal conductivity.	22,23
Teflon® (DuPont Co.)	Fire-resistant materials; thermal and electrical insulation; packings and gaskets.	316 (600)	3.62×10^5 (52,500)	High chemical resistance; low friction and adhesion; low shrinkage; great flex-abrasion resistance; radiation-resistant.	22,23

(continued)

TABLE 58 (continued)

		Properties			
Material (Manufacturer)	Product application	Temperature resistance[a] up to °C (°F)	Tensile strength[b] kPa (psi)	Comments	References
Kynol™ (American Kynol, Inc.)	Fire-resistant materials; packings and gaskets.	704[d] (1300)[d]	1.86×10^5 (27,000)	Low moisture absorption; acid-resistant; low toxic off gases; low shrinkage; is a carbon precursor; low abrasion.	15,24,25
P.B.I.™ (Celanese Plastics and Specialties Co.)	Fire-resistant materials.	500 (932)	2.07×10^6 (300,000)	Polybenzimidazole; nonflammable in air; little or no emittance of toxic off gases; acid-resistant; readily processed on conventional textile equipment; comfortable; good cryogenic characteristics; high moisture regain.	26,27
Fiberfrax® (Carborundum Co.)	Fire-resistant materials; thermal and electrical insulation; packings and gaskets.	1260 (2300)	1.72×10^6 (250,000)	Chemical-resistant; low thermal conductivity; resists oxidation and reduction; excellent resistance to thermal shock.	28,29
Carbon	Fire-resistant materials; packings and gaskets; friction materials.	1427 (2600)	Over 3.10×10^6 (450,000)	High flexibility, lightweight, good retention of fiber properties at high temperatures.	6,30,31
Celion® (Celanese Plastics and Specialties Co.)	Friction materials; packings and gaskets.	5432 (3000) (no oxygen)	3.24×10^6 (470,000)	Flexible, low shrinkage; excellent oxidative stability; excellent adhesion to organics; excellent electrical/thermal conductivity.	30,31
Celiox™ (Celanese Plastics and Specialties Co.)	Fire-resistant materials.	760 (1400)	2.10×10^5 (30,500)	Lightweight, flexible, high moisture regain, low density, readily converted into carbon	30,32
Quartz					
Alphaquartz® (Alpha Associates)	Fire-resistant materials; thermal and electrical insulation; packings and gaskets.	Over 1204 (2200)	8.69×10^5 (126,000)	Thermal stability; elastic; excellent resistance to thermal shock; easily impregnated; excellent abrasive characteristics; high purity; transparency to electromagnetic and radio waves.	33,34,35
Cotton (Westex, Inc.)	Fire-resistant materials.	232 (450)	8.62×10^5 (125,000)	Flame-resistant; is coated and treated; washable; fiber diameter 0.020 to 0.030 mm (0.0008 to 0.0011 inches).	11,36

[a] Temperatures depend upon product application.

[b] Figures are for fibers only, and are not necessarily related to fabric strength.

[c] Wire inserted asbestos textiles.

[d] Carbonizing temperature range.

In addition to providing high heat resistance and fiber strength, these asbestos replacement products offer insulating properties comparable to those of asbestos. A fourth asbestos replacement material, an aromatic polyamide cloth, is widely used in the manufacture of protective clothing, fire blankets, etc. Inorganic asbestos replacements also offer good chemical resistance and resist most attacks from most corrosive agents, with the exception of HF and phosphoric acids and strong alkalies. The aromatic polyamide is resistant to most commonly used solvents.

The competitive ability of a nonasbestos textile material is dependent upon economic considerations as well as technical factors. Substitution is limited to some extent by cost barriers, since only glass fibers are less expensive than asbestos fibers. However, when considering costs, the product life must also be considered because there are some occasions where the substitute products are more applicable for a particular job than an asbestos product--this may result in longer product life, and therefore lower overall costs.

MANUFACTURING

Primary Manufacture

Textile plants may produce more than a dozen different products. Thousands of operations may occur simultaneously as fibers are wound into strands, rewound, spun, twisted, braided, and woven providing numerous sources of fiber dust.

Two basic variations are used in asbestos textile manufacturing: the conventional process and the wet process. Most textiles are made with the conventional process, using either the dry or damp method. The dry and damp methods are identical except that during the damp process the yarn is moistened either by contact with water on a roller or by a mist spray to reduce fiber emissions. Conventional dry process manufacturing produces a small volume of highly specialized yarn without absorbing any water. The newly developed wet process yields a dense yarn by extruding a chemically dispersed slurry into a chemical coagulant. The product tends to hold asbestos fibers better than those produced by the conventional processes, reducing workplace fiber levels but the yarn formed has the disadvantages of poor absorption and impregnation characteristics.[1]

Raw asbestos fibers of various grades are mixed to obtain desired characteristics in the final product. The different asbestos grades received in bags from suppliers are weighed, then manually opened and dumped into blenders with several other raw materials.

The basic steps for the production of asbestos textile material are shown in Figure 29. Asbestos fiber is typically transported in a dry state by railcar or truck and is contained in palletized paper or plastic bags. A recent trend has been towards employing shrunk-wrapped pallets which is now a customer option. At the plant, this material is unloaded either manually or by

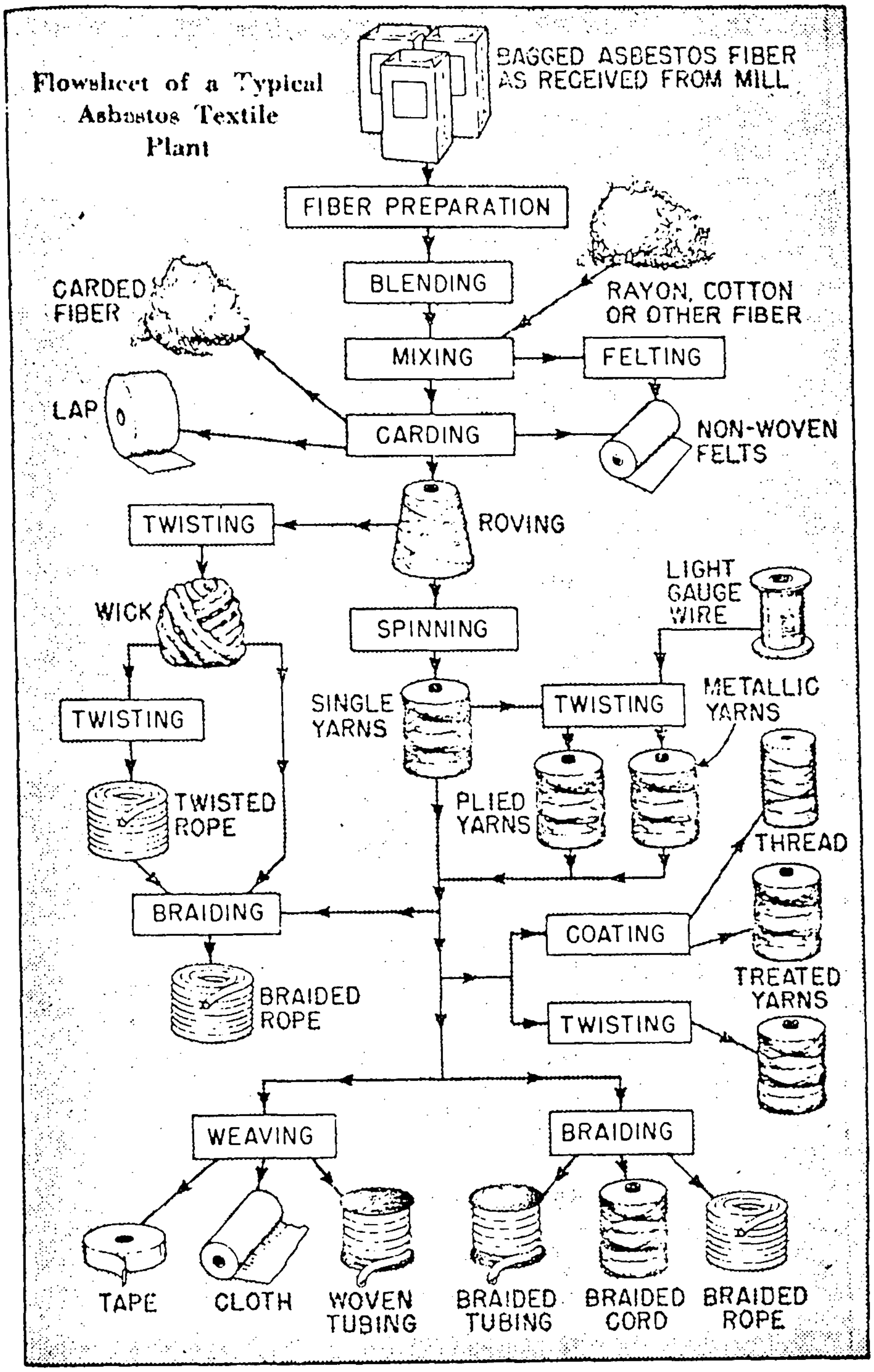


Figure 29. Manufacturing operations for asbestos textiles.[1]

powered fork-lift trucks and transported to a raw-fiber warehouse for intermediate storage. At most facilities housekeeping practices such as tapping broken bags and vacuuming the trucks or railcars prior to unloading are employed.

Raw asbestos fibers of various grades are mixed to obtain desired characteristics in the final product. The different asbestos grades received in bags from suppliers are weighed, then manually opened and dumped into blenders with several other raw materials. The asbestos fibers are often blended with a small portion (10 to 15 percent) of cotton or rayon stable to aid in the processing. The blenders continually mix the ingredients which slowly move to the rear of the machine, go up an incline and drop to the bottom while some of the mix falls into a hopper. The rear of the blender is enclosed and hooded to prevent fiber release. Once the hoppers are filled with blended material they are transferred to the carding operation.[1]

A carding machine combs the fiber mix into a paralleled fiber mat which is mechanically pressed and layered into a lap. At the finishing card, the lap is separated into thin, continuous fiber strips called roving. Cotton, rayon, or some other material may be added at this stage to impart strength or other characteristics. Lap, matting, or roving may be sold to a secondary processor; otherwise, the roving proceeds to spinning frames.

The roving is twisted or spun to a specified number of turns per inch to impart strength. In the damp process, the roving is wet before spinning to reduce asbestos dust but in some cases to retain product quality, the product is not wet.

During spinning and further processing many strands break. The whipping ends flying around spindles must be repaired manually, requiring workers to spend time in a dusty environment.

Spun roving, known as single yarn, may be twisted with other single yarns, wire, or other material to produce plied yarn which can be coated to produce thread or treated yarns. Otherwise, the plied yarn may be woven to produce tapes, cloth or woven tubing, or braided to produce cord, rope, or braided tubing. Spun yarn may also omit twisting and be used directly in woven, braided, or treated products. Asbestos yarn may then be processed at weaving looms, and placed on beams or cruels which feed the loom a large number of strands. Either damp or dry looms may be used.[1]

The wet process differs from the others in that raw asbestos is dumped directly into a slurry tank with water and chemicals. The slurry is extruded into strands that are then spun or otherwise processed similar to other fibers. The wet process completely avoids blending and carding, thus eliminating some sources of asbestos dust. Since wet-processed textiles have characteristics that differ from dry-processed textiles, manufacturers use different production techniques to compensate for altered process ability.

Secondary Manufacture

Primary asbestos textile products are fabricated into consumer end products by secondary processors and distributors. They may cut, sew, impregnate, recoat, mold, prime, and reform the primary products.

Manufacturing Plants

Presently, only three firms are known to be producing primary asbestos textile products. They are listed in Table 59.

TABLE 59. MANUFACTURERS OF ASBESTOS TEXTILES[1]

Company	Location
Raybestos - Manhattan Inc.	North Charleston, NC Marshville, NC
Southern Textiles Corp.[a]	Charlotte, NC
Amatex Corporation	Meredith, NH Norristown, PA

[a] A subsidiary of H. K. Porter Co., Inc., Pittsburgh, PA.

Production Volumes

As stated previously, an estimated 1,900 metric tons of chrysotile asbestos were used to manufacture textile products in 1980.[2] The majority of this total was grade 3 chrysotile. Asbestos used in electrical insulation materials, a subcategory identified separately from textiles by the Bureau of Mines, amounted to 2,900 metric tons in 1980.[2] This asbestos was used mainly in the forms of paper, roving, webbing, and braid where comparatively high temperatures may occur. Production volumes for individual asbestos textiles manufactured are not available.

ASBESTOS RELEASE

Input/Output

Figure 30 shows estimated process disposal and emissions for the asbestos textile industry based on Levine's[40] 1974 estimates projected to 1980 U.S. Bureau of Mines[2] consumption figures. Of the 1,900 metric tons entering the process as raw asbestos fiber, approximately 1,851.9 metric tons are contained in the final product and 48 metric tons are sent to disposal as vacuum cleaner and baghouse dust and product scraps. An estimated 0.3 metric tons escape through a control device (typically a baghouse). Levine's atmospheric emission estimates are based on gross assumptions with a reported uncertainty of at least an order of magnitude. Meylan[1] reports emissions of 1 to 3 orders of magnitude less. Atmospheric emissions from disposal based on GCA estimates, are shown to be 0.1 metric tons. This estimate is loosely based on Levine's

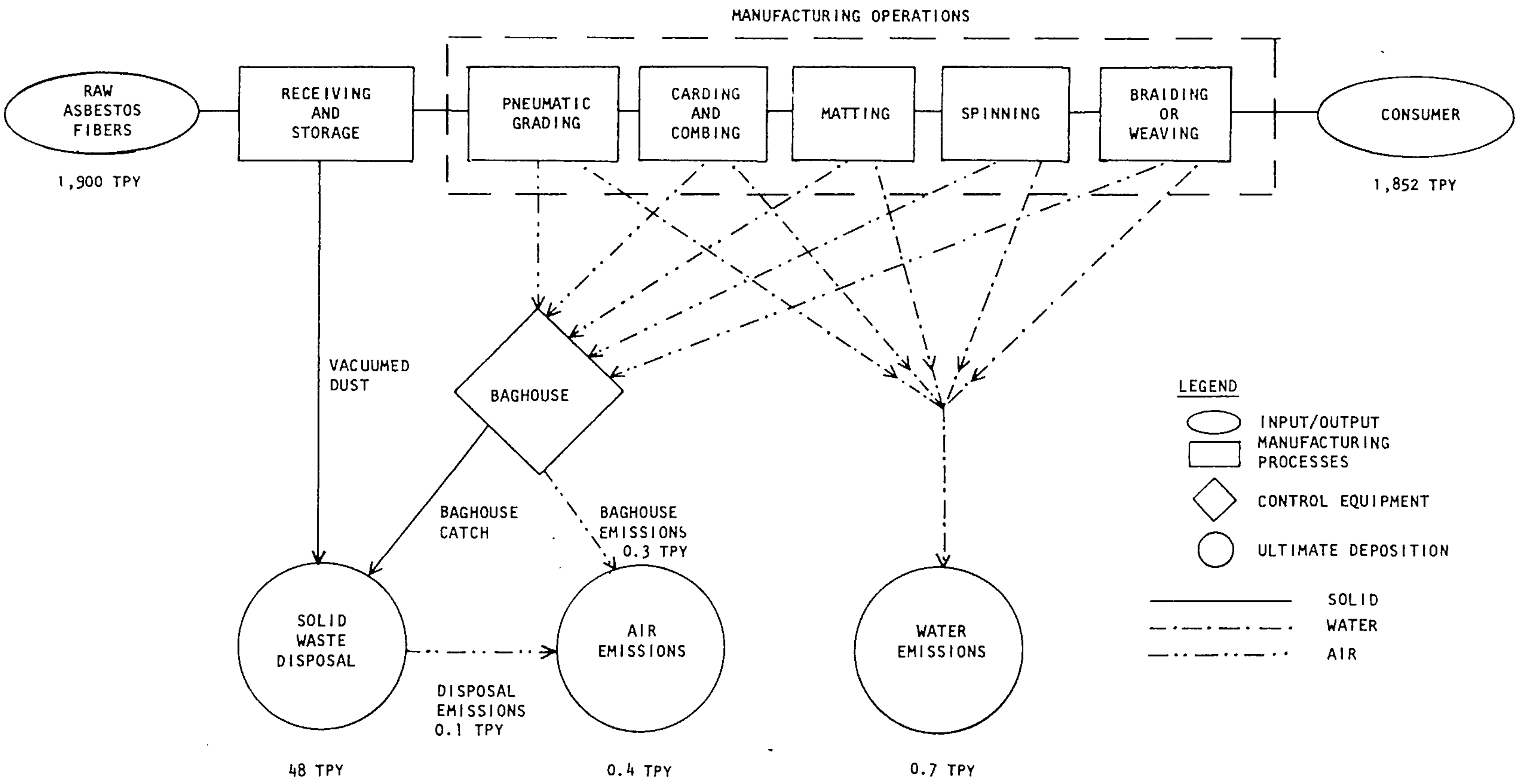


Figure 30. Process and disposal emissions (in metric tons/year) for asbestos textiles.[15]

data, and takes into account the Asbestos NESHAP's regulations amended in 1975 regarding the disposal of asbestos. An estimated 0.7 metric tons of asbestos are discharged in process wastewater.

During Manufacture

Workplace Exposure--

High fiber counts, relative to other asbestos processing industries, have been traditionally encountered throughout the asbestos textile industry. Dry processing plants have a potential to generate severe exposure problems since no phase of the process uses wetting to reduce dust. Table 60 shows the time-weighted exposure levels at different points in the textile production process.[7] As shown in this table, worker exposure levels can approach 15 fibers/cc. These high fiber levels can be substantially reduced by employing effective control measures such as well-designed ventilating equipment. Raybestos-Manhattan, a major manufacturer of asbestos textiles, implemented an extensive dust control plan (from 1975 through 1977) which dramatically decreased high fiber levels to below 1 fiber/cc.[41] This dust control plan, described below, exemplifies fiber control options available to the asbestos textile industry.

TABLE 60. TIME-WEIGHTED AVERAGE FIBER COUNTS[a] - ASBESTOS TEXTILES[7]

Process step	Fiber Count (fibers/cc)			
	Typical	Damp	Dry	Wet
Receiving and storage	1.0	0.25-2.5	0.25-2.5	0.25-2.5
Fiber introduction	4.0	2.0-10.00	2.0-10.00	2.0-8.0
Mixing and blending	4.0	N/A	2.0-10.00	N/A
Carding	4.0	N/A	2.0-10.00	N/A
Spinning	4.0	2.0-10.00	2.0-15.00	2.0
Twisting	4.0	4.0-10.00	N.A.	2.0
Weaving	3.0	1.0-4.0	N.A.	1.0
Braiding	3.0	2.0-5.0	N.A.	1.0

[a] NIOSH fibers 5 μm or longer counted using optical microscopy.

N/A = Not applicable
N.A. = Data not available

Based on plants representing 96 percent of asbestos textile production.

The Raybestos-Manhattan Marshville plant, prior to implementation of the Dust Control Plan, was an antiquated plant with high fiber levels associated with most of the processes. To reduce dust levels, which were barely below 12 f/cc, the following strategies were developed:

- Eliminate all manual handling of raw asbestos fiber by use of a closed system where possible.
- Reduce dust generation by effective exhausting or wetting where possible.
- Upgrade and expand existing building, simplify vacuum cleaning by having smooth walls and avoid ledges and surfaces that catch and retain dust.
- By design, provide for a safe, clean method of waste collection and reuse and/or removal.

Greatly improved particulate capture and dust control was achieved by the installation of extensive engineering controls that included a baghouse, enclosed hooding, and a well-designed ventilation network. Raybestos-Manhattan also adopted specific work practices and administrative procedures. The work practices established focused on improved maintenance, waste handling, baghouse operating, and housekeeping procedures. Administrative action included requiring protective equipment be worn, enforcing disciplining actions, assigning clean-up personnel to complement engineering controls, establishing employee education programs and instituting a dust monitoring program. The action plan to implement the dust control strategy required 2 years for completion after which fiber counts were reduced to less than 1 f/cc and at the same time increased the plant capacity considerably.[41]

Emissions to Air

Asbestos fiber release to the ambient air results principally from control equipment air exhaust. Since baghouses are almost universally employed to control fiber emissions, collection efficiencies are relatively high (99.9 percent). Providing the baghouses are well maintained and malfunctions and spills are minimized, emissions from control equipment exhaust is expected to be low.

A manufacturer of commercial grade asbestos textiles using the dry process, recently reported that much of the asbestos entering the process does not leave in final products.[41] For products containing 75 to 80 percent asbestos, it was estimated that about 10 to 15 percent of the input is lost in carding, 2 to 3 percent lost in twisting and an additional 2 to 3 percent lost in cording. This results in an average total manufacturing loss of 17.5 percent. By providing proper aspiration to control equipment, facilities are able to capture most of the loss in baghouses and recycle it. However, at a facility producing asbestos products other than textiles alone, the fiber is sent to other production units. It was found that relatively short fibers were released during textile manufacturing and if collected and recycled into the same process only wound up being released again. By sending the short fibers released from the textile process into a process like papermaking, where all fibers are short, overall emissions are reduced.

Assuming 0.0175 percent of the asbestos entering the processes is emitted to the ambient air through control equipment, (99.9 percent control) total fiber emissions to the ambient air from all asbestos textile manufacturing is calculated to be 0.03 metric tons, based on 1980 production figures. This estimation is very rough and requires verification by actual sampling of baghouse exhaust.

Fiber emissions to the ambient air from wet processing are considered to be minimal. Because of the high moisture content of the strands formed, wet processing completely eliminates dust generated in blending and carding since these steps are eliminated. Fiber is introduced directly into a slurry and underwater extrusion is used to produce strands. The amount of asbestos emitted to the atmosphere from textile operations is estimated to be less than 0.1 ton per year.

Actual measurements of the asbestos fiber concentration in the vicinity of an asbestos textile plant are very limited. However, Suta and Levine[42] estimated concentrations near industrial facilities using mathematically derived dispersion curves of assumed plant emissions. In the case of asbestos textiles, it was estimated that a population within 5 km of a manufacturing plant would be exposed to a median atmospheric asbestos concentration of 21.0 and 1.3 ng/m^3 for urban and rural facilities, respectively. Comparing this data with the median U.S. atmospheric asbestos fiber concentration (20 ng/m^3), it appears that asbestos textile manufacturing contributes little to nonoccupational exposure. However, actual ambient monitoring in the vicinity of an asbestos textile facility is necessary to confirm Suta and Levine's estimates.

Release to Land--

Solid waste from asbestos textiles arises from scraps produced in manufacture and from dust collected in baghouses treating vented air. Some scraps can be recycled to fabrication, but the total solid waste produced in cutting, trimming, and sizing may range from 1 to 2 percent or from 50 to 100 tons per year.[6] This agrees with estimates by Levine[40] of 48 metric tons when Levine's 1974 estimates are projected to 1980 U.S. Bureau of Mines[2] consumption figures.

Release to Water--

Dry textile production processes have no significant wastewater effluent streams. A small amount of water is generally used to wet yarns to reduce dust in the weaving process. However, the amount of water used is minimal and is evaporated.

Even in the wet process the amount of water to be disposed of is small and is generally discharged to city sewers. Projecting Levine's[40] estimates to 1980 consumption figures, it is estimated that 0.7 metric tons is lost to the water. GCA estimates that this figure represents a high end since it very likely includes asbestos captured by wet scrubbers used to control dust emissions. Wet scrubbers have typically been replaced with baghouses.

During Use

Textile products may be cut, torn, stitched, or stapled during installation or use. Measurements of ambient fiber levels have been made aboard ship in a British shipyard during application and stitching asbestos cloth. Measured values ranged from 0.05 to 0.26 fibers per cc.[43] A later study conducted by the same researcher revealed fiber counts of up to 43 fibers per cc while tearing and applying untreated cloth.[44] In the same study, tearing of asbestos-containing cloth produced fiber counts of less than 0.1 fibers per cc.[44] These study results, however, are somewhat suspect since the cloth was being applied over molded asbestos insulation. It is certain that some fibers emitted from the insulation contributed to the fiber count, but there is no way to estimate the extent of this contribution.[45]

One asbestos textile manufacturer reported low ambient fiber levels, 0.01 to 0.05 fibers per cc, during cutting of untreated lagging cloth and lower counts, 0.0 to 0.04 fibers per cc during application.[45] Almost all asbestos textiles produced in the United States are coated or impregnated to inhibit fiber release. On the basis of these data it seems reasonable to estimate that the use of asbestos textiles will not produce exposure levels above 0.01 fibers per cc.[45]

During Disposal

Textile products generally have short life applications, and are disposed of as worn out scrap in waste dumps. Nearly all textile materials are coated or impregnated to suppress dust, so release to the environment should be minor. It has been estimated that about 7,400 m.t. per year are scrapped and sent to landfills or other waste dumps.[1] The amount disposed of annually may be higher than the amount being produced simply due to the backlog of asbestos produced earlier and still in use. With time, disposal volumes will stabilize near the current production level.

CONCLUSION

The Bureau of Mines has projected a zero demand for asbestos in textiles by the year 2000.[2] This projection is based in part on the fact that there are a number of viable substitutes for asbestos textile materials that are well suited to replace asbestos in nearly every application. These include: Fiberglass, Kevlar, Nomex, Teflon, Refrasil, Siltemp, Norfab, Durette, Nextel, Kynol, Celiox, Celion, Zetex, and Fiberfrax. In addition, other products are still in developmental stages. Many of these substitutes have better property advantages for textile applications than asbestos. Although more costly in most cases, these alternatives are already on the marketplace, providing a nonasbestos choice for consumers. As in the other categories mentioned, where viable substitutes exist, the choice of substitutes involves consumer education and acceptance of a changeover from the established product. As there are some occasions where the substitute products are more applicable for a particular job, their use may result in longer product life, leading to lower overall cost and public acceptance. The small number of asbestos textile applications for which no satisfactory alternative exists at present includes lamp and stove wicks, wipes for molten metal, diaphragms for some of the electrolytic cells and some filter cloths.[10]

In the future, the market for nonasbestos, fire-resistant materials will undoubtedly improve. The performance of high temperature application substitute materials such as fiberglass and ceramics has proven that these materials not only compare with, but often exceed the performance characteristics of asbestos. With the substitute materials currently on the market, and assuming new developments of asbestos replacement products in the future, asbestos consumption in fire-resistant materials will drop significantly. Sales of asbestos insulation products have already shown this drop in their drastic decrease in sales over the past few years.

In summary, it is anticipated that the consumption of asbestos in textiles will continue to decline as only those applications where asbestos cannot be replaced economically continue to use asbestos.

REFERENCES

1. Meylan, W. M., et al. Chemical Market Input/Output Analysis of Selected Chemical Substances to Assess Sources of Environmental Contamination: Task III - Asbestos. EPA-560/6-78-005. August 1978.

2. Clifton, R. A. Asbestos. 1980 Mineral Yearbook. U.S. Bureau of Mines, Washington, D.C.

3. Clifton, R. A. Asbestos. 1978-1979 Mineral Yearbook. U.S. Bureau of Mines, Washington, D.C.

4. Davis, W. E. and Associates. National Inventory of Sources and Emissions: Asbestos - 1968. U.S. Environmental Protection Agency. February 1970.

5. Arthur D. Little, Inc. Impact of Proposed OSHA Standard for Asbestos - First Report to the United States Department of Labor. OSHA. April 28, 1972.

6. Sores, Inc. and Arthur D. Little, Inc. Characterization of the U.S. Textile Markets. Ministere De L'Industrie Et Du Commerce, Government du Quebec. Final Draft Report. May 1976.

7. Weston, Roy F. Environmental Consultants. Technological Feasibility and Economic Impact of OSHA Proposed Revision to the Asbestos Standard (construction excluded). Asbestos Information Association/North America. March 26, 1976.

8. Gregg, R. T. Development Document of Effluent Limitations Guidelines and New Source Performance Standards for the Textile, Friction Materials and Sealing Devices Segment of the Asbestos Manufacturing Point Source Category. U.S. National Technical Information Service, PB-240-860. December 1974.

9. Sullivan, R. J., and Athanassindis, Yanis. Preliminary Air Pollution Survey of Asbestos, A Literature Review, U.S. Department of Health, Education, and Welfare. October 1969.

10, Handbook of Asbestos Textiles. American Textile Institute. 3rd Edition. 1967.

11. Clifton, R. A. Asbestos 1978. U.S. Department of the Interior, Bureau of Mines, Washington, D.C. August 1979.

12. Michaels, L., and S. S. Chissizk, ed. Asbestos: Properties, Applications, and Hazards. Volume 1. John Wiley and Sons, 1979, pp. 305-367.

13. Bradfield, R. E. N. Asbestos: Review of Uses, Health Effects, Measurement and Control. Atkins Research and Development, Epsom Surrey, England. January 1977.

14. Manfer, S. G. The Carborundum Co., Niagara Falls, N.Y. Speech given at U.S. EPA/CPSC "Substitutes to Asbestos" Conference, Arlington, Va. July 14-16, 1980.

15. Telecon. Dixit, B., President, Newtex Industries, Inc., Victor, N.Y., (716) 924-9135, with T. Henderson, GCA/Technology Division, January 30, 1980. Notebook No. 07, Phone call No. 11.

16. Newtex Industries Inc. Zetex™ Bulletin. Victor, N.Y. 1979.

17. Telecon. Ellingson, L. Sales Representative, Ceramic Fiber Products/ 3M Company, St. Paul. Minn. (612) 733-1558, with T. Henderson, GCA/ Technology Division, January 31, 1980. Notebook No. 07, Phone call No. 18.

18. Ceramic Fiber Products, 3M Company. Nextel® 312 Ceramic Fiber Products. N-MTDS (79.5) MP. and N-MPBBS-(89.5) 11. St. Paul, Minn.

19. Telecon. Black, M., Sales Representative, Hitco Materials Division, Gardena, Calif., (213) 321-8080, with T. Henderson, GCA/Technology Division, January 30, 1980, Notebook No. 07, Phone call No. 11.

20. Hitco Materials Div. Refrasil Product Data Bulletins. P.O. LHT/MD-1779 15 M CP and LHT/MD-275 6M CP. Gardena, Calif. November 1979. p. 1-2.

21. E. I. DuPont de Nemours & Co., Inc. DuPont Technical Information Bulletin. N-236. Wilmington, Del. October 1969. p. 1-12.

22. Telecon. Chiostergi, R. Marketing Manager, E. I. DuPont de Nemours & Co., Inc. Wilmington, Del., (302) 999-3951, with T. Henderson, GCA/Technology Division, February 1, 1980. Notebook No. 07, Phone call No. 20.

23. E. I. DuPont Nemours & Co., Inc. Characteristics and Uses of Kevlar® 29 Aramid. N-375. Wilmington, Del. September 1976. p. 1-7.

24. American Kynol, Inc. Kynol™ novoloid Bulletin. A-10, 003. New York, N.Y. October 1974. p. 1-11.

25. Telecon. Storti, M., Marketing Manager, American Kynol Inc., New York, N.Y., (212) 279-2858, with T. Henderson, GCA/Technology Division. February 1, 1980. Notebook No. 07, Phone call No. 23.

26. Celanese Corp. PBI™, Polybenzimidazole Fiber. Charlotte, N.C. February 1979. p. 2.

27. Telecon. McCallister, K. C., Marketing Manager, Celanese Corporation, Charlotte, N.C., (704) 554-2000, with T. Henderson, GCA/Technology Division, February 1, 1980. Notebook No. 07, Phone call No. 22.

28. Telecon. Pietak, K., Textile Specialist, The Carborundum Company, Niagara Falls, N.Y. (716) 278-2000, with T. Henderson, GCA/Technology Division. January 30, 1980, Notebook No. 07, Phone call No. 08.

29. The Carborundum Company. Fiberfrax® Product Bulletins. C736-A-G. Niagara Falls, N.Y. p. 1-10.

30. Telecon. Timmons, B., Marketing Supervisor, Celanese Plastics and Specialties, Chatham, N.J., (201) 635-2600, with T. Henderson, GCA/Technology Division, January 28, 1980. Notebook No. 07, Phone call No. 05.

31. Celanese Plastics and Specialties Co. Celion® Carbon Filters Bulletins. Chatham, N.J. November 1979.

32. Celanese Plastics and Specialties Co. Celiox™ Fibers Bulletin. Chatham, N.J. November 1979.

33. Telecon. Saffadi, R., President, Alpha Associates, Woodbridge, N.J., (201) 634-5700, with T. Henderson, GCA/Technology Division, January 31, 1980. Notebook No. 07, Phone call No. 11.

34. Alpha Associates Inc. Alpha Quartz® Bulletins. Data Sheet Nos. 11690-11693. Woodbridge, N.J. May 1979.

35. Lubin, G. High Silica and Quartz. In: Handbook of Fiberglass and Advanced Plastics Composites. Reinhold Book Corporation. 1969. p. 191-200.

36. Telecon. Wilander, R., Sales Manager, Westex Inc., Chicago, Ill., (312) 523-6351, with T. Henderson, GCA/Technology Division, January 30, 1980. Notebook No. 07, Phone call No. 10.

37. Pye, A. M. A Review of Asbestos Substitute Materials in Industrial Applications. Journal of Hazardous Materials. 3:125-147. 1979.

38. Garlock Inc., Thermo-Ceram™. LX7/79-11m. Palmyra, N.Y.

39. Margolin, S. V., and B. U. M. Igeve. Economic Analysis of Effluent Guidelines: The Textile, Friction and Sealing Materials Segment of the Asbestos Manufacturing Industry. U.S. National Tech. Inform. Service, PB-250-682. 1975.

40. Levine, R., ed. Asbestos. An Information Resource. May 1978.

41. Lewinsohn, H. C., et al. Dust Control in a Conventional Asbestos Textile Factory, Annal. New York Academy of Sciences, 1979.

42. Suta, B. E., and R. J. Levine. Nonoccupational Asbestos Emissions and Exposures. Asbestos-Properties, Applications and Hazards. Volume 1. John Wiley and Sons, New York, N.Y. 1979.

43. Harries, P. G. Asbestos Hazards in Naval Dockyards. Annals of Occupational Hygiene. Vol. 11, pp. 135-145. 1968.

44. Harries, P. G. Asbestos Dust Concentrations in Ship Repairing: A Practical Approach to Improving Asbestos Hygiene in Naval Dockyards. Annals of Occupational Hygiene, Vol. 14, pp. 241-254. 1974.

45. Wright, M. D., et al. Asbestos Dust Technological Feasibility Assessment and Economic Impact Analysis of the Proposed Federal Occupational Standard: Part I. U.S. Department of Labor. OSHA. September 1978. (Draft).

SECTION 13

MISCELLANEOUS ASBESTOS USES

INTRODUCTION

In this section, the various users of asbestos fibers that do not fit into the other nine industry segments defined by the EPA are discussed. These miscellaneous products which have been used in the past or currently use asbestos are:

- drilling muds
- shot gun shell base wads
- asphalt/asbestos cement
- foundry sands
- sprayed on insulation
- artificial snows

Of the above products, only drilling muds currently contain asbestos. The other products, affected by Consumer Product Safety Commission bans or OSHA and EPA regulatory programs, have completely discontinued asbestos use. By discontinuing asbestos use in all but drilling muds, the total asbestos fiber consumption of this miscellaneous class has been substantially reduced from its 1976 usage rate of 58,000[1] metric tons to a 1980 usage rate of 10,400 metric tons.[2] Miscellaneous use of asbestos in 1980 accounted for 2.9 percent of total asbestos use.

DRILLING MUDS

Product Summary

Drilling muds, also called drilling fluids, are used when wells are drilled by the rotary method. This method involves a drill bit which is turned by a drill pipe extending down to the bit from the surface of the ground. The machinery for rotating the pipe is located at the ground surface. The drilling mud is pumped down through the drill pipe and the drill bit and then returns through the annulus between the drill pipe and the well bore hole.[3] As the fast-moving drilling mud passes through the bit and back up to the annulus, it cools and lubricates the bit and picks up the drilled cuttings, carrying them to the surface. The bottom of the hole is thus left clean for the drill bit. At the surface, the drilling mud passes through screening equipment which removes the chips of rocks ground away by the drill bit. The mud is replenished with new additives and is recirculated through the drill pipe to the drill bit. The process is repeated until the desired depth is attained.[4]

Drilling muds typically contain anywhere from three to twelve different additives out of over 150 minerals and chemicals which are appropriate for drilling mud applications. When drilling begins, mud additives are dumped into a hopper where they are blended with water. The mixture then goes to a tank near the well and is pumped from this tank through the drilling system.[4]

Asbestos is used in drilling muds to increase the carrying capacity of the mud (the ability of the mud to bring up cuttings) without significantly increasing the mud viscosity. This is a useful property since it is easier to pump a less viscous fluid which results in more power available at the bit and a faster drilling rate. Additionally, asbestos acts as a loss-circulation material; that is a material added to drilling mud to plug all passages, cracks, and cavities in the drill hole to prevent the loss of the drilling mud.[5] Asbestos has the dual ability of increasing the carrying capacity of drilling muds while at the same time acting as a loss-circulation material at relatively low costs.

In the field, asbestos is added to the drilling fluids through a mud hopper or large funnel. Asbestos is used in concentrations normally ranging from 2 to 5 pounds per barrel [1 barrel = 159 liters (42 gallons)] of mud.[6] However, values as low as 0.5 pounds per barrel and as high as 20 pounds per barrel have also been reported depending upon the desired characteristics of the drilling mud. Initially, a volume of drilling mud ranging from 150-200 barrels is prepared and as drilling progresses, more drilling mud is prepared. Under typical conditions, the drilling mud is prepared once every eight-hour shift. The amount of asbestos added each time is normally less than 230 kilograms (500 pounds).[6]

The choice of whether or not to use asbestos in a drilling mud is a function of the individual well site and depends upon the specific job, soil characteristics, materials being drilled for, and cost effectiveness.

Substitutes

Asbestos serves a dual function in drilling muds. It increases the carrying capacity (acting as a viscosifier) and also acts as a loss-circulation material. No single substitute, except perhaps bentonite or attapulgite clays, serve both functions, but a variety of substitutes can be used as viscosifiers and a large number of additional materials can be used as loss-circulation materials at a competitive cost to asbestos. These materials are both added to the drilling mud to serve the functions that asbestos would perform. Loss-circulation material substitutes can be used to obtain similar results to that seen with asbestos fiber. With viscosifiers, each substitute product may have a specific application and must be chosen according to the requirements at the drilling site. Asbestos has a universal application as a viscosifier, whereas substitute viscosifiers must be chosen for the specific application.

The temperature of circulating drilling mud in oil wells is normally 52°C to 60°C with a maximum temperature at the bottom of the hole of 149°C and sometimes as high as 204°C. Asbestos can be used at temperatures over 316°C before it breaks down.[7] Polymers can generally be used at temperatures of up to 148°C, although new copolymers have been demonstrated at temperatures of 260°C to over 371°C.[4] The bentonite, attapulgite, and other clays cannot withstand temperatures as high as asbestos, but can normally be used in most drilling applications from up to 177°C to 204°C. Bentonite is the most widely used viscosifier for fresh water drilling systems and attapulgite is the most common viscosifier for salt water drilling systems.[8]

Asbestos performance degrades readily from mechanical shear forces. Xanthan gum polymer can be subjected to high mechanical shear without degradation.[9] Clays, such as attapulgite, have the advantage of actually increasing viscosity at higher shear forces.[10]

Manufacturing Summary

Manufacturing Process--

One manufacturer of asbestos used in drilling muds (Johns-Manville) processes the asbestos in the following manner. The asbestos is extruded, highly moisturized (12-15 percent) and then pelletized, thus binding the fibers together. The manufacturer claims that this process produces an asbestos product with negligible fiber release when it is used to make drilling muds.[11]

Name and Number of Manufacturers--

The asbestos product described above is sold under the tradename of FLOSAL® and marketed by Drilling Specialties in Bartlesville, OK.[12] Approximately 1.6 million kilograms (3.5 million pounds) per year of FLOSAL are made and marketed in the United States. The other American manufacturer of an asbestos product for use in drilling muds is Union Carbide Corporation. This product is marketed by Montello Company of Tulsa, OK under the tradename Super Visbestos® and is advertized as being sheared, wet-refined, pelletized, chrysotile asbestos.[13] Information about annual product rates was given for Super Visbestos, but upon further consideration, the Montello Company considered this information to be proprietary and it is not listed in this report. The Johns-Manville Company mines their asbestos in Canada and the asbestos used by Union Carbide is mined in California.[11]

Production Volumes--

Approximately 9900 metric tons (10,000 tons) of asbestos fiber were used in drilling fluids in 1978.[14,15] Current production is estimated to be 4900 metric tons (5000 tons) annually.[6] The shorter grades of chrysotile fiber are normally used in either pelletized or loose fiber form.[16] Because the two American manufacturers both produce a pelletized form of asbestos for drilling muds, the loose fiber form is assumed to come from non-American manufacturers.

ASBESTOS RELEASE

Input/Output

During Manufacture

Workplace Exposure--

Worker exposure data, specific to the manufacture of pelletized asbestos for use in drilling muds, is not available. The generation of free fibers from shipping, receiving, pouring and mixing is likely to be in the same concentration range as similar operations in the previously discussed nine product categories. Fiber release from extruding and pelletizing are expected to be minimal since the product is highly moisturized (12 to 15 percent).[17]

At drilling site, typically an amount of asbestos less than 500 pounds is introduced for mud production once every 8 hours during drilling. The drilling workers are exposed to free fibers when bags of asbestos are opened, emptied, and handled for disposal. The fiber counts are dependent on many factors including the fiber form (pellets or loose) and atmospheric conditions. Daly et al.,[16] have reported the time-weighted average fiber count at the mud pit as 0.4 fibers/cc with a maximum ceiling level of 1.9 fibers/cc. The low level is probably achieved when pelletized asbestos is used.

Release to Land--

When drilling operations have been completed, the mud is usually dumped or left in the mud pit and covered with dirt. The asbestos is encased and, therefore, free fibers would not be expected. It is not known how empty raw asbestos containers such as bags are discarded. More than likely they are disposed of with other trash in a conventional manner.

Release to Water--

Asbestos fibers are very likely leached out of disposed drilling muds which are usually dumped or left in the mud pit. Since there has been no actual monitoring to determine the asbestos concentration in the leachate from a drilling operation, it is not possible to quantify releases to water. In addition, the fiber release rate would depend heavily on the drainage characteristics of the dump site or mud pit.

During Use

The frequent moving from site to site makes fixed air pollution control equipment unfeasible. Therefore, when asbestos is added to the drilling mud, an undetermined quantity of fibers become airborne, dependent upon weather conditions and the form of asbestos used (pelletized asbestos creates less emissions). Once the fibers are incorporated into the mud, however, airborne releases are unlikely to occur. The free-fiber releases will probably settle on the ground or be washed by rain from the air and eventually become stabilized in ground or river sediments. It should be noted that most drilling sites are located remote from population centers. Meylan, et al.,[14] have estimated that perhaps 0.5 percent of the asbestos consumption for drilling fluids is lost to the air during onsite mixing. Since 4900 metric tons are consumed annually, 24.5 metric tons of fibers would become airborne. This is higher than process and disposal emission estimates arrived at for the entire miscellaneous products category using Levine's[31] assumptions. Combining Levine's 1974 estimates with 1980 asbestos consumption data, an estimate of 5.2 tons per year for process emissions and 0.5 tons per year for disposal emissions can be calculated. For consistency with the other chapters, these estimates will be used for the entire miscellaneous products category. The use of pelletized asbestos by the entire industry would significantly reduce the amount of asbestos released to the air.

Conclusion

The use of asbestos in drilling muds has been decreasing due to concern for worker's health and standards promulgated by the Occupational Safety and Health Administration concerning airborne asbestos. In instances where asbestos is used, asbestos in pellet form, as opposed to fiber form, should be employed to decrease fiber release to the air. The ultimate disposal of asbestos containing drilling muds is in the mud pit which is covered with dirt.

Adequate substitutes are available to replace both functions of asbestos in drilling muds, i.e., to provide carrying capacity (viscosifier) and to act as a loss-circulation material. A large number of substitutes exist for loss-circulation material at a competitive cost. The substitute materials which are viscosifiers are the bentonite, attapulgite, and sepiolite clays and a variety of polymers. The clays are competitive with asbestos in cost. The polymers are more expensive than asbestos, but less material is necessary to make up the drilling mud resulting in a cost per barrel figure that is still more expensive, but nevertheless competitive. The use of asbestos in drilling muds is not mandatory and probably not even necessary in most applications as adequate substitutes exist at a competitive cost.

SHOTGUN SHELL BASE WADS

Asbestos has been used to manufacture base wads for shotgun shells. Base wads are formed from a mixture of about 36 percent by weight of asbestos, 54 percent wood flour and 10 percent wax which is pressed to form the required shape.[18]

Only one shotgun shell manufacturing plant (operated by Remington Arms Company in Bridgeport, CT) is known to use asbestos. However, the manufacturer is currently phasing out asbestos in shotgun shell base wads. The asbestos-containing shells are being replaced with a one piece polyethylene shell which is a more stable shell in addition to being less costly. The Remington Arms Company recently reported that they will have converted 95 percent of the asbestos-containing shotgun shells to one piece asbestos-free shells by the end of the year 1980. The remaining 5 percent will be converted to asbestos-free shells by the end of the year 1981.[18]

The major source of emissions from manufacturing occurs during handling and introduction of the raw material. Processing areas are typically vented to fabric filters. The material collected in the baghouse is recycled. Fiber release in process water and product scrap wastes are judged to be minor. Also, fiber emissions probably occur when the shotgun shell is fired from a gun but there is presently no means of determining the amount of fibers that become airborne as opposed to those that remain encased in the wad mixture.[14]

ASPHALT/ASBESTOS CEMENT

Asphaltic cement consists of aggregates cemented together with ordinary paving grades of asphalt such as AC-10 and AC-20.[19] The idea behind adding asbestos to asphaltic cement was to increase the amount of asphalt that could be put into the mix, which would increase the strength of the material and increase the life of the pavement.[20] While there is some indication that asbestos might improve the quality of asphalt cement, the prevailing opinion appears to be that if there is actually anything to be gained by adding asbestos, it isn't enough to make it worthwhile. A spokesman for the National Asphalt Paving Association said that there was evidence that asbestos might actually be an agent contributing to cracking.[19] In a recent survey, individuals associated with asphaltic cement manufacture and use were not aware of any intentional use of asbestos in asphalt paving in the United States.[21] The only place where asphalt/asbestos cement is known to be used in North America is Canada.

FOUNDRY SANDS

Foundry sands are used to make expendable molds for metal castings. The sand is used with a bonding agent to give the mold the necessary strength required for castings. The mold is filled with metal through a system of channels called runners or gates. In addition, there is a system of risers which ensure that the mold is properly filled and compensated for shrinkage.

Asbestos is an undesirable material in foundry sands since it lowers the refractory point of the sand mold. For this reason, asbestos is not used in foundry sands for making molds for the production of castings.[22] Personnel from the American Foundryman's Society as well as suppliers of foundry sands and asbestos stated that asbestos is not used in foundry sands at this date.[23-26]

Asbestos has been used in the past as a filler in the formulation for the manufacturing of insulating sleeves for risers on castings. However, as a result of Occupational Safety and Health Administration (OSHA) standards for airborne asbestos in the workplace, asbestos use for insulating sleeves or risers has ceased.[22,23]

Substitute materials for asbestos fibers used in insulating sleeves on risers for castings include any inert mineral material that can: (a) withstand high heat, (b) insulate, and (3) does not crystalize with water at high temperatures. The materials used to manufacture the insulating sleeves for risers on castings are proprietary but include such mineral compounds as vermiculite, perlite, and diatomaceous earth.[22]

SPRAYED-ON INSULATION

The use of asbestos in sprayed-on insulation was regulated in 1973 by the National Emission Standard for Asbestos (40 CFR 61) promulgated by the U.S. Environmental Protection Agency. This standard limits the amount of asbestos in spray-on materials used to insulate or fireproof buildings, structures, pipes, and conduits to less than one percent asbestos on a dry weight basis. This standard effectively eliminated the use of asbestos as sprayed-on insulation. The one percent limitation prevents the use of asbestos while allowing the use of other materials in which asbestos is a trace contaminant. In 1978, the standard was revised to limit the use of sprayed-on asbestos for decorative purposes to materials containing less than 1 percent asbestos.

Prior to 1973, it had been common practice to coat pipes, ducts, boilers, tanks, reactors, turbines, furnaces, and structural members with sprayed-on asbestos materials.[27,28] At present, however, the major source of asbestos fiber emissions is during demolition of existing structures and manufacturing equipment. The National Emission Standard for Asbestos requires removal of asbestos insulation before demolition with adequate wetting of all exposed asbestos during the removal process.

It has been estimated that about 450,000 metric tons of installed asbestos insulation may be in place.[29] Wear and release of asbestos fibers from installed insulation were calculated at a rate of 0.05 percent per year of total installed tonnage. The release of fibers into the building atmosphere has been found to be greatest from contact such as maintenance and reentrainment during custodial activities such as heavy dry dusting, sweeping and vacuuming. Asbestos emissions from these and other situations are compared in Table 61. Comparison of the optical microscope measurements in this table suggest that high optical microscope counts relative to the fiber concentrations on a weight basis may be largely due to the presence of nonasbestos fibers. More extensive measurements are needed to characterize the collected fibers and to determine the extent of this asbestos exposure risk.

ARTIFICIAL FIREPLACE ASHES AND ARTIFICIAL SNOWS

Between 1971 and 1976, over 100,000 logs for gas-burning fireplace systems were reported sold which were frosted or treated with asbestos-containing materials. At approximately 1/2 pound of asbestos per log, approximately 4.5 m.t. of asbestos, mostly chrysotile, were sold annually for artificial embers.[14] In mid-1977, manufacturers stopped producing the product in anticipation of a subsequent consumer ban by the Consumer Products Safety Commission. The ban of artificial emberizing materials (ash and embers) containing respirable free-form asbestos became effective December 15, 1977. Manufacturers of artificial gas log amberizing material are currently using four substitutes in their products: vermiculite, rock wool, mica, and synthetic fibers.[30] Health considerations have also nearly halted the use of asbestos in artificial snows.

CONCLUSION

The use of asbestos in the miscellaneous products discussed in this section has nearly been disconstinued. Concerned with worker safety, the Occupational Safety and Health Administration has imposed regulations on the handling of asbestos at manufacturing facilities. The cost of complying with these regulations has tended to encourage the use of alternative fibers where asbestos had been used because it was cheap and convenient. Products such as foundry sands for special mold applications have readily adopted other materials. A few products have been forced out of the market by health concerns. This is especially true for decorative, nonessential products such as artificial snows.

TABLE 61. AIRBORNE ASBESTOS IN BUILDINGS[29]

Sampling conditions or situation	Mean counts (f/cc) [O.M.]	Number of samples	Standard deviation
University dormitory, UCLA	0.1	-	0 to 0.8 (range)
Exposed friable surfaces, 98 percent amosite			
General student activities			
Art and Architecture Building, Yale			
University--Exposed friable ceilings, 20 percent chrysotile			
Ambient air, City of New Haven	0.00	12	0.00
Fallout			
Quiet conditions	0.02	15	0.02
Contact			
Cleaning, moving books in stack area	15.5	3	6.7
Relamping light fixtures	1.4	2	0.1
Removing ceiling section	17.7	3	8.2
Installing track light	7.7	6	2.9
Installing partition	3.1	4	1.1
Reentrainment			
Custodians sweeping, dry	1.6	5	0.7
Dusting, dry	4.0	6	1.3
Proximal to cleaning (bystander exposure)	0.3	-	0.3
General Activity	0.2	36	0.1
Office buildings, Eastern Connecticut			
Exposed friable ceilings, 5 to 30 percent chrysotile			
Custodial activities, heavy dusting	2.8	8	1.6
Private homes, Connecticut			
Remaining pipe lagging (dry) amosite and chrysotile asbestos	4.1	8	1.8 to 5.8 (range)
Laundry: contaminated clothing	0.4	12	0.1 to 1.2 (range)
Chrysotile			

(continued)

TABLE 61. (continued)

Sampling conditions or situation	Mean counts (f/cc) [O.M.]	Number of samples	Standard deviation
Office building, Connecticut			
Exposed sprayed ceiling, 18 percent chrysotile	79[a]	3	40 to 110 (range)
Under asbestos ceiling	99[a]	2	
Remote from asbestos ceiling	40[a]	1	
Urban Grammar School, New Haven			
Exposed ceiling, 15 percent chrysotile asbestos			
Custodial activity: sweeping, vacuuming	643[a]	2	186 to 1100 (range)
Apartment Building: New Jersey, heavy housekeeping	296[a]	1	
Tremolite and chrysotile			
Office buildings, New York City			
Asbestos in ventilation systems	2.5 to 200[a]		0 to 800
Quiet conditions and routine activity			

[a] Nanograms/cubic meter, determined by electron microscope.

Where regulation has been unable to indirectly halt manufacture of an asbestos product, the Consumer Product Safety Commission has imposed bans of specific product categories for use in the consumer sector.

The only miscellaneous industry where asbestos fiber is still used is in oil and gas drilling. When asbestos is used in drilling muds, pelletized asbestos is the preferred choice over raw fibers since pelletized asbestos generates less fiber release to the air during the opening and emptying of bags and mixing. The future of asbestos use in drilling muds, however, is uncertain because adequate substitutes are available to replace the functions of asbestos for this application.

Many of the miscellaneous products using asbestos have short service lives and are discarded to a dump or landfill in a bound fiber form after only a few years of service. Although products such as spray on insulation have been banned, they will likely be of concern for health reasons for years to come. Asbestos containing insulation in place in schools, factories, offices and homes will continue to be a potential hazard to a high percentage of the population. Also as structures containing asbestos materials are demolished, free fibers may be emitted even in controlled situations.

REFERENCES

1. Clifton, R. A. Asbestos--1979. U.S. Department of the Interior. July 1979.

2. Clifton, R. A. Asbestos. 1980 Minerals Yearbook. U.S. Bureau of Mines, Washington, D.C.

3. Huebotter, E. E. and G. R. Gray. Drilling Fluids. Kirk-Othmer Encyclopedia of Chemical Technology. Second edition. Volume 7. pp. 287-307.

4. Zwicker, D. A. Glorious Mud, The Lamp, Exxon Corporation, New York, NY. Volume 61, No. 4, Winter (1979). pp. 26-29.

5. Pundsack, P. L. and W. O. Jackson. Fibers, Inorganic. Encyclopedia of Polymer Science and Technology. Volume 6, pp. 671-690. John Wiley and Sons, Publishers, NY.

6. Letter from B. J. Pigg, Asbestos Information Association to Lester Y. Pilcher, GCA/Technology Division, February 13, 1980. Amount of Asbestos used annually in Drilling Mud.

7. Binder, G. Exxon Production Research Company. Houston, TX. (713) 965-4810, Personal communication with Lester Y. Pilcher, GCA/ Technology Division. January 24, 1980. Notebook No. 04, Phone call No. 7.

8. Wright, T. R., Jr., and W. Dudley, Jr., ed. Guide to Drilling Workover, and Completion Fluids. World Oil. p. 116. June 1979.

9. Kennedy, B. Messina, Inc. Dallas, TX. (713) 225-6383, personal communication with Lester H. Pilcher, GCA/Technology Division, January 29, 1980. Notebook No. 04, Phone call No. 11.

10. Drilling Fluids: Computer Planning and New High-Temperature Fluid. World Oil. December 1979.

11. Fenner, E. Johns-Manville Corporation. Denver, CO. (303) 979-1000, personal communication with Lester Y. Pilcher, GCA/Technology Division, January 30, 1980. Notebook No. 04, Phone call No. 13.

12. Clear, E. E. Drilling Specialties, Bartlesville, OK. (918) 661-5405, personal communication with Lester Y. Pilcher, GCA/Technology Division, February 4, 1980. Notebook No. 04, Phone call No. 22.

13. Petri, C. Montello, Co. Tulsa, OK (918) 665-1170, personal communication with Lester Y. Pilcher, GCA/Technology Division, February 4, 1980. Notebook No. 04, Phone call No. 20.

14. Meylan, William M. et al. Chemical Market Input/Output Analysis of Selected Chemical Substances to Assess Sources of Environmental Contamination: Task III. Asbestos. Prepared for OTS, EPA, Washington, D.C.

15. American Petroleum Institute. Oil and Gas Well Drilling Fluids. API Bulletin 13F, Washington, D.C. August 1978. p. 6.

16. Daly, A. R., et al. Technological Feasibility and Economic Impact of OSHA Proposed Revision of the Asbestos Standard (Construction Excluded). Asbestos Information Association/North America. March 26, 1976.

17. Bradfield, R. E. N. Asbestos: Review of Uses, Health Effects, Measurement and Control. Atkins Research and Development, Epsom Surrey, England. January 1977.

18. Telecon. T. McCawley. Remington Arms Corp. Bridgeport, CT with R. Bell, GCA Corporation, GCA/Technology Division. 1980.

19. Foster, C. Consultant. National Asphalt Paving Association. Riverdale, MD. (301) 779-4880, personal communication with S. Duletsky, GCA Corporation, February 11, 1980. Notebook No. 05, Phone call No. 49.

20. Leman, M. Johns-Manville Corporation. Denver, CO. (303) 979-1000, personal communication with S. Duletsky, GCA Corporation, February 14, 1980. Notebook No. 05, Phone call No. 58.

21. Plate, H. Manager of Marketing. ASARCO, Inc. New York, NY. (212) 732-9500, personal communication with S. Duletsky, GCA Corporation, February 20, 1980. Notebook No. 05, Phone call No. 60.

22. Kotzin, Ezra. American Foundryman's Society. Des Plaines, IL. (312) 824-0181, personal communication with Mr. L. Y. Pilcher, GCA/Technology Division, February 15, 1980. Notebook No. 04, Phone call No. 39.

23. Mosher, Gary. Industrial Hygienist. American Foundryman's Society. Des Plaines, IL. (312) 824-0181, personal communication with Mr. L. Y. Pilcher, GCA/Technology Division, February 12, 1980. Notebook No. 04, Phone call No. 33.

24. Kuhn, S. Johns-Manville Regional Sales Office. Atlanta, GA. (404) 449-3300, personal communication with Mr. L. Y. Pilcher, GCA/Technology Division, February 15, 1980. Notebook No. 04, Phone call No. 35.

25. Penters, A. Sales Manager. Whitehead Brothers Co. Florham Park, NJ. (201) 377-9100, personal communication with Mr. L. Y. Pilcher, GCA/Technology Division, February 12, 1980. Notebook No. 04, Phone call No. 29.

26. Marvel, H. Pennsylvania Foundry Supply and Sand Co. Philadelphia, PA. (215) 333-1155, personal communication with Mr. L. Y. Pilcher, GCA/ Technology Division, February 15, 1980. Notebook No. 04, Phone call No. 38.

27. Cavaseno, F. Latest Work on Asbestos Won't Be the Last. Chemical Engineering. November 6, 1978. pp. 76, 80.

28. Reitze, W. B., et al. Application of Sprayed Inorganic Fiber Containing Asbestos: Occupational Health Hazards. Am. Ind. Hyg. Ass. J. 1972. Vol. 33, pp. 178-191.

29. Sawyer, R. N., and C. N. Spooner. 1978. Sprayed Asbestos-Containing Materials in Buildings: A Guidance Document. Part 2. U.S. Environmental Protection Agency. Research Triangle Park, North Carolina. EPA Report No. EPA-450/2-78-014.

30. Part 1305--Ban of Artificial Emberizing Materials (Ash and Embers) Containing Respirable Free-Form Asbestos. Federal Register, Chapter 11--Consumer Product Safety Commission. December 15, 1977.

31. Levine, R., ed. Asbestos. An Information Resource. May 1978.

SECTION 14

RESULTS, DISCUSSION AND CONCLUSION

RESULTS

The format of this report has been structured to assist the reader in understanding the rationale for using asbestos fibers in each of the product categories. In this regard each asbestos product is presented in the same manner, with specific data on the product, its method of manufacture and potential atmospheric emissions of asbestos that may result from its production. This sequential presentation familiarizes the reader with all pertinent facets of asbestos products and facilitates comparison between product categories.

For each product category, the composition of the asbestos product is described, together with the uses and applications of the product and the special qualities that have, to this time, made asbestos an indispensable constituent of the product. This information provides the background information on the product that is necessary if we are to understand why the product is manufactured, the qualities the product must have to be commercially viable and how asbestos fulfills this need. Once this background is understood, the commercially available substitutes for the asbestos product are discussed. These substitutes may take the form of a fiber by fiber replacement for asbestos or they may be a completely new asbestos-free product. The development and production of asbestos-free substitutes are dependent upon a variety of changing factors including cost, customer preference, substitute qualities and regulatory controls. Listing the currently available substitutes serves to inform the reader of the type and extent of activity in this area.*

A discussion of product manufacture then follows in each section, detailing the major points of fiber introduction and therefore potential fiber release. Work practices and pollution control devices that are used to minimize worker exposure to asbestos fibers are listed. The extent of emission control helps quantify plant asbestos emissions and provides an indication of industry's response to the potential health hazards posed with occupational exposure to asbestos. In addition, the number and location of plants producing asbestos products are listed, based on the best available data, for each product category.

Finally, the release of asbestos to air, water and land from the manufacture, use and disposal of the asbestos products is discussed. Engineering estimates have been made for the various potential releases to quantify total annual asbestos emissions. As there are few published data on asbestos emissions from the product categories, emission estimates can only be a qualitative statement on asbestos release. They should not be used as categorical

---

*For more detail on asbestos substitute products, refer to "Asbestos Substitute Performance Analysis," U.S. EPA, OPTS.

emission quantities. Furthermore, these estimates are directly related to 1980 asbestos consumption data, which itself was an atypically low use year. Nevertheless, in order to understand the magnitude of the asbestos problem and to compare product categories, asbestos release rates must be quantified, and numbers are assigned in this report to each avenue of asbestos release to the environment. These and other emissions estimates will be subsequently discussed.

Asbestos Release Potential

As discussed, the potential for release of asbestos fibers during the life cycle of products in the major product categories can only be estimated in general terms. Nevertheless, many useful conclusions are possible. Data are summarized in Table 62. These data have been taken from the individual product category chapters presented in this report.

The number of sources of asbestos fiber releases increases as one proceeds from mining and mills to primary manufacturers to secondary fabricators and on to users. There are four operating mines and associated mills in the United States. There are approximately 130 major primary manufacturers in the nine major product categories. There are many hundreds, perhaps thousands, of secondary fabricators.

A complete documentation of the asbestos release potential at each of these primary manufacturing plants would necessarily require individual site inspections. This has not yet been done, and such a series of visits was beyond the scope of this report. Nevertheless, generalized statements as to the extent to which typical control measures are practiced for each product category can be made based on published data and a few, select site visits. These statements on asbestos release have been summarized by high, medium, and low potential and appear in Table 62. This quantification of asbestos release potential has been made for primary and secondary finishing, installation, use, removal and disposal. In addition, substitute availability is also summarized in Table 62. While the fiber release potential at domestic mines and mills is high, this area has not been a primary focus of this report and is not reported here.

Fiber shipment, receipt, transfer to storage, and bag opening are common to all product manufacturing facilities. Site visits indicate that there is a wide variation in the extent of fiber release. The conditions of shipping vehicles, loading docks, and storage areas varied from spotlessly clean and free of visible fiber to filthy and coated with deposits of fiber. There seems to be no consideration other than cost which prevents users of asbestos from eliminating essentially all breakage and the resultant fiber release. The use of plastic shrink-wrapping for asbestos fiber shipments and the palletizing of asbestos fibers at the asbestos mills are gaining in popularity throughout the asbestos industry. Such practices are proven methods of minimizing fiber release from accidental spills. Until these packaging techniques are adopted in each asbestos product industry, the asbestos release potential will remain high at shipping, receiving and fiber transfer stations, as listed in Table 62.

TABLE 62. ASBESTOS RELEASE POTENTIAL[a]

					1° Processing			2° Processing and finishing	Installation		Use				Substitute availability	
Number	Product category	Number of manufacturing locations	Mining	Milling	Shipping receiving opening	Processing	Finishing		Proper	Improper	Proper	Improper	Demolition or removal	Disposal	Good	Not good
1	Paper	18/1°	H	H	H	M	M	M-H	U(H)	U(H)	U(L)	U(M)	U(H)	U(L)	X[b]	
2	Friction products	34/1° some 2°	H	H	H	L	H	H	L-M	L-M	L	-	M-H	L-M	X[d]	
3	A/C pipe	11/1°	H	H	H	M	H	-	L	M-H	L	M	U	U	X	
4	A/C sheet	5/1° many/2°	H	H	H	L	H	H	L	M-H	L	-	U(L)	L	X[d]	
5	Floor tile	10/1°	H	H	H	L	L	-	L	L	L	-	L-M	L	X[c]	X
6	Gaskets and packing	27/1° many/2°	H	H	H	L	M	H	L	-	L	H	L	L	X[e]	
7	Sealants	20/1° 0/2°	H	H	H	L	L	-	L	-	L	-	L	L	X[d]	
8	Plastics	7/1° 3000/2°	H	H	H	L	-	L-H	L	M-H	L	-	L	L	X[d,e]	
9	Textiles	6/1° many/2°	H	H	H	H	H	H	U	U	U	U	H	L	X	
10	Miscellaneous	many	H	H	H	U	U	U	U	U	U	U	U	U	X	

KEY

H = high	U = unknown
M = medium	U( ) = the figures are unknown but estimates indicate the letter in ( ).
L = low	

[a] GCA estimates.

[b] With the exception of beater-add gaskets.

[c] Substitutes for the product exist, but not for the asbestos fiber use itself.

[d] Substitutes are available, but at higher prices.

[e] No substitute has all the needed properties of asbestos.

The next common stage in asbestos product manufacture is bag opening and initial mixing of fibers with other ingredients. For products which can tolerate pulpable kraft fiber, there is no need to open bags before mixing. For other products, adequate control seems possible through the use of hoods and automatic bag handlers with eventual landfilling of used bags. For wet mix products a hydropulper is generally employed but the energy input rate is higher. Batch mixing with a hydraulically closed cover on the pulper appears to prevent fiber emission. For dry mix processes the potential for fiber emission seems to be uniformly high.

For paper products, the fiber release potential is strongly dependent on the binder or saturant employed. For starch bound papers release potential is high. For latex bound or asphalt saturated papers release potential is lower. During the drying of paper, high volumes of air are passed over the paper in the dryer section to carry off moisture. Depending on the facility in question this dryer air may be vented to the outside directly, vented to the outside after passing through heat recovery units or vented back into the building for space heating. It does not seem to be a common practice to pass this air stream through a baghouse. Finishing consists of trimming and slitting with a possibility but not necessarily a high probability of significant fiber release. Due to the wide variety of products in this category it is not possible to generalize on fiber release potential during installation, use, demolition or disposal. There is a possibility that removal of old commercial roofing (asbestos paper base) may result in significant fiber releases.

The greatest fiber release potential association with asbestos-cement pipe is not in the pipe production, where manufacturing processes are closely monitored and controlled. It is in the field installation of the pipe, where uncontrolled finishing techniques can lead to significant fiber emissions that a problem exists. Abrasive disk sawing and drilling can release the asbestos fibers from their cement matrix and lead to an emission of free asbestos fibers. In addition, asbestos-cement water mains when used with aggressive water supplies can suffer a degradation of the cement binder and subsequent release of asbestos fibers into the water.

Production of vinyl asbestos floor tile has a small fiber release potential as the asbestos fibers are encapsulated in a vinyl bonding agent which seals them in. Removal of vinyl asbestos floor tiles by sanding might result in some fiber release. While small quantities of fibers might be released to the air and water by normal wear and tear of this product, no quantitative measurement of fiber release from fresh, worn or weathered products were found.

In friction products, asbestos cement sheet, gaskets, and plastics, the fibers are contained in a rigid or semirigid matrix which has a low potential for releases of high concentrations of fiber. For exposed asbestos cement sheet building products, it is possible that the large area of exposed, weathered product in old installations could result in the emission of significant numbers of fibers over time. For all of these rigid matrix products there is a high potential for fiber release during energy-intensive fabrication steps such as sawing, drilling, or grinding. This is especially true with regard to millboard and rollboard.

Since there is little binder used in conjunction with the raw asbestos fibers, packings and textiles have a high potential for fiber release whenever they are handled, especially when abraded.

Worker Exposure

The current OSHA occupational standard for asbestos is 2 f/cc for an 8-hour time weighted average (TWA). In-plant measurements of asbestos concentrations have been taken at several asbestos products manufacturing facilities. These data have been presented throughout this report and are summarized in Table 63. Most of these data were measured prior to the effective date of the OSHA regulation, therefore they should not be used as a measure of compliance with this regulation. Rather, these data provide a relative measure of asbestos concentrations at various process points within a facility. As noted on Table 63, for all product categories the highest asbestos exposure is at the shipping, receiving and bag opening stations. This is consistent with the previously described high exposure potential at these areas where the raw fiber is handled and introduced into the system. Exposure at processing stations drops dramatically for products, such as paper, A/C pipe and sealants, where the fiber is encapsulated by a binder. Conversely, for textiles the measured asbestos concentration for processing increases due to the continued unaltered presence of the asbestos fiber. Concentrations at finishing stations are close to those of processing points, with some products showing an increase as the product is cut and machined to final specifications. Secondary processing exposure is virtually identical to that of primary finishing, with the exception of A/C pipe, where improper installation techniques may cause localized elevated asbestos levels. Finally, a qualitative estimate has been made as to the exposure that results from installation, use, demolition and disposal of each product, and this is reported in Table 63 as well.

Control of fiber release can be achieved through manufacturing equipment design, fabricating equipment design, add-on pollution control equipment, work practices and use practices. Control efforts instituted to date have been made in response to health effects knowledge as formalized in OSHA and NESHAPS standards. Higher degrees of control (at increased cost) are certainly possible for many of the asbestos release points in each product life cycle.

DISCUSSION AND CONCLUSION

Quantification of asbestos emissions from the production, use and disposal of asbestos-containing products is at best an inexact science. There is little published data in this area and the few relevant articles often differ by orders of magnitude in their emissions estimates. This report has attempted to use these estimates by modifying them with engineering evaluations of the extent and effectiveness of emissions control in the asbestos products industry today. In addition, these data have been upgraded to account for 1980 asbestos

TABLE 63. EXPOSURE DATA (TYPICAL fibers/cc TWA)[a] - 1975

Number	Product category	Mining[b]	Milling[c]	1° Processing: Shipping receiving opening	1° Processing: Processing	1° Processing: Finishing	2° Processing	Installation: Proper	Installation: Improper	Use	Demolition	Disposal
1	Paper	H	H	1.9	0.8	1.0	U	U(H)	U(H)	U	U	U
2	A/C pipe	H	H	3.6	0.9	1.3	2.5	L	L-M	L-M	M	L
3	Floor tile	H	H	3.0	3.0	-	-	L	L	1.2[d]	U	U
4	Friction products	H	H	2.5	2.3	2.0	2.0	L-M	L-M	M-H	M-H	L-M
5	Sealants	H	H	2.5	1.0	-	-	L	-	L	L	L
6	A/C sheet	H	H	2.0	2.0	2.0	2.0	L	M	L	L	L
7	Gaskets and packing	H	H	1.5	0.5	-	U	L	-	U	U	U
8	Plastics	H	H	1.5	1.1	1.0	1.0	L	H	L	U[e]	U[f]
9	Textiles	H	H	2.5	4.0	3.0	-	U	U	0.01	L	L
10	Miscellaneous	H	H	1.5	M	-	-	U	U	L-M	L	L

KEY

H = high	L = low
M = medium	U = unknown

[a] Optical microscope fibers.

[b] Drillers have the highest mining exposures.

[c] Blenders, baggers and packers have the highest milling exposures.

[d] From sanding operations on installed floors.

[e] These products would normally be discarded while still whole, as in parts in old autos, etc.

[f] Estimates indicate that baghouse fine emissions may take place but the scrap product asbestos fibers would be well bound.

consumption. Nevertheless, the emissions data provided in this report should only be considered refined estimates. Substantial sampling and analysis work needs to be done at and around asbestos manufacturing facilities to provide a true measure of ambient asbestos release today.

A summary of the asbestos release data presented in this report is presented in Table 64. An examination of the data in this table indicates that the overwhelming majority (98.2 percent) of asbestos fibers released to the environment from manufacturing are deposited on the land. This release is in the form of product scrap, baghouse and vacuum cleaner dust and sludge from industrial water effluent clarifiers. If properly disposed of in a regulated sanitary and/or hazardous waste landfill, this asbestos will not represent an additional environmental hazard. Waterborne asbestos represents the second largest emission, with approximately 95 metric tons per year being carried away in plant effluent. The fate of this emission is unknown. Some of this asbestos may be subsequently removed from the industrial discharge by municipal wastewater treatment plants. From here it is either landfilled or burned in a sludge incinerator. No data are available to estimate the exact fate of this waterborne asbestos. Air emissions, both from process and disposal operations make up the smallest amount in terms of annual tons emitted. Yet this asbestos is potentially the greatest health problem, as it can be carried great distances by the wind and a portion of it may be inhaled by the general populace. More work in this area is needed to quantify the cause and affect relationship between plant asbestos emissions and population exposure to asbestos fibers.

This report has traced the fate of asbestos in the industrial and commercial sectors of society from its introduction into the plant to final use and disposal. Atmospheric emission rates have been estimated for air, water and land disposal. Data on asbestos exposure resulting from use of the final asbestos product is still too inconclusive to be quantified. As the scientific community learns more about the potential health hazards associated with asbestos use and regulatory action in this area is increased, additional environmental controls will be adopted to minimize asbestos release. Occupational exposure levels have initially received the most attention and asbestos fibers today are generally carefully controlled within the plant environment. As the emphasis shifts toward nonoccupational exposure to asbestos, additional controls in this area will be adopted. States, such as Connecticut, are considering adopting an ambient air quality asbestos standard. This increased awareness of the problems associated with asbestos will help ensure that all asbestos fiber release in the future is minimized and carefully monitored.

TABLE 64. GCA ESTIMATES OF ASBESTOS RELEASE FROM MANUFACTURING AND DISPOSAL TO AIR, WATER AND LAND, IN Mt/yr - 1980

Product category	Air		Water	Land	Total
	From process	From disposal			
Paper	45	4.5	45	4,451.5	4,546
Friction	10.9	2.2	13.1	1,111.9	1,138.1
A/C pipe	14	7	34	3,599	3,654
A/C sheet	0.8	0.4	1.8	198	201
Floor tile	3.6	2	a	939	944.6
Gaskets and packing	6.1	0.6	a	307	313.7
Sealants	0.5	0.5	a	109	110
Plastics	a	0.1	a	38	38.1
Textiles	0.3	0.1	0.7	48	49.1
Miscellaneous	5.2	0.5	c	c	5.7
Totals	86.4[b]	17.9	94.6	10,801.4	11,000.3
	(0.8%)	(0.2%)	(0.9%)	(98.1%)	100%

[a] Minimal amounts.

[b] Differs slightly from Table 8 estimates due to rounding off.

[c] Unknown.

GCA-TR-79-73-G

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Toxic Substances
Washington, D.C.

Submitted in Partial Fulfillment of
Contract No. 68-02-3168
Technical Service Area 3, Work Assignment No. 18

EPA Project Officer
James Bulman

LIFE CYCLE OF ASBESTOS IN COMMERCIAL AND INDUSTRIAL USE INCLUDING ESTIMATES OF RELEASES TO AIR, WATER AND LAND

Final Inhouse Report

February 1982

Prepared by
David Cogley
Nancy Krusell
Robert McInnes
Peter Anderson
Ronald Bell

GCA CORPORATION
GCA/TECHNOLOGY DIVISION
Bedford, Massachusetts