ANALYSIS OF FIBER RELEASE FROM CERTAIN ASBESTOS PRODUCTS

Draft Final Report
Task 1

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DRAFT

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## SECTION 1

## INTRODUCTION

Over recent years, much has been written about worker exposure to asbestos fibers during the manufacture and subsequent fabrication of asbestos-containing products. Governmental regulatory agencies such as the Occupational Safety and Health Administration (OSHA), Consumer Product Safety Commission (CPSC), and United States Environmental Protection Agency (EPA) have been entrusted with the responsibility of protecting workers, consumers and the environment from exposure to asbestos fibers. Under the Toxic Substances Control Act (TSCA),[1] EPA's Office of Toxic Substances is responsible for controlling human exposure to asbestos that may present an unreasonable health risk. Within the confines of TSCA, this study was undertaken to profile the activities routinely performed on asbestos-containing products in secondary finishing operations, installations, repair, or day-to-day handling and to report the levels of asbestos fibers encountered during such activities.

It is estimated that asbestos fibers have been used to produce 2,000 to 3,000 discrete commercial and industrial products.[2] Asbestos fibers may be released during product manufacturing, distribution in commerce, and end use. Persons may be exposed to asbestos fibers during the performance of these activities. Because OSHA studies provide a relatively adequate data base for fiber release during primary manufacturing and fabricating, this study has focused on identifying asbestos fiber release from secondary and consumer product use activities.

The information presented in this report was compiled from an extensive survey of publicly available data and telephone interviews with manufacturers, fabricators, distributors, and end users of asbestos-containing products. A computerized literature search of eleven data bases revealed that the amount and diversity of asbestos fiber release data publicly available is limited. Various product testing laboratories have monitored fiber release from experiments simulating actual product use activities, but due to the preliminary nature of their findings or to proprietary agreements they are not willing to disclose publicly the results of their studies.

The purpose of this study is to report measured or expected airborne asbestos fiber concentrations resulting from secondary and consumer product use activities. The data presented are intended to provide EPA officials with the information they need to assess whether exposure to asbestos throughout its life cycle presents an unreasonable risk to human health. Where the presence of risk is determined, EPA will consider developing regulations, under TSCA authority, to eliminate the human exposure. Once it has been determined that the substance in question presents an unreasonable health risk, the Agency under Section 6(a) of TSCA, can restrict chemical processing, limit quantities that can be used, require appropriate labels, and/or mandate recordkeeping.

## REPORT ORGANIZATION

This report is organized by the asbestos product categories presented in Table 1. The chapters are arranged sequentially by category based on descending rate of annual asbestos consumption. Due to the versatility of some products and the intermediate uses of others, there will be some overlap of products between categories. The overlap will be noted but not repeated

Product profiles include a brief description of product manufacturing and/or fabricating operations, a discussion of secondary and consumer product uses and a presentation of monitoring data or potential fiber release estimates when they exist. Secondary and consumer product use activities include product finishing, installation, repair, and day-to-day handling.

## ANALYTICAL RESULTS

Asbestos fiber concentrations presented are based on the results of three different analytical techniques. The three microscopic analysis techniques are phase contrast, polarized light microscopy (PLM) and scanning electron microscopy (SEM). Phase contrast and PLM are optical light microscope analytical procedures.

Phase contrast analysis is the recommended method of the National Institute for Occupational Safety and Health (NIOSH) for counting asbestos fibers.[4] Fibers counted are those that are 5 microns (um) long or longer and have a length to width aspect ratio of 3 or greater. The major disadvantage of phase contrast analysis is that the technique cannot be used to differentiate asbestos fibers from nonasbestos fibers.

Polarized light microscopy analysis is used to count fibers of the same dimensions as the phase contrast method. However, PLM analysis allows the operator to distinguish asbestos fibers from nonasbestos fibers. The technique takes advantage of the specific optical properties each asbestiform mineral exhibits, thus allowing qualitative identification. Scanning electron microscopy analysis is the most powerful analytical tool of the three, providing the operator high levels of magnification. Compared with either of the two optical techniques, fiber counts by SEM analysis can exceed 50 times the number counted by phase contrast or PLM. Used in conjunction with energy dispersive X-ray analysis, which is almost always the case, SEM analysis provides qualitative results. Because of its powerful magnification capabilities, SEM analysis is also used to determine particle size distribution of material sampled.

TABLE 1. MAJOR ASBESTOS-CONTAINING PRODUCTS WITHIN EACH PRODUCT CATEGORY

I. Asbestos-Cement Pipe - (40.2)[a]

- Water Transmission Pipe (pressurized)
- Sewer Transmission Pipe (nonpressurized)
- Other - Electrical conduits, chemical process pipe

II. Asbestos Paper Products - (25.1)

- Flooring Felt
- Roofing Felt
- Beater-Add Gaskets
- Pipeline Wrap
- Millboard
- Specialty Papers
- Commercial Papers
- Electrical Insulation

III. Friction Material - (12.2)

- Brake Materials (linings and disc pads)
- Clutch Facings
- Other
  - Discs for automatic transmissions (paper product)
  - Woven clutch facings (textiles)

IV. Flooring Products - (10.1)

- Vinyl-Asbestos Floor Tile
- Asphalt-Asbestos Floor Tile

(continued)

TABLE 1 (continued)

V. Gaskets and Packing - (3.4)

- Compressed Sheet Gaskets
- Impregnated Millboard } Packing
- Yarn (textile) } Packing

VI. Coatings and Sealants - (3.0)

- Petroleum-based products
- Water soluble Latex or Gypsum-Based products

VII. Asbestos-Cement Sheet - (2.2)

- Roofing Shingles
- Siding Shingles
- Flat Sheet
- Corrugated Sheet

VIII. Textiles - (0.5)

- Industrial Packings
- Electrical Insulation
- Thermal Insulation
- Textiles (fire retardant clothing, belt conveyors, and curtains)

IX. Asbestos Reinforced Plastics - (0.4)

- Electronic Industries (commutators)
- Automotive Industries
- Printing Industries

[a]Percentage of 1980 annual asbestos consumption.[3]

Discretion should be employed when interpreting and comparing the fiber concentration data presented in this report. Care should be taken not to compare optical microscopy results directly with SEM analyses. Similarly, the quantitative results of phase contrast analysis should be fully understood before comparing them to quantitative and qualitative results obtained from PLM analysis. A concerted effort has been made to identify these analytical characteristics which are important to remember when interpreting the data.

In addition, one should not mistakenly compare peak concentrations occurring during the performance of an activity with time weighted average concentrations that have been scaled over an eight hour period. Finally, some of the data reported may be out of date. Implementation of new control measures and changes in product formulations should result in fiber release levels lower than some of those presented. In all cases, the most recent fiber concentration data are reported.

## REFERENCES


1. Toxic Substances Control Act, 15 USC 2601. Promulgated October 11, 1976. Public Law 94-469, 94th Congress.

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

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

4. National Institute for Occupational Safety and Health: Asbestos Fibers in Air - Analytical Method. (March 1976). pp. 239-1 to 239-20, unpublished.

## SECTION 2

## ASBESTOS-CEMENT PIPE

### INTRODUCTION

Asbestos-cement (A/C) pipe is manufactured in sizes ranging from 10 to 81 centimeters (ca. 4 to 32 inches) in diameter.[1] The product is used primarily for water distribution and sewage transport. Approximately 70 to 75 percent of all the A/C pipe produced is used for water supply systems, 20 to 25 percent is used for sewer pipes. The remaining pipe produced is installed as telephone and electric wire conduit, with a minor fraction for air ducting.[1] In 1978, 321,800 kilometers (ca. 200,000 miles) of A/C pipe was estimated to be used to distribute water to U.S. consumers.[2] Proportionally, most of this pipe is located West of the Mississippi River.[1].

Release of airborne asbestos fibers from A/C pipe is minimized after manufacture and finishing. Candidates for exposure would be contractors who install, maintain, and repair or modify water (pressure) supply or sewer (nonpressure) systems. During these operations, cutting may be required which could release fiberous emissions. Asbestos fibers contained within A/C pipe are bound in a cement mortar matrix.[2] In addition, A/C pipes are often coated with a layer of $CaCO_3$ or other detourant to erosion of fibers from the surface.[3] The pipes are also laminar in structure slowing any corrosion/erosion processes as well as enabling cutting for branch pipes with little risk of cracking beyond the cut area.[4]

Once permanently installed, the greatest potential for environmental fiber release is to the water or sewer system. Fluids passing through the pipes have the potential to pick up fibers through erosion and leaching. Several studies have been conducted to determine the asbestos content of water supplied to the consumers.[5-8] Although the overall consensus is that much of the asbestos is derived from natural sources such as serpentine rock formations, most studies do not distinguish between the sources of asbestos fibers found in the water. Studies concerned strictly with fiber release from A/C pipe, however, all show a slight increase of asbestos fiber counts in water which has passed through such pipe.[3,9-11]

### PRODUCT MANUFACTURING AND COMPOSITION

The manufacture of asbestos cement pipe is governed by specifications set by the American Water Works Association (AWWA).[12] Pipe is classified according to the designed internal pressure, ranging from 2070 to 6206 kilopascals (ca. 300 to 900 psi), and according to chemical composition. Type I A/C pipe has no limit upon the amount of uncombined calcium hydroixde permitted in the product, and Type II A/C pipe must not contain greater than one percent uncombined calcium hydroxide. Type I pipe is generally cured under ambient conditions. The mixture is 15 to 25 percent asbestos and 75 to 85 percent portland cement. Type II pipe (autoclave cured) is made of 15 to 25 percent asbestos, 42 to 53 percent cement, 34 to 40 percent silica and up to 6 percent finely ground solids from crushed or damaged pipe as filler.[1] Chrysotile asbestos is most commonly used in A/C pipe production. A relatively small amount of crocidolite and an even smaller amount of amosite is also used.[13]

Manufacturing begins when raw asbestos, generally packaged in 50 kg (ca. 100 lb) bags, is delivered to the plant by railcar or truck, and stored until needed for mixing. The raw asbestos is weighed and charged with the cement and other ingredients into a dry mixer, which acts to fluff the fibers and prepare a homogeneous mixture. The dry mix is then conveyed to a wet mixer or beater where water is added to make an A/C slurry of approximately 37 percent water.[14] 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, 0.05 to 0.25 cm (ca. 0.02 to 0.10 in.) thick, is transferred to an endless-felt conveyor belt that travels over vacuum boxes to remove the water.[14] The wet mat is then transferred to a mandrel or accumulator roll which winds the mat into pipe stock of the desired thickness. Pressure rollers bond the mat to the layer previously deposited and further remove excess water. The pipe, usually cast in 3.0 to 4.6 meter (ca. 10 to 15 foot) lengths, is then removed from the mandrel, air cured, and final cured in an autoclave using saturated steam. Cured pipe sections are transported to finishing operations where the pipe is cut to uniform lengths and machined in a variety of ways (sawing, lathing, drilling) and outfitted with a coupling. To ensure a tightly fitted pipe joint, the ends of the pipe sections are machined smooth on a lathe. The finished pipe is inspected, and each section of "pressure pipe" (pipe used for conveying water under pressure) is tested hydrostatically.[15]

In addition to full and partial lengths, manufacturing plants also produce a variety of standard and special fittings. Pipe couplings are the most widely used fittings. To mate with a machined pipe, inside surfaces of the coupling must be grooved to hold a rubber seal. Other fittings (tees, elbows, reducers, etc) are produced on a less frequent schedule.[15] Most manufacturing plants also produce specialty fittings and pieces on an individual basis. Pipe fittings production include sawing, drilling, machining, boring, and bonding. Some specialty applications require pipe lengths to be machined over their entire length with a lathe.[15] As a final step, the pipe may be lined with a coating to further increase its corrosion resistance and improve flow characteristics. Vinyl is a commonly used liner.[16]

Reliable production volumes of A/C pipe cannot be accurately estimated because such information is considered proprietary by manufacturers. The total quantity of asbestos consumed for the production of A/C pipe can be used, however, as a market indicator. In 1980, 144,000 metric tons or 40 percent of the total annual domestic asbestos consumption was for A/C pipe production.[17] Projected trends for A/C pipe consumption vary from modest growth (5 to 7 percent over the next 3 to 7 years), through market stability,[13] to actual decline.[17] Between 1978 and 1980 asbestos consumption for A/C pipe dropped. Polyvinyl chloride (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 pipes, especially in the southern U.S. where higher temperatures and low flow rates accelerate acidic deterioration of A/C pipe, PVC pipe may claim a substantial share of the market, perhaps eventually displacing A/C pipe if the latter's cost cannot be lowered.[15]

## SECONDARY AND CONSUMER USE

A/C pipe has a relatively narrow range of application compared to other asbestos-containing products. As indicated above, nearly 100 percent of the A/C pipe produced is used for water or sewage transport. The remaining pipe is used for conduits for electrical or telephone wire or air ducts.[1]

It is noted that A/C pipe is not really a consumer product. Finished pipe is distributed primarily to municipal water works construction personnel and contractors. Installation is almost always performed by professional workers, who are familiar with recommended installation procedures.

Because of its relatively recent introduction (about 50 years ago) and very long service life, there is little information available on the repair and/or replacement of A/C pipe used for water transport systems. Except under very aggressive water conditions, once in the ground, A/C pipe lasts forever. Engineering standards recommend that urban lines be replaced every 75 years.[18] 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.[18] In highly populated 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, minimal asbestos fiber release from the old pipe is expected and in the latter instance, none.

## ENVIRONMENTAL RELEASE

One of the major advantages of A/C pipe use is the ease of installation. Relatively little onsite sawing, cutting, drilling, or machining of A/C pipe is required during installment. Although there may be transitory worker exposure, the likelihood of significant asbestos fiber release into the environment is minimized since the fibers are immobilized in the cement matrix. Piping is placed in ground and fitted with rubber gaskets which act as a cushion aga[illegible] abrasion as well as providing a more flexible decay resistant seal.[1] Once layed in ground the pipe is completely buried with the only mechanism available for fiber release being through the water which it carries. As a result of these activities, the general public's exposure to airborne asbestos fibers from installing A/C pipe is minimal.

Should field finishing be required, it would be a potential source of airborne asbestos fibers. Cutting or lathing pipe has the potential to release airborne asbestos fibers, although this can be minimized with the proper use of specifically designed tools and cleanup equipment. Special saws and lathing tools as well as drills have been developed that are equipped with dust control devices.[15,19] Control devices include local vacuum systems with filters, wet cutting tools and lathes or tools with self-contained vacuum and filter fittings.

A recent study sponsored by the Association of Asbestos Cement Pipe Producers (AACPP),[19] was conducted to measure worker exposure during the following A/C pipe field operations:

1. Unloading
2. Laying pipe in the trench
3. Cutting operations on both pressure and sewer pipe
    a. Cutting with hack saw
    b. Cutting with snap cutting equipment
    c. Cutting with abrasive disc, wet
    d. Cutting with abrasive disc, dry
    e. Cutting with hammer, chisel and rasp
4. Machining operations
    a. Machining with a manual field lathe
    b. Machining with a power-driven lathe
    c. Cutting and machining with Doty machine
5. Hole Cutting
    a. Hole cutting with power-operated equipment
    b. Hole cutting with drill, hammer and rasp

6. Tapping operations

   a. Dry tapping with Mueller J. tool

   b. Tapping operations with Mueller B-100 tool

7. Coupling removal

   a. Removal of coupling with hammer and chisel

The above operations are representative of the activities routinely performed at construction sites installing A/C pipe. Depending on the magnitude of the job, any one or all of these operations may be conducted. Although, all of these operations are fabricating processes, typically A/C installation requires minimal field fabrication.

The operations identified, are performed intermittently and vary widely in duration. Reportedly an average of only 1.1 percent of A/C pipe installation time involves cutting, tapping or machining.[19] This is translated to approximately 5.3 man-minutes per day.[19]

Measured concentrations during the unloading and laying of A/C pipe were found to be 0.1 fiber/$cm^3$.[19] The unloading activity involved the use of a forklift which handled palletized pipe. Twenty centimeter (8 inch) pressure pipe was arranged on 1.2 meter (4 foot) pallets, 8 per bed plus miscellaneous short lengths and couplings. The material was unloaded in 15 minutes from a truck carrying 16 pallets. The sample analyzed was obtained from a 24-minute personal sample taken on the forklift operator.

The pipe laying operation involved trenching, laying pipe, and back-filling simultaneously. Personal samples were taken on two men performing the activity, one man in the trench at the forward end of the pipe and the second worker, working both topside and in the trench. The second worker attached a lowering clamp to the pipe, lubricating the pipe end, then entered the trench to guide the pipe into place for coupling.

Personal monitoring of workers performing the operations listed above was conducted to determine worker exposure to asbestos fibers. The results of the monitoring activity are presented in Table 2. Only two operations, cutting with abrasive discs and cutting and machining with a Doty tool without a shroud, resulted in fiber releases greater than the OSHA 8-hr TWA* standard of

*TWA - Time Weighted Average.

TABLE 2. RESULTS OF PERSONAL MONITORING OF EMPLOYEES PERFORMING A/C PIPE OPERATIONS [19]

| Operation | Average peak exposures (up to 15 minutes): A/C sewer pipe: Operator (f/cm³) | Average peak exposures (up to 15 minutes): A/C sewer pipe: Helper (f/cm³) | Average peak exposures (up to 15 minutes): A/C pressure pipe: Operator (f/cm³) | Average peak exposures (up to 15 minutes): A/C pressure pipe: Helper (f/cm³) | Ranges of 8-hour time-weighted average concentrations: A/C sewer pipe: Operator (f/cm³) | Ranges of 8-hour time-weighted average concentrations: A/C sewer pipe: Helper (f/cm³) | Ranges of 8-hour time-weighted average concentrations: A/C pressure pipe: Operator (f/cm³) | Ranges of 8-hour time-weighted average concentrations: A/C pressure pipe: Helper (f/cm³) | Comments |
|---|---|---|---|---|---|---|---|---|---|
| Cutting Operations | | | | | | | | | |
| Hack saw | 0.18 | <0.10 | <0.10 | 0.11 | <0.10[a] | ND-<0.10 | ND | ND-<0.10 | Sampling time ranged from 12 to 15 minutes. A standard hack saw was used. |
| Snap cutting | <0.10 | <0.10 | <0.10 | ND | ND-<0.10 | ND-<0.10 | ND | ND | A Wheeler chain cutter (Model 2990) was used to make 5 to 8 cuts per sampling period (13 to 16 minutes). |
| Abrasive disc, wet | 42.10 | 10.20 | 65.00 | 49.20 | | | | | A gas-powered saw with a 25 cm diameter carbide blade was used with a water delivery rate to the blade of 2 to 3 gallons per minute. Two to three cuts were made per sample period (3 to 6 minutes). |
| Abrasive disc, dry | 35.50 | 64.00 | 20.30 | 59.70 | | | | | A gas-powered saw with a 25 cm diameter carbide blade was used to make one cut per sample period (30 to 45 seconds). |
| Chisel, hammer and rasp | 0.30 | 0.25 | 1.99 | 0.87 | <0.10 | <0.10 | <0.10-0.50 | <0.10-0.22 | Two cuts (4 to 6 minutes each) were made on the sewer pipe; cutting (one cut) the pressure pipe lasted 11 minutes. |
| Machining Operations | | | | | | | | | |
| Hand lathe | 0.15 | 0.13 | 0.51 | 0.22 | <0.10 | <0.10 | <0.10-0.12 | <0.10 | Twenty cm pipe was cut using a Pilot ratchet field lathe. Actual cutting time on the sewer pipe took 2 minutes, cutting time on pressure pipe lasted 4 minutes. |
| Power lathe | <0.10 | 0.10 | 0.29 | 0.18 | ND-<0.10 | ND-<0.10 | <0.10 | <0.10-0.14 | Twenty cm pipe was cut using a Pilot electric powered field lathe. Actual cutting time on the sewer pipe took 1/2 to 1 minute, cutting the pressure pipe lasted 1-1/2 minutes. |
| Cutting and machining with Doty machine dry | 3.83 | 0.29 | 1.90 | 2.23 | | | | | A Doty machine is custom-manufactured for cutting and machining and has three operating |

(continued)

TABLE 2 (continued)

| Operation | Average peak exposures (up to 15 minutes) | | | | Ranges of 8-hour time-weighted average concentrations | | | | Comments |
|---|---|---|---|---|---|---|---|---|---|
| | A/C sewer pipe | | A/C pressure pipe | | A/C sewer pipe | | A/C pressure pipe | | |
| | Operator (f/cm³) | Helper (f/cm³) | Operator (f/cm³) | Helper (f/cm³) | Operator (f/cm³) | Helper (f/cm³) | Operator (f/cm³) | Helper (f/cm³) | |
| | | | | | | | | | modes, dry, dry with shroud, and wet with shroud. Two to four cuts and two to four machining operations were completed per sample cycle. Sample periods were as follows Dory tool dry, pressure pipe 10 to 11 minutes and sewer pipe 9 to 15 minutes, with dry shroud, pressure pipe 13 to 17 minutes, and sewer pipe 12 to 14 minutes, with wet shroud, pressure pipe 13 to 18 minutes and sewer pipe 12 to 16 min. |
| Dry shroud | 0.23 | 0.10 | 1.29 | 0.18 | <0.10 | ND-<0.10 | <0.10-0.32 | <0.10 | |
| Wet shroud | 0.20 | 0.10 | 0.21 | 0.27 | <0.10 | ND | <0.10 | <0.10 | |
| [illegible] pressure pipe | 0.18 | <0.10 | | | <0.10 | | | | Tapering, which is similar in principle to that of the field lathe, was performed for 14 22 minutes on a 25 cm A/C air-duct pipe which had a wall thickness of approximately 0.64 cm. |
| Machining with manual lathe of differing sizes of pipe | | | | | | | | | |
| [illegible] cm pipe | | | ND | <0.10 | | | ND | ND | Testing included one cut and one machining operation. Actual cutting time lasted 3 minutes, machining lasted 8 minutes. |
| 20 cm pipe | | | <0.10 | 0.13 | | | ND | <0.10 | Testing included one cut and one machining operation. Actual cutting time lasted 2 minutes, machining lasted 10 minutes. |
| [illegible] cm pipe | | | <0.10 | <0.10 | | | ND | ND-<0.10 | One partial cut was made, including machining. Cutting time was 12 minutes, machining lasted 20 minutes. |
| <u>Hole Cutting</u> | | | | | | | | | |
| Pilot hole cutter | 0.44 | 0.23 | 1.65 | 0.38 | <0.10-0.12 | <0.10 | 0.10 | <0.10-0.10 | A gasoline-powered Pilot Hole Cutter was used to cut a 11 cm diameter hole with a small |

(continued)

## TABLE 2 (continued)

| Operation | Average peak exposures (up to 15 minutes): A/C sewer pipe, Operator ($f/cm^3$) | A/C sewer pipe, Helper ($f/cm^3$) | A/C pressure pipe, Operator ($f/cm^3$) | A/C pressure pipe, Helper ($f/cm^3$) | Ranges of 8-hour time-weighted average concentrations: A/C sewer pipe, Operator ($f/cm^3$) | A/C sewer pipe, Helper ($f/cm^3$) | A/C pressure pipe, Operator ($f/cm^3$) | A/C pressure pipe, Helper ($f/cm^3$) | Comments |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | center plug. Four holes were cut per sample activity. It took 1 minute to cut a hole in the sewer pipe and 1-1/2 to 2 minutes to cut a hole in the pressure pipe. |
| Hole cutting with drill, hammer and rasp | 0.23 | 0.13 | 0.22 | <0.10 | | | | | Activity included drilling 1.6 cm holes in a pipe in a circular pattern about 15 cm in diameter, after which the central portion was knocked out with a hammer and the rough edges smoothed with a rasp. Sampling times, which did not always cover the hammering and rasping operations, lasted 16 to 24 minutes for pressure pipe and from 17 to 21 minutes for sewer pipe. |
| Dry tap with Mueller J tool | <0.10 | <0.10 | <0.10 | 0.10 | ND- 0.10 | ND | ND-0.10 | ND- 0.10 | Mueller J tool is used for tapping pipe for customer service connections. A manually operated tool was used which cuts and threads a hole. Two 2.5 cm holes were cut. Sample periods for the pressure pipe lasted 14 to 29 minutes; for sewer pipe 15 to 18 minutes. |
| Tapping operations with Mueller B-100 | <0.10 | ND | 0.11 | 0.13 | ND- 0.10 | ND | ND-0.10 | 0.10 | A Mueller B-100 tool is used for tapping pipes already in place and containing water. Two holes were cut per sampling period, which for both pressure and sewer pipe covered 14 to 19 minutes. |
| <u>Coupling removal</u> | | | | | | | | | |
| Removal of Coupling with hammer and chisel | <0.10 | ND | 0.30 | <0.10 | ND- 0.10 | ND- 0.10 | 0.10 | ND- 0.10 | A hammer and chisel were used to make a longitudinal trough in the coupling, afterwhich a crowbar was used to separate the coupling. For pressure pipe this took 22 minutes per coupling. For sewer pipe the process lasted 10 minutes. Later tests were performed when couple removal lasted 10-30 seconds and 3 to 4 couples were removed. |

[a] No range is reported when both values were <0.10 $f/cm^3$.

[b] ND = Not detected.

2 fibers/cm$^3$. Theoretical TWA exposure ranges calculated assuming the duration of the operation ranged from 15 minutes to 2 hours, with the remaining time calculated at zero exposure, are also presented in Table 2.

Based on these findings, the AACPP has published a field manual entitled "Recommended Work Practices for A/C Pipe." Because of the widespread acceptance of this manual, the American Water Works Association adopted the same work practice recommendations and included them in their own work practice manual.[19]

Other exposure data that are based on laboratory glove box tests have been reported in the literature. The results of A/C pipe testing by GCA/Technology Division are presented in Table 3.[20] Fiber concentrations reported in the GCA study for A/C pipe sawing are similar to those found by the AACPP study. The concentrations associated with hammering, however, were substantially higher than those measured by the AACPP field studies. The higher laboratory readings may be attributed to fiber accumulation in the nonventilated air space of the glove-box chamber used in the testing program. Additionally, because the AACPP operation was performed outdoors, the lower levels recorded probably result from air dilution and wind movement.

TABLE 3. RESULTS OF LABORATORY A/C SEWER PIPE[a] PRODUCT TESTING PERFORMED BY GCA.[20]

| Operation | Sample time (minutes) | Fiber concentration SEM[b,c] (f/cm$^3$) | Fiber concentration Phase contrast[c] (f/cm$^3$) |
|---|---|---|---|
| Sawing | 1 | - | 59.4 |
| Sawing (repeat) | 1 | 65.1 | 56.5 |
| Hammering | 1 | 20.6 | 19.8 |
| Hammering (repeat) | 3 | 7.3 | 12.2 |

[a]A 25 cm (10 in.) section of Johns-Manville sewer pipe having a wall thickness of 1.6 cm (0.63 in.) was acted upon using an electric circular saw equipped with an aluminum oxide blade.

[b]SEM - Scanning Electron Microscopy Analysis.

[c]Fibers 5 μm or longer with a length to width aspect ratio of 3 or greater were counted.

With respect to A/C pipe handling operations, transportation poses little threat of fiber release. If pipe is broken during shipment there is a possibility for fibers to become airborne, although the fibers would likely be bound in a cement mortar matrix. Prompt cleanup with the proper vacuum equipment reduces fiber migration significantly.[15]

Beyond air releases, water transported through A/C pipe may carry asbestos fibers into the homes of a great number of people. Several studies on the asbestos fiber release from A/C pipe into potable water systems conclude that the fiber increase in the water passing through these pipes is slight.[3,9-11] The amount of release is generally dependent upon the aggressiveness of the water. The more aggressive a water is the greater its potential to aid in the release of fibers from the cement pipe walls. The aggressiveness of water is determined by factors such as pH, alkalinity and calcium hardness.[21]. Generally speaking, the higher the pH, alkalinity, and hardness of the water the less aggressive a water system is. According to Millette et al.,[21] 16.5 percent of the U.S. water utilities are highly aggressive, 52 percent are moderately aggressive and 31.5 percent are nonaggressive. However, it has been noted that even those systems which carry highly aggressive waters do not necessarily carry higher concentrations of asbestos fibers. This phenomena can be accounted for by the following factors:[22]

1. Type II autoclaved pipe is less susceptible to corrosion.

2. The majority of A/C pipe sold in the U.S. in the last 35 years has been Type II pipe.

3. Zinc, iron, and perhaps magnesium and organic materials can have a protective effect on A/C pipe.

Similarly, in the case of the enlargement or modification of existing water pipeline systems, Millette et al.[21] cite evidence that residents may have been exposed to transitory increased asbestos levels in drinking water as a result of improperly performed pipe tapping. This, however, should not occur if the proper tools are used. Available tapping devices flush cutting debris away thereby avoiding drinking water contamination and possible airborne fiber release.

With respect to health effects, studies have concluded that asbestos fibers consumed through drinking water do not appear to be intestinal carcinogens in humans or other animals.[1] The amount of asbestos naturally occurring in drinking water or added during passage through A/C pipes is so small that one could not expect it to induce intestinal cancer; all epidemiological studies are consistent with this view.[1]

Under certain conditions, it may be possible for asbestos fibers in water to become airborne. For example, certain types of commercial and residential humidifiers operate on the principle of atomizing water into forced heating air. If it is assumed that the water supply to this type of humidifier contains asbestos, it may be possible that the fibers are emitted into room enclosures through heating ducts.[1] The following hypothetical calculation[1] attempts to estimate the levels of asbestos which may be added to indoor air as a result of humidifiers using water containing asbestos. Levels of asbestos monitored in water supplies have ranged from $10^5$ to as high as $10^7$ fibers/liter; also, aggressive waters can cause A/C pipe to raise asbestos levels to the same ranges. For the purposes of this calculation, the severe case is assumed that the asbestos water concentration is $10^7$ fibers/liter. It is assumed that an atomizing humidifier is being used by a homeowner, whose house contains roughly 400 $m^3$ (14,000 $ft^3$), and is connected to the central heating system. The humidifier injects one liter of water, containing $10^7$ fibers/liter, into the heating system each hour. Therefore, during the course of one day, the asbestos air concentration of the house could theoretically be raised:

$$\frac{24 \text{ hr} \times 10^7 \text{ fibers/hr}}{400 \text{ m}^3} = 6 \times 10^5 \text{ fibers/m}^3 = 0.6 \text{ fibers/cm}^3 = 600 \text{ ng/m}^3$$

This calculation is completely theoretical and is not based upon any indoor air monitoring.[1]

## REFERENCES


1. Meylan, W. M., et al. 1978. Chemical Market Input/Output Analysis of Selected Chemical Substances to Assess Sources of Environmental Contamination: Task III Asbestos. Prepared for the U.S. Environmental Protection Agency, Office of Toxic Substances, EPA-560/6-78-005.

2. Levine, R. J., Editor. Asbestos: An Information Resource prepared for the U.S. Department of Health, Education, and Welfare. National Cancer Institute. (NIH) 79-1681, May 1978. p. 63.

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

4. Pye, A. M. A Review of Asbestos Substitute Materials in Industrial Applications, Journal of Hazardous Materials 4.1.2. 3(1979), p. 128.

5. Olson, H. L. Asbestos in Potable Water Supplies, Journal of American Water Works Association. 66:515-518. 1977.

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

7. Survey of Water Main Pipe in U.S. Utilities Over 25,000 Population. American City, Morgan-Grampian Pub. Co., Pittsfield, Mass. 1975.

8. Survey of Sewer Main Pipe in U.S. Utilities Over 250 Population American City, Morgan-Grampian Pub. Co., Pittsfield, Mass. August 1975.

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

10. Buelow, R. W., et al. Field Investigation of the Performance of Asbestos Cement Pipe Under Various Water Quality Conditions. Prepublished copy. Water Supply Research Division, Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, Ohio, April 1977, EPA-600/2-77-020.

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

12. American Water Works Association. AWWA Standard for Asbestos-Cement Transmission Pipe, 46 cm through 107 cm (18 through 42 inches) for water and other liquids. AWWA C402-77, January 30, 1977.

13. Clifton, R. A., Asbestos in 1978 Mineral Industry Surveys, U.S. Bureau of Mines, Washington, D.C. August 22, 1979.

14. Cogley, D., et al. Life Cycle of Asbestos in Commercial and Industrial Use Including Estimates of Releases to Air, Water and Land. Draft Report Prepared by GCA/Technology Division for U.S. Environmental Protection Agency, Office of Toxic Substances, Under EPA Contract No. 68-02-3168, November 1981.

15. Research Triangle Institute, et al. Asbestos Dust. Technological Feasibility Assessment and Economic Impact Analysis of Proposed Federal Occupational Standards, Part I. U.S. Department of Labor, OSHA, NTIS No. RTI/1370/02-01-F, September 1978.

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

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

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

19. Association of Asbestos Cement Pipe Producers, Recommended Standard for Occupational Asbestos Exposure in Construction and Other Non-Fixed Work Operations. Internal Report, February 7, 1980.

20. Cogley, D., et al. The Experimental Determination of Asbestos Fiber Size Distribution During Simulated Product Use. Draft Report Prepared by GCA/Technology Division for U.S. Environmental Protection Agency, Office of Toxic Substances, Under EPA Contract No. 68-02-3168. May 1981.

21. 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. EPA-600/1-79-038.

22. McCullagh, S. G. Is There a Risk to Health in Using Asbestos-Cement Pipes for the Carriage of Drinking Water. Ann. Occup. Hyg., 23(2) 189-193.

## SECTION 3

## ASBESTOS PAPER

### INTRODUCTION

Asbestos paper products include any product manufactured on a fourdrinier or cylinder paper-making machine. Products in this category are all manufactured using similar asbestos handling, production, and emission control equipment. The products do differ, however, in the amount of asbestos they contain and their end-uses.

The 1980 consumption of asbestos fibers for the production of paper products was estimated by the U.S. Bureau of Mines to be 90,020* metric tons or 25.1 percent of all asbestos consumed in the United States.[1] Thus, it ranks second to cement-pipe in the amount of asbestos consumed annually in the United States. Asbestos paper products include eight general categories, which are listed below in descending order of annual asbestos consumption (category percentage):

- Flooring Felts (45)
- Roofing Felts (33)
- Beater-Add Gasket (9)
- Pipeline Wrap (5.6)
- Millboard (3.0)
- Specialty Papers (2.4)
- Commercial Paper (1.3)
- Electrical Insulation (0.4)

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*This figure was arrived at by rearrangement of the Bureau of Mines (BOM) data such that Paper Products would now include roofing and flooring felt figures, which were extrapolated from BOM's roofing and flooring product categories, respectively.

The basic manufacturing operations are similar for most asbestos paper products. The raw materials, which include asbestos fibers, binding fillers and various other ingredients, are blended in a mixing operation. A pulp beater or hollander is used to mix the fibers and ingredients with water to form a stock, which typically contains 3 percent asbestos fiber. This base stock is stored in a container vessel (chest) until needed. Upon leaving the storage chest, the stock is diluted to as low as 0.5 percent asbestos fiber in a discharge chest. The amount of dilution depends upon the quality of the paper being produced.[2]

The asbestos paper is now formed on either a fourdrinier-type or a cylinder-type paper machine. The cylinder-type machine is more widely used in the asbestos industry. Formed paper, carried along on a felt conveyor, is dried by either applying heat causing evaporation or pressure, in the form of rollers. The rollers squeeze the water out of the sheets. Calendering follows to produce a smooth side and then the paper is wound onto a spindle.

It is estimated that 60 percent of asbestos paper goes through some form of secondary fabrication before reaching the end-user. Typically finishing operations include slitting, sawing, punching, pressing, and laminating. Typical asbestos exposure ranges during manufacture have been estimated at 1.0 to 3.5 $f/cm^3$.[3]

The products contained in this category have a variety of uses in industrial, commercial and residential settings. Most are used in construction type work as an insulation/protector from the environment around the object being built or installed. Others perform as insulators and/or fire-retardants in appliances or some other type of apparatus which use requires it to have the ability to withstand high temperature. While still others are used as filters to purify liquids such as alcoholic beverages and fruit juices.

In this report, only the major asbestos paper product groupings are presented. While hundreds of individual asbestos paper products may exist, many are used in a manner similar to those described in the following discussions and almost all originate from the same primary manufacturing process.

## FLOORING FELTS

### Product Manufacturing and Composition

Asbestos is used in flooring felts to add dimensional stability and resistance to moisture, rot, and heat.[4] The asbestos flooring felts are composed of about 85 percent asbestos and 15 percent latex binder.[5] The latex binder is normally a styrene-butadiene type, although acrylic latexes have been used in the past.[6] The type of asbestos used is chrysotile, with shorter grades, grades 5 and 7, primarily being employed.

Asbestos flooring felt is manufactured into a final consumer product by coating one side of the felt with a resilient vinyl-type surface. The surface coating applied is usually a plastisol or an organosol. The vinyl surfaces are applied to the asbestos felt by various extrusion coating and laminating and spread coating methods. After or during the coating operation, the flooring is decorated to enhance its appearance. The vinyl sheet is then edge trimmed by razor scoring or shear cutting and wound into a sheet product.

Flooring felt production accounts for 45 percent of the asbestos consumed in the paper products category or about 40,509 metric tons per year in 1980[1]. From the period 1971-1975 the growth rate was estimated at 14.8 percent annually.[5] Today, industrial sources indicate that the growth rate for asbestos flooring felts will be minimal through 1985.[5,6]

Secondary and Consumer Use

Vinyl-asbestos sheet flooring felt is used in commercial and residential applications. The asbestos felt backing is used because it adds dimensional stability to the flooring, it is resistant to moisture and rot and has an excellent fire protection rating.

During installation vinyl-asbestos flooring is cut to the size of the floor area it is to be applied to. The cutting is accomplished using a razor, knife, or shears. The subfloor is then coated with adhesives that secure the vinyl-asbestos sheeting to the floor. All cutting and installations are done by hand.

For certain applications asbestos felt is used without a vinyl surface coating.[6] Under these conditions, the flooring felt is adhered directly to the floor, with final flooring applied on top of the asbestos felt. The final flooring may be vinyl tile, vinyl sheet or carpeting. This type of application is usually restricted to concrete floors where moisture problems exist. The asbestos paper helps to transfer water to the walls.

The life span of asbestos-containing flooring felt is dependent on the amount of traffic the surface layer must withstand. It has been estimated that a normal life span is between 10 and 30 years. During the life of the flooring, the top coat will be worn away by prolonged wear. The surface material is usually replaced long before the vinyl foam layer or size coat are lost to expose the underlying felt.[7]

Environmental Release

During normal use, few or no asbestos fibers are released from asbestos-containing flooring felt. The fibers are considered locked-in; that is, the fibers are sufficiently bonded to one another by inorganic cements, thermosetting polymers, thermoplastic resins, or elastomic compositions such that they cannot be readily separated or removed from one another or the product during normal product handling and use. During installation the vinyl-asbestos sheet flooring is cut with sharp knives or scissors at which time few fibers are expected to be released.[7] The adhering of vinyl sheet flooring on top of the felt further isolates the asbestos fibers from the environment.

Foot traffic moving over the flooring and continual washing, wears away the vinyl coating, but does not wear down to the asbestos containing flooring felt. By the time the surface layer starts to wear away the floor design is lost and the flooring would mostly like be replaced.

Environmental release of asbestos fibers may occur during the removal of old, worn out vinyl sheet flooring. Although the back of the felt is generally covered with adhesive, it is possible in some instances to have felt pieces split apart and remain attached to the floor. Fibers in the residual pieces remain bound in the flooring felt by the resin matrix. Removal of the residual pieces adhering to the floor by sanding, however, could release asbestos fibers to the ambient environment. Few or no fibers are expected to be emitted, however, if the material is thoroughly wetted prior to scrapping or sanding.[7]

Asbestos fiber release during the installation and removal of vinyl sheet flooring has been monitored. Table 4 presents the results of tests conducted for the Resilient Floor Covering Institute (RFCI) by SRI International. As shown, fiber releases are well below the OSHA TWA limit of 2 fibers/$cm^3$.

ROOFING FELTS

Product Manufacturing and Composition

Asbestos roofing paper consists mainly of 85 to 87 percent asbestos along with 8 to 12 percent cellulose fiber and 3 to 5 percent starch binder.[5] The paper is made in either single or multilayered grades and may have fiber glass filaments or strands of wire embedded between paper layers for reinforcement. Chrysotile asbestos, grades 6 and 7, are principally used for making roofing felts. The felts are converted into conventional roofing products by saturation of the felt with asphalt or tar.

Roofing felt production accounts for 33 percent of the asbestos consumption in the paper products category or an estimated 29,707 metric tons in 1980.[1] Industry sources believe the market had peaked in 1979.[1] It is expected that the market will decline at a rate of slightly less than the 5 percent per year between 1982-1985.[5,6] The two major reasons for the expected decline are:

1. Competition from fiberglass roofing, and

2. Labor unions[1] and the construction industries[1] apprehension about using asbestos-containing products.

TABLE 4. ASBESTOS FIBER CONCENTRATIONS ASSOCIATED WITH THE INSTALLATION AND REMOVAL OF VINYL SHEET FLOORING BACKED WITH ASBESTOS FLOORING FELT[a]

| Site description | Age of vinyl sheeting and method of attachment (years) | Operation | Measured asbestos TWA range[b] (fiber/cm$^3$) |
| --- | --- | --- | --- |
| Residential home - kitchen | New adhered | Installation | 0.01 to 0.02 |
| Residential home - kitchen | 6-adhered | Installation | 0 |
| Residential home - kitchen | 13-adhered | Installation | 0.06 to 0.07 |
| Residential home - foyer | 2-adhered | Installation | 0.01 to 0.06 |
| Residential home - kitchen | 8-unadhered | Installation | 0.03 to 0.10 |
| Residential home - kitchen | 13-adhered | Partial removal[c] | 0.02 to 0.04 |
| Residential home - foyer | 2-adhered | Total removal[c] | 0.04 |
| Residential home - kitchen | 8-unadhered | Total removal[c] | 0.01 |
| Residential home - kitchen | 6-adhered | Wear layer removal | 0.08 to 0.16 |
| Residential home - kitchen | 6-adhered | Wet scrape felt layer | 0.41 |
| Residential home - kitchen | 6-adhered | Dry scrape felt layer | 1.12 to 2.03 |
| Residential home - kitchen | 6-adhered | Dry scrape felt layer | 0.83 to 1.06 |

[a]Source: Comments on the advance notice of proposal rulemaking on the commercial and industrial use of asbestos fibers. The Resilient Floor Covering Institute. Washington, D.C. February 18, 1980.

[b]Values have been rounded by GCA/Technology Division.

[c]Operations were performed according to Resilient Floor Covering Institute practices that do not include sanding, sweeping, or dry-scaping.

A 47 percent drop from 1978 to 1980 was mainly attributed to poor economic conditions in the construction industry.[1] An extended 20 year forecast projects an annual asbestos consumption rate of 15,520 metric tons.[1] This forecast was developed prior to the release of 1980 asbestos figures.

## Secondary and Consumer Use

Asbestos roofing paper is used on all types of buildings, whether they be commercial, residential, or industrial. Two types of roofs primarily use this material, built-up roofs and roofs that need an underlayment. More than 60 percent of asbestos roofing paper is utilized in the reroofing industry and the remainder is for new construction.

There are three basic types of built-up roofs; gravel surface, mineral surface, and smooth surface. Built-up roofing material is usually prepared at the project site. The asbestos roofing felt is cut to required sizes and shapes using razors, knives or shears. Strips of paper roofing are then layed on top of each other with hot asphalt or tar spread between the layers to provide adhesion and weatherproofing. The built-up roofing is attached to the roof's deck by tar (adhesion) or is nailed down. After laying the last strips of asbestos roofing felt, the roof surface is covered completely with a coat of asphalt, onto which gravel or ground minerals are applied.

As an underlayment for other roofing materials, asbestos roofing felt is attached to the building surface with adhesives, such as tar or asphalt, or by nailing. The asbestos felt is then covered with shingles, cement sheets, or other forms of roofing material.

Built-up roofs comprised of asbestos roofing felts have an expected life span of at least 20 years.[7] With an aggregate surface application, the roof will reach a point of failure and require refurbishing prior to any direct exposure of the enclosed felt. Older smooth-surface roofs, however, may weather to a point where the asbestos fibers are exposed.

## Environmental Release

Asbestos fibers contained in roofing felts are bound within the product matrix. The degree of bonding as determined by the latex resins and the asphalt should be adequate to essentially eliminate any liberation of fibers. During installation the asbestos paper roofing is cut with sharp knives or shears.[7] The attaching of the roofing felts to the roof deck with asphalt or tar further isolates the asbestos fibers from the atmosphere and the effects of weathering.

As stated above, the weathering of the roofs is dependent on the type of surface covering. A mineral (gravel) surface wears in such a way that it will reach a point of failure prior to the exposure of the roofing felt material, while a smooth surface roof may wear to a point where the roofing felt will be exposed. Under the latter condition, the breakdown of the top coat exposes the underlying felt, which can release asbestos fibers by wind and water erosion. The top layer of felt reportedly remains intact for a period of many years indicating a slow degradation with extremely low levels of fiber release.[7]

The potential for asbestos fiber release during the removal of worn-out roofing material is minimized because the fibers are bound within the roofing matrix. In addition, an asphalt top covering on the roofing felts keeps the top layer together and protects the material from surface weathering. Asbestos fibers have been detected (0.007 to 0.54 $f/cm^3$) in the ambient air surrounding a roof removal work site.[8] It was not determined whether the asbestos detected was due to the removal work or represented ambient background levels.[8] During the removal process, old roofing material was cut into small 0.19 square meter (2 feet square) sections using a circular saw and then ripped up using shovels.

BEATER-ADD GASKET

Product Manufacturing and Composition

There are two major types of asbestos-containing gaskets, compressed sheet and beater-add sheet. Compressed sheet gaskets will be discussed in Section 6 under Gaskets and Packing. Beater-add asbestos paper gaskets consist of 60 to 80 percent asbestos fibers and 20 to 40 percent binder, usually a latex compound.[6] Almost all beater-add gaskets are formulated using various grades of chrysotile asbestos. The chemical composition of the binder used determines the suitability of the gasket to its end use application. Beater-add gaskets are so named due to the fact that the binder is added during the beater process of the production steps.[4]

Beater-add gaskets are usually produced in sheet form or sheet-roll form. Thicknesses vary from very thin paper to that resembling millboard, 0.6 to 1.3 cm (0.25 to 0.5 in.) thick. Beater-add gasket paper is sold in this form to secondary fabricators. The fabricators 'cut-out' the gasket material to sizes and dimensions specified by their customers. The gasket material can then be used as is or it can be modified by adding reinforcements such as wire inserts or sheating the paper with metal foils, plastics or cloth.[6]

The amount of asbestos consumed annually to manufacture beater-add gaskets is 9 percent of the total amount consumed by paper products or about 8,100 metric tons.[1] Throughout the early '70s, the growth rate for asbestos paper gaskets has been roughly 9.8 percent per year and was expected to continue at that rate into the future.[5] In 1979, manufacturers were still projecting continued growth but at a rate less than the 9.8 percent annual increase predicted by Little, 1976.[5] The reason for such a strong growth rate is that there are few competitive products.

Secondary and Consumer Use

Beater-add gaskets are used in industrial and commercial applications to obtain a tight seal between two rigid elements such as connections between piping, covers, joints and openings of all types.[4] The major industrial user of this type of gasket is the automotive industry. The material is used as head gaskets, carburator gaskets, manifold gaskets, and oil and transmission gaskets, to name a few.[6] In addition, asbestos gaskets are widely used in other transportation applications, such as trains, airplanes, and ships. Further, they are used in a variety of industrial and commercial equipment, including heat exchangers, boilers, furnaces, and pipe connections. The chemical industry uses asbestos gaskets extensively for equipment connections because of the chemical inertness of asbestos.[4]

Prior to installation, the asbestos-containing paper material (roll form) is die-cut to form gasket shape. The gaskets are normally cut at a fabricating shop although some could be cut by hand at the job site for specific applications. Since a gasket is designed to fit between two adjoining elements, its faces are never exposed; i.e., they are completely isolated from the ambient environment.

The life span of a gasket is dependent on the severity of use and maintenance practices. It has been estimated[5] that 25 percent of the gasket materials consumed annually have less than a 1 year useful span, 60 percent are used for maintenance and long-time replacement, with the remaining 15 percent for new installation.

Environmental Release

Asbestos fibers contained in the gasket material are locked in the product matrix and therefore are not readily dislodged during normal handling. Measured asbestos fiber levels resulting from secondary fabricating operations such as cutting and packaging have ranged from 0.1 to 0.5 fiber/$cm^3$.[10] No fiber release is expected during material installation because the gaskets have been precut to size and in many cases covered with an adhesive sealant.

Asbestos release during a gasket's useful life time is extremely small because the faces of the gaskets are isolated from the environment as are the edges since most are usually covered with metal.

The removal of the gaskets is not a source of asbestos fibers if the gasket is removed in one piece. If any portion sticks to the surface it is usually scraped off. This action is not expected to liberate asbestos fiber because the bonding material should remain intact. However, if it is dry and brittle, fiber release is possible. Should sanding be required to remove the asbestos gasket, wetting it down prior to commencement of the activity will reduce the potential for fiber release. No asbestos fiber release data have been reported for beater-add gasket use activites.

## PIPELINE WRAP

### Product Manufacturing and Composition

Asbestos pipeline wrap is manufactured by a process similar to that employed to manufacture roofing felts. During processing, the pipeline wrap is pulled through a bath of hot asphalt or coal tar until it is thoroughly saturated. After saturation, the paper passes over a series of hot rollers to allow the asphalt or coal tar to permeate the paper. Following impregnation, the felt is air dried, rolled and packaged for sale.

The amount of asbestos used to manufacture pipeline wrap represents 5.6 percent of the asbestos consumed in the paper product category, or about 5,041 metric tons per year.[1] The predicted future for new pipeline construction is one of continued strong growth. However, competitive alternatives to asbestos wrap, such as plastic wrap, epoxy resins, and extruded coatings, are becoming more available, therefore increasing competitive pressures.[11] Cost effectiveness is still in favor of asbestos pipe wraps. Although, with the rapidly rising cost of asbestos fiber and coal tar products, the advantage will begin to shift away from asbestos.[6] Consequently, growth rates may decline or stagnate over the next few years.

### Secondary and Consumer Use

Asbestos paper wraps are used by industries and municipalities to protect underground pipelines from corrosive soil, chemicals, rotting, and decay. The major user of asbestos wraps is the oil and gas industry. Other industries such as the chemical industry, with underground steam and hot water piping, use asbestos paper wrap because of its rot resistant property. The life span of the underground asbestos pipe wrap is the same as the pipe it is wrapped around. Very seldom if ever is a pipe rewrapped unless it is damaged. Asbestos paper wrap use above ground is minimal. The only reported use is for cooling towers where rot and decay are also a problem.[12]

Installation of the asbestos paper wrap is usually done by machine winding. Hand winding is used only for special field fabrication or damage repairs. The wrapping paper can be attached or bonded to the pipe surface by special adhesive coatings or by hot enamels which are coated to one side of the paper. The coatings or enamels also aid in the corrosion protection of the pipe.

### Environmental Release

Because the fibers are bonded by the latex binders and then further locked in by an asphalt or coal tar coating, the release of asbestos fibers to the atmosphere is expected to be minimal. Laboratory experiments simulating pipeline wrap removal activities have been performed by GCA.[13] Monitoring results of fiber release from cutting, tearing, and crumpling activities are presented in Table 5. As shown, cutting and tearing caused no or a minor amount of fiber release. Crumpling, however, did increase the measured air concentration to a level above OSHA's 2 fiber/$cm^3$ TWA standard. The simulated activities were performed in a nonventilated glove box chamber. Such a sampling environment may have resulted in increased fiber levels due to fiber accumulation in the confined air space.

TABLE 5. ASBESTOS FIBER[a] CONCENTRATIONS ASSOCIATED WITH SIMULATED PIPELINE WRAP REMOVAL ACTIVITIES[13]

| Activity performed | Duration (minutes) | Phase contrast analysis ($f/cm^3$) | SEM[b] analysis ($f/cm^3$) |
|---|---|---|---|
| Cut | 1 | 0 | 0 |
| Tear | 1 | 0 | 0 |
| Tear | 3 | 0.9 | 0 |
| Crumple | 3 | 1.9 | 6.1 |
| Crumple | 4 | 14.5 | 6.1 |

[a]Fibers counted were ≥5 μm in length and had a length to width aspect ratio of 3 or greater.

[b]Scanning electron microscopy.

As stated above, attachment of the wrapping paper to piping is done by machine with special adhesive coatings or hot enamels. During application there should be no release of asbestos fibers since the material remains intact. Also, the binders and the asphalt or coal tar add extra strength to hold the material together. For these reasons, once the wrapped pipe is installed, there should be no fiber release to the environment.

## MILLBOARD

### Product Manufacturing and Composition

Millboard consists of 60 to 95 percent asbestos and 5 to 40 percent binders. Chrysotile is the most common type of asbestos used, with grade 5 preferred.[6] The binders are usually portland cement and starch. Clay, limestone, mineral wool, and several other materials are frequently used as fillers or to provide special qualities. The amount of each material used in production varies widely. Purchasers frequently specify the ingredients and composition of the millboard they want to ensure that the product meets their requirements.

Millboard is manufactured in individual sheets, this being the only difference from the continuous sheet production of asbestos paper. The process uses a wet cylinder paper machine equipped with one or two cylinder screens, conveying belts, pressure rolls, and a cylinder mold. A cylinder rotating in a vat of slurry picks up the fibers which are removed from the cylinder and drawn through a press for partial dewatering. The sheet is wound on another cylinder until the desired thickness is achieved, at which time the built-up layer is cut and peeled off the cylinder. The sheet is then dried until it contains 5 to 6 percent water.[4]

Rollboard, a form of millboard, differs from millboard in that it is thin enough to permit flexibility. Rollboard, however, cannot withstand temperatures greater than 177°C (350°F) because of its thinness and starch binder composition.

Millboard production accounts for 3 percent of the asbestos consumed in the paper products category, or about 2,700 metric tons.[1] The outlook for increased millboard production is unclear. In the mid to late seventies, millboard production was predicted to grow at an annual rate of 0.9 to 1 percent through 1985.[5] Today, millboard production is predicted to decrease, as manufacturers find acceptable and economical substitutes. This is presently the situation for heat and flame protection applications. The gasket application of millboard is currently stable because there are no substitutes for it.

Secondary and Consumer Use

Millboard is used for a variety of industrial, commercial, and residential applications. Finished millboard is purchased by (1) secondary fabricators who install it or incorporate it into other products, (2) industrial distributors who supply such operations as steel mills and glass factories, (3) construction workers as building material, and (4) asbestos specialty houses.[6]

Millboard used for boiler gasket applications is usually die-cut by a secondary manufacturer, but if a special design is needed, the material may be cut by the product consumer. Millboard is also used as a filler for metal reinforced gaskets, which are frequently used on small air-cooled engines such as lawnmowers. Another application includes gaskets used for laying pipes at aluminum plants.

Millboard use as a flame or heat barrier has increased with the upsurge in wood and coal burning stoves in residential settings. It is also used in the manufacture of prefabricated fireplaces. Residential uses extend to the linings of safes, stoves, heaters, and electrical switch boxes, stove pipe rings, stove mats, and table pads.

Commercial applications include heat or flame barrier shields for welding and soldering operations, office partitions, and fireproof wallboards. Industrial uses, which are numerous, include mats to place hot products on, linings for furnaces, oven insulation, sealings for holes and flues in roofs of furnaces, thermal door gaskets, and heat protection walls.

In both the glass and steel industries, millboard rolls and discs are used to convey flat glass or annealed or pickled steel from one point in the manufacturing process to another. Millboard is used because it is heat resistant and it does not disfigure the product.

Millboard is also used by manufacturers as slip planes to insulate the silica furnace linings of an induction furnace. When the silica lining wears out and needs to be replaced, the millboard must also be replaced.

In summary, millboard is one of the most widely used asbestos-containing products. Its numerous applications are listed in Table 6. Attributes that make it so versatile include the way in which it can be acted upon during installation; millboard is easy to cut, can be punched into shape, and can be wet molded and is compressible.

The useful life span of a piece of installed millboard is indeterminable because of its varied uses. Depending on its application, a piece of millboard could have a short life expectancy as a result of being the lining for an induction furnace or a long life expectancy as a fire barrier liner of a door or wall partition.

Environmental Release

Asbestos fiber release from handling millboard is related to the material's composition and its end use. Peak fiber releases from handling millboard will occur during preparation for installation, including cutting and shaping, and removal, especially if the millboard needs to be scraped off. Because the asbestos composition of millboard can vary greatly, the potential and magnitude of asbestos fiber release change accordingly.

Installation of millboard requires it be cut to size to accommodate its intended use. Cutting is accomplished using a saw, knife, or shears. In a controlled laboratory glove box test,[8] scoring and sawing of millboard resulted in measured fiber levels of 8.4 and 6.2 fibers/$cm^3$, respectively, as determined by scanning electron microscopy (SEM) analysis.

With respect to fastening millboard to support structures, adhesives, nails, or bolts are used. When used for an enclosed application, such as the top or side panels of an oven, the millboard may simply be held in place by a metal guide frame. To simulate the fastening activity, a piece of millboard was subjected to hammering for 10 minutes. Again, this test was performed in a laboratory controlled glove box. The resultant monitored fiber level was reported to be 1.4 fibers/$cm^3$ as determined by SEM.[8] In all three of these cited tests, the glove box results may be higher than those one would expect under actual field conditions. Fiber accumulation in the nonventilated air space of the glove box chamber could account for the relatively high fiber levels recorded.

Once installed, asbestos fiber release from millboard should be minimal. In the case of millboard gaskets, both faces are normally isolated from the external environment and the edges are usually covered. Millboard used as a fire retardant or insulating barrier is normally enclosed in walls, ceilings, and doors, thus preventing any asbestos fiber release to the environment. The same is true for millboard slip planes, in that the millboard is usually contained within a finite space. Once installed for insulation, it is expected to last indefinitely.

TABLE 6. INDUSTRIAL, COMMERCIAL, AND RESIDENTIAL USE OF ASBESTOS MILLBOARD AND INDIVIDUAL APPLICATIONS[12]

| User | Individual application |
|---|---|
| Industrial | |
| General | In boilers, as gaskets, which may be metal reinforced, as flame and heat barriers, as slip-planes for furnace linings, as rolls or discs to convey a material from one point in the manufacturing process to another. |
| Electrical | Thermal protection in large circuit breakers |
| Appliance | Fire-proofing 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 babbitt operation |
| Ceramic | Low mass kiln cars |
| Glass | As insulation in glass tank crowns, melter, refiner, sidewalls, etc. |
| Commercial | |
| Metal-clad doors | Between outside metal and wood core |
| Office partitions | Between metal sheets, valued as a fireproofing and sound deadening material. Very large potential market |
| Soldering fixtures and soldering blocks | |
| Spark and glare shields in welding shops | |
| Fireproof wallboard | |
| Washers in electrical apparatus | |
| Linings for safes, drycleaning machines, incinerators, heater rooms | |
| Garage paneling | |
| Residential | |
| Linings for home safes, stoves, heaters and electric switch boxes | |
| Tent shields | |
| Stove pipe rings | |
| Stove mats, table pads[a] | |
| Perfume rings for oil lamps | |

[a]Millboard is no longer used in toasters as element boards for wire insulation. It has been replaced by reconstituted mica.

In the steel and glass industries, millboard rolls or discs are subjected to extensive wear. Based on an extensive literature search, the amount of asbestos fibers released from such activities has not been determined yet.

Removal of millboard has the potential to release asbestos fibers. The amount of release is estimated to be similar to, if not more than, the release expected during installation.

SPECIALTY PAPER PRODUCTS

There are six major types of asbestos specialty paper:

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

Other specialty paper products are produced, but asbestos is used in minimal amounts.

Cooling Tower Fill

Product Manufacturing and Composition--

Cooling tower fill is manufactured using a base paper consisting of two grades of chrysotile asbestos and a few different latex binders depending on the manufacturer. The base paper (90 to 91 percent asbestos) is sold to the tower fill manufacturer who saturates it with thermosetting resins. Fluted sheets, formed by preceding operations, are then bonded together to form packs, the edges of which are normally reinforced. In use, the corrugated surface of each section of paper increases the surface area of the water film passing over it, thereby improving cooling efficiency.[6]

The amount of asbestos paper being used as cooling tower fill is decreasing.[6] However, in those applications where high heat and chemical resistance are required, asbestos-containing tower fill will continue to be used. In 1976, it was found that several thousand tons of asbestos fiber were consumed annually to make cooling tower saturates.[5] Although consumption figures are not available, the amount of asbestos fiber used since 1976 has been declining and is presumed to continue to do so. One reason for the decline in consumption is that asbestos paper and processing is becoming too expensive when compared to readily available substitutes.

Secondary and Consumer Use--

Asbestos-containing cooling tower fill is an industrial product, not a consumer product. Asbestos is used to manufacture cooling tower fill because of its heat and chemical resistant properties. The installation process simply involves attaching the fill material to the inner walls of the cooling tower. The life span of the cooling fill is not known, but it is expected to be as long, if not longer, than that of other asbestos paper products.

Environmental Release--

During processing, the asbestos paper is saturated with an oil-based product, cut to size, and then layered. As a result of this treatment, asbestos fiber release during handling and use is expected to be minimal. A study[14] of the pollution potential from cooling towers using asbestos paper fills indicated virtually zero asbestos release to the environment.

## Transmission Paper

Product Manufacturing and Composition--

Asbestos transmission paper is a latex-based product made with chrysotile asbestos.[6] The base transmission paper is saturated with phenolic resins to create a very hard and resilient product. After saturation and hardening, the paper product is then cut to required sizes in the shape of discs. The average automobile with an automatic power shift contains from 8 to 12 of these paper-lined discs. In 1977, an estimated 900 tons of asbestos fibers were consumed in the production of automatic transmission paper.[11] Present consumption and future projections are not available.

Secondary and Consumer Use--

Transmission discs are industrial and limited retail products. The general consumer population would not normally be involved in handling such products. Installation of the discs would take place at automotive assembly plants or local service garages. With respect to use, the discs are enclosed within the transmission housing and are coated with a lubricating oil to reduce friction wear. These two factors virtually eliminate the potential for environmental fiber release during use. Wear of the discs depends on the amount of slippage during gear shifts. Once the transmission can no longer hold a gear shift, it must be repaired or replaced.

Environmental Release--

Because the asbestos-containing paper is impregnated with a phenolic resin before being cut to size, the amount of asbestos material released is expected to be minimal during installation. As stated above, during use, the asbestos transmission paper is completely isolated from the environment. Asbestos release while repairing or replacing the transmission or its parts should also be minimal as discs are coated with a transmission fluid when they are removed. No monitoring data for transmission paper use or handling was discovered during the literature search.

## Beverage and Pharmaceutical Filters

Product Manufacturing and Composition--

Asbestos filters used in the beverage and pharmaceutical industries are made on a conventional fourdrinier papermaking machine.[6] The amount of chrysotile asbestos used varies from a high of 50 percent for pharmaceutical grades to as low as 5 percent for rough filtering applications.[12] The asbestos used for filters is a very high purity grade. Other filter constituents include cellulose fibers, various types of latex resins, and occasionally diatomaceous earth. In 1979, the estimated quantity of asbestos fiber consumed to manufacture asbestos-containing filters was 90 metric tons.[11] This is down from over 900 metric tons annually in the early 1970's, and forecasts are for the disappearance of asbestos filters as more cost-effective substitutes are developed.[11]

Secondary and Consumer Use--

Asbestos-containing filters are used primarily by the beer, wine, and liquor industries. As recently as 1979, about 30 percent of the wine, 10 percent of the beer, and 25 percent of the distilling producers used some form of asbestos filtration.[6] Asbestos paper filters are also used for specialty applications in the cosmetic and pharmaceutical industries and for the filtration of various fruit juices. Again, these uses are primarily industrial and not general consumer. The life span of filters varies from a one-time application to being used until they are clogged or no longer effectively filter out undesirable materials.

Environmental Release--

Asbestos fiber release during asbestos filter use has been monitored extensively to identify potential health concerns. Gaudichet et al.[15] tested 42 different types of wines before and after filtration and found 15 to be significantly positive for chrysotile asbestos. Concentrations ranged from 2 to 60 x $10^6$ fibers/liter. Table 7 presents a comparison of the results from the six samples tested after undergoing various common filtration processes.

## Electrolytic Diaphragms

Product Manufacturing and Composition--

Asbestos fibers are used as a filtering medium in an electrolytic process that produces chlorine and caustic soda. The process involves the electrolysis of a brine solution whereby chlorine is produced at an anode element and hydrogen, together with sodium hydroxide, at a cathode element. Diaphragm cells coated with asbestos fibers are used to separate the anode from the cathode element. With use, the diaphragm becomes clogged with migrating particles. When the efficiency of the cells drops off, the diaphragms are removed from the cells and renewed. The useful life span of a cell will vary depending on use but can last from 6 months to 1 year.

TABLE 7. ASBESTOS CONTAMINATION IN FILTERED WINES[15]

| No. | Filtering process | Number of asbestos fibers ($10^6$/l) | Mean length (μm) | Other particles |
|---|---|---|---|---|
| 1 | Original wine | 2 | 2.5 | Diatomite remains and some phyllosilicates |
| 2 | Filtration with continuous injection of filter additive ASBESTOS + DIATOMITE | 24 | 2.7 | Diatomite remains |
| 3 | Filtration with continuous injection of filter additive CELLULOSE + DIATOMITE | 0.8 | 1.6 | Many diatomite remains |
| 4 | Normal pad filtration ASBESTOS sheets | 9 | 1.1 | Exceptionally numerous diatomite remains and phyllosilicates |
| 5 | Sterilized pad filtration ASBESTOS sheets | 46 | 2 | Exceptionally numerous diatomite remains |
| 6 | Normal pad filtration CELLULOSE + DIATOMITE sheets | nd[a] | - | Diatomite remains and phyllosilicates |
| 7 | Sterilized pad filtration CELLULOSE + DIATOMITE sheets | 0.8 | 0.6 | Diatomite remains and phyllosilicates |

[a]nd = Fiber not detected.

The renewal operation typically involves immersing the cell diaphragm (a perforated steel plate) into a vat containing a homogeneous mixture of asbestos and cell liquor (sodium hydroxide and sodium chloride). A vacuum is drawn through the immersed diaphragm, pulling the asbestos onto the steel plate to form the filtering surface. After the diaphragm has been coated (~0.3 cm thick), it is removed from the vat and dried by continuing to pull a vacuum across the filtering membrane.

At present, almost all industrial diaphragm cells are made using an asbestos slurry, with a minor amount using asbestos paper. Johns-Manville is reportedly still manufacturing a high quality paper for diaphragm cell renewal purposes.[12] The paper is comprised of special long-fiber asbestos and is available in various weights from 58 to 146 kg/100 $m^2$ (ca. 12 to 30 lb/100 $ft^2$). Yearly asbestos consumption figures for electrolytic diaphragm renewal are not known. The majority of consumption is for asbestos slurry generation and not specialty diaphragm paper production.

Secondary and Consumer Use--

Asbestos use during electrolytic cell renewal is strictly an industrial application and represents an occupational safety hazard. Human expsoure is not expected beyond the production room environment.

Environmental Release--

Information concerning the release of asbestos fibers during electrolytic diaphragm cell renewal is scant. Once added to the slurry, the asbestos is in solution and should not become airborne. Removal of the spent filtering membrane from the diaphragm is accomplished by washing the material off the plate using water under high pressure. The waste asbestos material, in a wetted state, is then cleaned up and containerized for ultimate disposal. The high moisture environment also suppresses airborne fiber release, thus minimizing exposure.

<u>Decorative Laminates</u>

Product Manufacturing and Composition--

Decorative laminates are a specialty use paper which is completely saturated with a thermosetting resin. The laminates are made from a latex-bound asbestos paper. The laminated sheet is formed by heat curing successive layers of paper that have been saturated with a thermosetting resin. Due to the concern of working with asbestos minerals and the availability of substitutes, asbestos-containing paper has not been used to produce decorative laminates since 1979.[6]

Secondary and Consumer Use--

Decorative laminates can be bonded to plywood, fiberboard, or metals. It can be sawed, drilled, or sanded using conventional woodworking tools. Asbestos decorative laminates have been used where Class 1 fire resistant ratings were required. They have been applied to wall or ceiling paneling, desktops, countertops, or worktable tops.

Environmental Release--

Release of asbestos fibers during handling and applying decorative laminates is expected to be minimal because the asbestos fibers are initially bonded in the asbestos paper and then the paper is saturated with either a phenolic or melamine thermosetting resin. No monitoring data were discovered during the literature search.

Metal Lining Paper

Product Manufacturing and Composition--

Metal lining asbestos paper is manufactured for use as a corrosive protecting layer attached to metal siding products and culvert pipe products. The asbestos paper lining is manufactured similarly to commercial paper except this paper contains a higher percentage of binder and a smaller percentage of clay.[6] Production rates for this product are very stable, and decreases in the near future are not expected.

Secondary and Consumer Use--

The metal lining asbestos paper is sent to a secondary manufacturer where it is attached to building siding and culvert pipe. Typical applications include building siding and roof paneling in the chemical industry and building siding for other industries exposed to corrosive conditions. Culvert piping is used in sewage sanitary landfill applications, which require the safe transport of corrosive liquids.

Environmental Release--

Atmospheric release of asbestos fibers is essentially limited to cutting the paper to size at the secondary manufacturing plant. The magnitude of the release is expected to be similar to that expected for cutting commercial asbestos paper (see below).

COMMERCIAL PAPER

Product Manufacturing and Composition

Commercial asbestos paper spans a wide range of product applications, including general insulating paper, muffler paper, and corrugated papers, all varying in weight and thickness. The compositon of the general insulating paper is normally 95 to 98 percent asbestos fiber and 2 to 5 percent starch binder.[5] The types of asbestos used are short and medium grades of chrysotile.

With specific reference to muffler and corrugated paper, muffler paper consists of a very high percentage of asbestos fiber and only a small percentage of starch binder. The surface of the paper 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 chrysotile asbestos content and starch binder.

Manufacturing of commercial asbestos paper is done on conventional papermaking machines which produce sheetrolls or tapes as finished products. The manufacturing of corrugated paper differs only by the addition of a corrugation machine that produces the desired corrugated molding of the paper surface.[6]

Commercial asbestos paper production accounts for 1.3 percent of the asbestos consumed annually in the paper products category, or about 1,170 metric tons of asbestos in 1980.[1] In 1975, the amount of asbestos used was much larger; muffler paper and corrugated paper each used over 3,000 metric tons. In 1977, the estimated production of corrugated paper was down to approximately 2,500 tons. The decline of these products has been caused by the consumer's desire to use a reasonably priced substitute containing no asbestos. Consequently, there has been and probably will continue to be a negative growth rate for commercial paper.[6]

Secondary and Consumer Use

The principal end use of all commercial asbestos paper products is to provide good insulation of minimum thickness against fire, heat, and corrosion. General insulating paper is currently the major subclass of commercial asbestos paper products. General insulating paper can be subdivided into four types:[11]

- Commercial Grades: A medium length fiber paper with a minimum 95 percent fiber content. Available in 49, 59, 78, 156, and 312 kg/100 $m^2$ weights; in widths of 46, 91, and 352 cm; in 11, 23, and 45 kg rolls. Suitable for most general purposes in industry. Good for temperatures up to 316°C or 427°C where loss of strength is not critical. Meets Federal Specification HH-P-1784.

- Nonburn Paper: A medium length fiber paper with high fiber content. Available in a weight of 20 kg/100 $m^2$, 91 cm wide, in 23 or 45 kg rolls. Suitable for continuous service at temperatures of 316°C.

- Long Fiber Paper: Made with a high-grade, long asbestos fiber; minimum fiber content of 98 percent in 2.7 kg and heavier papers. For use as a thermal insulation, gasketing, and base sheet for saturating.

- Doublex Asbestos Paper: Completely inorganic; will not burn, char, or smoke. Has high wet strength. Available in a weight of 49 kg/100 $m^2$, 91 cm wide, in 23 or 45 kg rolls. Developed for use as a neon sign pattern paper. Also used as liner for foundry funnels and pouring gates. Temperature limit of 427°C or 649°C where some embrittlement and loss of strength is not critical.

A large portion of the general insulating paper produced is sold to secondary fabricators and/or distributors who sell to their customers. 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. Some of the end uses are described below:[11]

- Thermal insulation in annealing furnaces,
- Trough lining for smelting process,
- Refractory lining,
- Expansion joints between brick layers of furnace,
- Backing insulation, and
- Insulation to catch molten metal drippings and hot metal.

In foundries, asbestos paper is used as mold liners, as refractory liners, and as expansion joint material on induction coil heaters. In the glass/ceramic industry, commercial paper is used for kiln insulation, linings, and as a separator for hot and cold flat glass sheets. In a laminated form, commercial asbestos paper is used to fireproof steel decks. Commercial paper is also used in electrical insulation applications such as dielectric and thermal protection of transformers for fluorescent tubes and housings for mercury vapor lamps.[11]

Installation of the paper typically involves cutting it to size at the site and then laying, nailing, and/or gluing it in place. The life span of the paper depends on how it is used. No general estimate can be made because of the multitude of its various uses. Asbestos insulating paper is usually ripped out when removed, being crumpled up and thrown away.

Muffler paper is used by the automotive industry primarily in the construction of catalytic converters for engine exhaust emission control systems. The paper is applied as a wrap between the inner and outer skins of the converter or muffler for two reasons; first, it maintains the high temperatures required for pollution control within the converter reaction chamber, and secondly, it insulates the outer skin, preventing it from becoming too hot. In a less common application, muffler paper is used as a heat shield between the muffler and the automobile body.[11]

Corrugated asbestos paper is used as a thermal insulator for pipe coverings, block insulation, and specialty panelings. Applications of corrugated asbestos paper include appliance insulation up to 149°C, hot-water and low-pressure steam pipe insulation, process line insulation, and panel insulation, such as paneling in elevators.[11]

## Environmental Release

Asbestos insulating paper has a tendency to crumple, crease, or tear during preinstallation handling and installation. These actions, including cutting during installation, can result in asbestos fiber release. Laboratory tests simulating these handling activities have been performed on two types of asbestos paper and one type of asbestos tape.[8] Table 8 presents the results of these tests that were conducted in a nonventilated glove box chamber.

During the testing of the 25 percent asbestos household paper for fiber release due to cutting, a small amount of visible material was released into the sampling chamber air space. Upon tearing, the edges of the paper appeared to be friable; further, the paper could be separated into layers. This latter occurrence results from manufacturing methods that allow for the buildup of layers which adhere to each other upon drying, forming the finished paper product. During product tearing, fibrous material was observed being released into the chamber air space. Material released accumulated on the base of the glove box after the paper was crumpled.

The commercial paper tested was composed of 75 percent asbestos, 10 percent cellulose, 5 percent opaques, 1 percent glass, and trace amounts of clay, binder, and carbonate. The paper became quite friable while cutting with scissors. During tearing and crumpling, pieces of the paper were released, falling to the base of the glove box or becoming airborne.

The asbestos-containing paper tape tested was 7.6 cm (ca. 3 inches) wide and was similar to a brand previously tested by a California TV station.[16] The tape consisted of 20 percent asbestos, 60 percent cellulose, 5 percent opaques, 5 to 10 percent glass, 5 to 10 percent carbonates, and trace amounts of binder, clay, and gypsum. The release of fibrous material was also observed from this product during cutting, tearing, and crumpling activities. The tape was very friable during handling, and the material released appeared smaller in size than that released from the other products tested.

The study[8] presenting these test results reports that NIOSH fiber concentrations (phase contrast analysis) are 10 to 20 percent of the fiber levels determined by SEM analysis. The reason for the difference is the capability of SEM analysis to identify fibers as small as 0.5 μm in length and 0.05 μm in width. The authors also conclude that the physical conditions the experiments were performed under do not allow one to predict fiber release levels during actual use. The researchers do insinuate, however, that asbestos fiber release would be likely.

As shown in Table 8, the household roll paper and commercial paper handling activities resulted in the lowest fiber release levels. The asbestos paper tape revealed the greatest fiber release during routine handling. All three products are believed to be readily available to consumers. With respect to potential human exposure, discretion should be employed when interpreting these test results. The experimental chamber in which the tests were performed limited normal ventilation that would have a dilution effect on fiber concentrations.

TABLE 8. ASBESTOS FIBER RELEASE FROM SIMULATED ASBESTOS PAPER HANDLING ACTIVITIES[8]

| Material | Operation | Test[a] No. | Optical microscopy analysis[b] ($f/cm^3$) | SEM analysis[c] ($f/cm^3$) |
|---|---|---|---|---|
| 25% Asbestos household paper roll[d] | Cutting | 1 | 2.2 | 13.8 |
| 25% Asbestos household paper roll[d] | Tearing and cutting | 2 | 4.8 | 27.6 |
| 25% Asbestos household paper roll[d] | Replicate of No. 1 | 3 | 2.0 | 22.3 |
| 25% Asbestos household paper roll[d] | Tearing | 4 | 2.3 | 8.9 |
| 75% asbestos commercial paper[e] | Cutting | 5 | Not analyzed | Not analyzed |
| 75% Asbestos commercial paper[e] | Tearing and crumpling | 6 | 7.3 | 58.9 |
| 20% Asbestos paper tape[f] | Cutting, tearing and crumpling | 7 | 49.0 | 262.0 |

[a]All tests of 10-minute duration, with the sampling pumps set at "6", (2.2 lpm).

[b]Fibers counted were ≥5 μm in length and had a length to width aspect ratio equal to or greater than 3 to 1.

[c]SEM - Scanning Electron Microscopy. All asbestos fibers observed were counted.

[d]Paper roll supplied by Grant Wilson.

[e]Commercial paper manufactured by Johns-Manville.

[f]Paper tape supplied by Grant Wilson.

As indicated above, a California TV station sponsored an asbestos paper product testing program to determine fiber release during product use.[16] Fiber counts of 18 and 24 $f/cm^3$ were measured, respectively, during the cutting, rubbing, rolling and tearing of 70 to 80 percent asbestos tape and shelf paper. Results were obtained by polarized light microscopy. Testing was conducted inside a 30 x 43 x 43 cm glove box. The high levels recorded are likely attributed to fiber accumulation in the confined air space of such a sampling chamber.

Once installed, minimal asbestos fiber release is expected from the paper products tested. Only during removal of the paper, or an accidental tear, is it likely that the paper would release asbestos fibers. Fiber levels during such incidents, occurring under actual conditions, are expected to be lower than those reported. Additionally, the amount of material released would be reduced if the paper was wetted before being removed.

## ELECTRICAL INSULATION

### Product Manufacturing and Composition

Asbestos electrical insulating paper is manufactured on conventional paper machines. It is produced in various thicknesses and sizes in the form of sheets, tapes, rolls, and tubes. The insulating paper's composition varies with intended application, but generally contains asbestos fibers and cellulose bound by latex polymers.[6]

Electrical insulating paper production accounts for approximately 0.4 percent of the asbestos used in manufacturing asbestos paper products, or about 360 metric tons in 1980.[1] Because of developing substitute products and employee concern about working with asbestos, a declining market is forecasted for this product.

### Secondary and Consumer Use

Finished electrical insulating paper may be used directly[9] or be converted, by lamination, for other uses. Electrical insulating paper is used in industrial, commercial, and residential applications. Industrially, it is used in situations where electrical equipment is subjected to high temperatures. Commercial use includes insulation in such items as stoves, toasters (limited), and other appliances. Laminated insulating paper is used for low-voltage household applications.[6] On a larger scale, sheet laminate is used for making telephone switchboards and television circuit boards.

Similar to other asbestos-containing paper products, the useful life span of electrical insulating paper is related to its end use. Industrial use may result in a short life span, less than 1 year, while laminated insulating paper may be expected to last for several years.

Environmental Release

Actions taken upon electrical insulating paper during fabrication and product installation include punch pressing, shearing, cutting, winding, and slitting. All of these handling activities were tested to determine asbestos fiber release.[17] As shown in Table 9, the amount of asbestos fiber released was found to be quite low. The low levels monitored are attributed to the manufacturing process whereby the asbestos fibers are bound by saturants and binders in the product matrix.

Asbestos fiber release caused by normal wear is assumed to be less than the amount released during installation. If the insulating material separates or splits, a release equivalent to that determined for product installation is expected. Because of the more rigorous activity associated with it, removal of the insulating paper could result in higher fiber releases than those shown in Table 9. Overall, the fiber levels reported are significantly lower than OSHA's 2 fiber/$cm^3$ TWA limit and, therefore, should not pose any severe health hazard.

TABLE 9. AIRBORNE ASBESTOS CONCENTRATIONS RESULTING FROM ASBESTOS ELECTRICAL INSULATING PAPER AND BOARD MANUFACTURE AND INSTALLATION[17]

| Activity performed | Measured fiber concentration ($f/cm^3$) | Date of tests | Duration of activity (min) | Analytical method |
|---|---|---|---|---|
| Sterling magna ply package operator | <0.016 | 1980 | 43 | Phase contrast |
| Paper machine rewind operator, 0.008 cm thick paper | <0.004 | 1980 | 178 | Phase contrast |
| Paper machine rewind operator, 0.04 cm thick paper | <0.006 | 1980 | 112 | Phase contrast |
| Millboard cutter operator 0.08 cm thick paper | <0.005 | 1980 | 141 | Phase contrast |
| Winding operator, 0.03 cm thick paper | <0.008 | 1980 | 90 | Phase contrast |
| Slitting operator, 0.03 cm thick paper | <0.008 | 1980 | 90 | Phase contrast |
| Winding operator, 0.008 cm thick paper | <0.008 | 1980 | 90 | Phase contrast |
| Slitting operator, 0.008 cm thick paper | 0.031 | 1980 | 90 | Phase contrast |
| Electrical insulating paper--punch press operator (TV BORD) | 0.097 | ND | 298 | Phase contrast |
| Electrical insulating paper--shear operator (TV BORD) | 0.064 | ND | 153 | Phase contrast |
| Electrical insulating paper--assembly dept. operator (TV BORD) | 0.008 | ND | 165 | Phase contrast |

(continued)

TABLE 9 (continued)

| Activity performed | Measured fiber concentration ($f/cm^3$) | Date of tests | Duration of activity (min) | Analytical method |
|---|---|---|---|---|
| NECO, shear machine operator | 0.033 | 1978 | 120 | Phase contrast |
| NECO, winding area operator | 0.038 | 1978 | 180 | Phase contrast |
| Highlander, band saw operator | 12.3[a] | 1978 | 30 | Phase contrast |
| Highlander, slitter operator | 0.53 | 1978 | 42 | Phase contrast |
| Coil cutter operator | 0.094 | ND | 118 | Phase contrast |
| Coil cutter operator | 0.015 | ND | 94 | Phase contrast |
| Acme paper cutter | <0.008 | 1979 | 91 | Phase contrast |
| Acme coil cutter | <0.013 | 1979 | 53 | Phase contrast |
| Acme conv. winding | <0.008 | 1979 | 87 | Phase contrast |
| Acme heavy handwinding | <0.006 | 1979 | 108 | Phase contrast |
| Acme coil pulling | <0.008 | 1979 | 87 | Phase contrast |
| Acme compound pourer | <0.012 | 1979 | 60 | Phase contrast |
| Resinite band saw operator | 0.034 | ND | 372 | Phase contrast |
| Square D saw operator | 0.062 | 1980 | 111 | Phase contrast |

ND - No Data

[a]Reported as excessive.

## REFERENCES


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

2. Carton, R. J. Development Document for Effluent Limitation Guidelines and New Source Performance Standards for the Building, Construction and Paper Segment of the Asbestos Manufacturing Point Source Category. PB-238-320, U.S. Environmental Protection Agency. February 1974.

3. Daly, A. P. et al. Technological Feasibility and Economic Impact of OSHA Proposed Revision of the Asbestos Standard. Prepared by R. F. Weston for the Asbestos Information Association/North America, Washington, D.C. March 29, 1976.

4. Cogley, D. et al. Life Cycles of Asbestos in Commercial and Industrial Use Including Estimates of Releases to Air, Water and Land. Draft Final Report, Prepared by GCA/Technology Division for the U.S. Environmental Protection Agency, Office of Toxic Substances, Washington, D.C. November 1981.

5. Arthur D. Little Co., Characterization of the U.S. Asbestos Papers Markets, Prepared for the Minister of Industry and Commerce--Government of Quebec. Final Draft Report to Sores Inc., Montreal, Report C-79231. 1976.

6. Meylan, W. M. et al. U.S. Asbestos Paper Industry and Substitutes for Asbestos Paper and Asbestos Brake Linings. Draft Report, SRC No. L1415-05, Syracuse Research Corporation. September 1979.

7. Blecher, L. GAF Corporation. Comments on Advance Notice of Proposed Rulemaking on Commercial and Industrial Use of Asbestos Fibers. EPA Docket No. OTS-61005. February 1980.

8. Roy, N. et al. Asbestos Product Test Results. Draft Final Report, Prepared for the U.S. Environmental Protection Agency, Office of Pesticides and Toxic Substances by GCA/Technology Division. February 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. Report Prepared for U.S. Environmental Protection Agency, EPA-560/6-78-005. August 1978.

10. Chapman, J. H. et al. Asbestos Dust Technology Feasibility Assessment and Economic Impact Analysis of the Proposed Federal Occupational Standard: Part 1. U.S. Department of Labor, OSHA, NTIS No. RTI/1370/02-01-F. September 1978.

11. Krusell, N. and D. Cogley. Asbestos Substitutes Performance Analysis. Final Report, Prepared by GCA/Technology Division for the U.S. Environmental Protection Agency, Office of Pesticides and Toxic Substances, Washington, D.C. May 1981.

12. Roy, N. et al. Substitute Performance Analysis for Asbestos Paper Products and Brake Linings. Prepared by GCA/Technology Division for the U.S. Environmental Protection Agency, Office of Toxic Substances, Washington, D.C. Draft Task Report. September 1979.

13. Cogley, D. et al. The Experimental Determination of Asbestos Fiber Size Distribution During Simulated Product Use. Prepared by GCA/Technology Division for the U.S. Environmental Protection Agency, Office of Toxic Substances, Washington, D.C. 1981.

14. Lewis, B. G. Asbestos in Cooling Tower Water. Argonne National Laboratory, Argonne, IL. NTIS No. ANL/ES-63. December 1977.

15. Gaudichet, A. et al. Asbestos Fibers in Wines: Relation to Filtration Process. J. Tox., Environmental Health, 4:853-860, 1978.

16. Asbestos Paper Product Testing Results. Unilab Research, Berkeley, California. Testing performed for Channel 7, KGO TV, San Francisco, CA. November/December 1979.

17. Wardly, F. L. , President, Quin-T Corporation, Electrical Insulations. Written correspondence to Mr. Richard Guimond, U.S. Environmental Protection Agency, Office of Toxic Substances, Washington, D.C. October 30, 1980.

# SECTION 4

# FRICTION MATERIAL

## INTRODUCTION

Friction materials represent a broad classification of products that include automobile brakes, both disc and drum (brake linings), truck brakes, fan and transmission clutches, torque limiters and other devices used in the automotive, truck, bus, heavy vehicle, aircraft and other industries to stop, slow or control moving mechanical parts. These materials may contain anywhere from zero (0) to 60 percent asbestos by composition depending upon the nature of the heat build up generated and required for control of the mechanical device involved.[1]

In 1980, an estimated 43,700 metric tons of asbestos, about 12 percent of the United States fiber consumption, was used to manufacture friction materials.[2] Production volumes for each subcategory are not available, but 1981 value estimates show brake linings are the largest component at an estimated 58.9 percent of total value of friction materials produced (see Table 10).[3] Disc brake pads (6.8 percent) and clutches (33 percent) make up the majority of remaining value except for a small portion which is listed as various other uses.[3] Because of their near total representation (92 percent) of the friction products category, the following discussion pertains solely to brake linings and clutch facings.

## BRAKE LININGS

### Product Manufacturing and Composition

Asbestos is used in the production of brake linings because of its thermal stability, relatively high friction level and reinforcing properties. Asbestos fiber composition ranges from 40 to 60 percent of the final product by weight. All grades of chrysotile are used, but in 1980 grades 5 through 7 accounted for 94 percent of the 43,700 metric tons of asbestos consumed for the production of friction materials.[2] Because asbestos does not offer all of the desired properties, other materials known as property modifiers and binders are added. Depending on the requirement of the brake linings, different types and amounts of modifiers are used. A list of the binders and modifiers used in automobile brake linings are shown in Table 11.

TABLE 10. VALUE OF ASBESTOS FRICTION MATERIAL SHIPMENTS (IN MILLIONS OF 1981 DOLLARS)[a]

| Final product | Total product shipments, including interplant transfers ($) | Percent of total |
|---|---|---|
| Brake linings | | |
| Woven, containing asbestos yarn, tape or cloth | 27.8 | 4.9 |
| Molded, including all nonwoven types | 308.4 | 54.0 |
| Disc brake pads | 38.8 | 6.8 |
| Clutch facings | | |
| Woven, containing asbestos yarn, tape or cloth | 54.2 | 9.5 |
| Molded, including all nonwoven types | 132.2 | 23.1 |
| Other | 9.8 | 1.7 |
| Total asbestos friction material | 571.2 | 100 |

[a]Projected from Meylan et al.[3] using September 1981 Engineering and Mining Journal cost index factors.

TABLE 11. PROPERTY MODIFIERS IN FRICTION MATERIALS[3]

| 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 |

Most linings are produced from a wet-mix resin by extrusion or in rolling processes. Initially, asbestos and various property modifiers are mixed with liquid resin at 50°C (120°F), then binder solvent is added to yield a putty-like mass with good wet strength. In the extrusion process, the mix is heated to 90°C (195°F) and extruded as a flat, pliable sheet which is dried for 2 hours at 80°C (175°F). In the rolling process, the partially dried mix is fed between two rolls that align the fibers into flat, pliable "green lining." Linings are then cut to length, formed at 150°C (300°F), and molded for 4 to 8 hours at 180° to 250°C (360° to 480°F). The final product is surface ground to produce the desired dimensions.[4]

Linings for heavy-duty use are produced by a dry-mix process. Asbestos, modifiers, and resin are mixed and formed into 60 x 90 cm (24 x 35 inches) briquets (blocks) that are pressed for 3 to 10 minutes at 140° to 160°C (340° to 375°F), and cured in molds for 4 to 8 hours at 220° to 280°C (425° to 540°F). These block linings are then finished by grinding.[4]

Asbestos demand for friction products forecasted to the year 2000 is expected to grow at an annual rate of 2.2 percent.[2] But based on an estimated number of motor vehicles produced in the year 2000, and on the assumption that the use of asbestos per vehicle will remain below present standards, the demand could vary from 0 to 70,000 metric tons.

Secondary and Consumer Use

Brake linings are used primarily in the transportation industry but have numerous uses wherever motion must be controlled. During operation the brake lining engages with a metal rotor to form a sliding friction couple which converts the kinetic energy of the rotating members into heat, absorbs the heat, and dissipates it to the surroundings.[3] The brake lining is considered to be the expendable portion of the brake couple which over a long period of time is converted to debris and gases.

With specific reference to consumer use, potential asbestos exposure occurs during installation. Although most brake lining installations occur at an assembly plant or service garage, millions of Americans perform their own brake repairs. The following seven-step procedure (condensed) has been developed to minimize exposure during commercial brake lining repair or replacement:[5]

1. The work area should be set apart from others,

2. During dissembling, all parts should be set on the floor and cleaned by vacuum,

3. Precaution should be taken during machining of the lining,

4. Cleaning equipment should be cleaned with care,

5. All floor cleaning should be done with a vacuum,

6. Clean work clothes or leave them at work, and

7. Proper hygiene practices will help minimize exposure.

In addition, all asbestos-containing waste material should be properly containerized to prevent exposure during handling and ultimate disposal.

Environmental Release

During use, brake lining surfaces are suspected to be subjected to temperatures in excess of 800°C (1472°F), which would cause chrysotile asbestos to transform to forsterite or to an amorphous magnesium silicate phase.[6] However, because the heat distribution is not uniform across the lining surface, braking may liberate partially altered or even unaltered chrysotile fibers. Abrasion and macroshear are other physical forces that also contribute to the physical breakdown of the lining.[7,8]

Upon review of the literature, it is not absolutely clear whether fibrous asbestos is or is not released during vehicle braking. Lynch (1968)[9] has suggested, similar to the discussion above, that the crystal structure of the asbestos mineral fiber is degraded by heat released during braking, causing the chemical conversion to olivine or forsterite. Findings published by Holt and Young (1973),[10] however, conclude that fibers collected from the atmosphere showed little evidence of loss of crystallinity. This latter summation was further documented by Alste et al. (1976)[11] who concluded that the major effect of braking appears to be in separating bunches of fibers and reducing their average length but not in altering their crystal structure. Sampling conducted by Alste et al. revealed an estimated average asbestos concentration of $5 \times 10^5$ fibers/$m^3$ in the vicinity of a heavily traveled freeway exit.[11]

Elevated levels of asbestos were found in a study by Bruckman and Rubino[12] in which airborne asbestos concentrations were monitored at three Connecticut toll plazas. Asbestos concentrations were found to vary between 3 ng/$m^3$ (ca. 60 f/$m^3$) and 41 ng/$m^3$ (ca. 820 f/$m^3$).* A nearby large industrial asbestos user was suspected of influencing the highest measured concentration. Although no direct 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. With respect to fiber size distribution, Rohl et al. (1977)[6] reported for 10 brake dusts sampled in New York City that 80 percent of the chrysotile is in free fibril form and is shorter than 0.4 µm in length. Over 57 percent reportedly had lengths of about 0.2 µm. Analysis was performed by transmission electron microscopy at 42,000x magnification.

*Assumed that 1 ng/$m^3$ equals 20 f/$m^3$.

## TABLE 12. SUMMARY OF PUBLISHED DATA - ASBESTOS EMISSIONS FROM BRAKE LINING USE[13,14]

| 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[9] | Laboratory simulations utilizing brake-testing machines or dynamometers. Samples collected on 0.8 pore size membrane filters. | Electron micrographs | Not discussed | <1%, except under severe-stress conditions |
| Hatch, 1970[15] | A dust cloud was generated by using compressed air jets to remove dust from brake linings in an auto repair garage. Samples were collected by means of a hand pump located in center of dust cloud. | Not stated | 94% of fibers fell in 2-5 μm length category. Only 6% were longer than 5 μm | ~1% |
| Hickish and Knight, 1970[16] | 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[17] | Laboratory simulations utilizing a disc brake assembly mounted on an inertial dynamometer. Samples were collected on suitable filter paper. | Neutron activation | Not discussed | ~44% |
| Anderson et al., 197_[16] | Laboratory simulations utilizing a disc brake assembly mounted on a dynamometer. Air samples of wear debris collected down wind of disc brake. | Transmission electron microscopy | Test results and procedures precluded a size distribution estimate | ~0.02% |
| Jacko and DuCharme,[13] [illegible] Jacko et al., 1973)[14] | 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 12 (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[19] | Ten samples of automobile brake drum dusts were collected from maintenance shops in the New York City 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; <u>no</u> percentages are given |
| [illegible] et al., 1976[11] | 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[illegible] | 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 |

In addition to those just cited, a number of researchers have discussed the concern of asbestos fiber release from the handling and use of brake linings. Table 12 summarizes the published data. Meylan et al. (1978)[3] present a detailed treatise of the literature relating to asbestos fiber release from brake lining use and handle, one which we believe the reader should review if he or she requires information beyond that presented in this report.

The Jacko and DuCharme study[13] states that approximately 33.6 million kilograms of asbestos in friction material wears away annually. Their findings show that only about 0.2 percent of the debris is not converted to some other nonasbestiform substance, thus total annual asbestos is estimated at 71,759 kilograms. Of this amount 85.6 percent or 61,426 kilograms were estimated to drop out on the ground, 11.2 percent or 8,037 kilograms were estimated to be retained within the brake or clutch housing, and only 3.2 percent or 2,296 kilograms were believed to become airborne.

Asbestos fiber release during the removal, repair and/or replacement of worn brakes has also been monitored.[19] The results presented in Table 13 indicate that the OSHA 2 f/cm$^3$ TWA asbestos concentration standard can be exceeded during brake cleaning operations, particularly when compressed air blowing is used to remove dust from the drums and back plates. It is important to note that the data were obtained in 1976 and that the institution of improved work practices that lower fiber release levels has occurred. Some of these work practices are discussed below.

TABLE 13. ASBESTOS FIBER[a] CONCENTRATIONS RECORDED DURING AUTOMOBILE AND TRUCK BRAKE SERVICING[19]

| Operation | Distance (m) | Number of samples | Fiber concentration (fibers/cm$^3$) Mean | Range |
|---|---|---|---|---|
| Auto - Blowing dust out of brake drums with compressed air | 0.9-1.5 | 4 | 16.0 | 6.6-29.8 |
| | 1.5-3.0 | 3 | 3.3 | 2.0-4.2 |
| | 3.0-6.1 | 2 | 2.6 | 0.4-4.8 |
| Truck - Renewing used linings by grinding | 0.9-1.5 | 10 | 3.8 | 1.7-7.0 |
| Truck - Beveling new linings | 0.9-1.5 | 5 | 37.3 | 23.7-72.0 |

[a]Fibers 5-1000 μm in length, counted by optical microscopy.

Alternative cleaning methods to air blowing have been found to reduce asbestos exposure.[20] Table 14 presents a comparison of asbestos fiber concentrations recorded for various types of brake drum cleaning methods.

TABLE 14. ASBESTOS FIBER CONCENTRATIONS ASSOCIATED WITH EIGHT TYPES OF BRAKE DRUM CLEANING METHODS[20]

| | | |
|---|---|---|
| 1. | Airblowing | 43.8 fibers/cm$^3$ x min |
| 2. | Dry brushing | 15.0 fibers/cm$^3$ x min |
| 3. | AMMCO detergent washer and vacuum | 2.9 fibers/cm$^3$ x min |
| 4. | Nilfisk dry vacuum | 2.2 fibers/cm$^3$ x min |
| 5. | Sears dry vacuum | 0.8 fibers/cm$^3$ x min |
| 6. | Sears wet vacuum | 0.6 fibers/cm$^3$ x min |
| | Bag-emptying exposure | |
| 7. | Nilfisk empty (dry) | 0.3 fibers/cm$^3$ x min |
| 8. | Sears empty (wet) | 0.0 fibers/cm$^3$ x min |

Workers may also be exposed to asbestos fibers during brake lining refacing and rebuilding even though raw asbestos fibers are not handled. Asbestos exposure levels measured at three such fabricating plants are presented in Table 15 by processing step.

## CLUTCH FACINGS

### Product Manufacturing and Composition

Asbestos is used in clutch facings for the same reasons as in brake linings; thermal stability, relatively high friction level, and reinforcing properties. The asbestos level in the product ranges from 40 to 60 percent of which most is grades 5 through 7 chrysotile. Other materials used at various times are wire reinforcers, rubber friction compounds, and various solvents.

These materials are combined to produce clutches by five different methods; dry-mix, wet-mix, molded, paper, and woven textiles. Dry-mix and wet-mix processes are similar to those described for brake linings. Molded clutch facings are produced by combining materials in a mixer, conveying this through a two-roller mill which compresses the mixture. The resultant sheeting is then cut to size, dried, finished, inspected and packaged. Paper clutch facings are punched from rolls of asbestos paper as described under transmission paper in the previous section on asbestos paper products. Woven clutch facings are manufactured from high strength asbestos textile fabric that may be reinforced with wire. The fabric is saturated with resins and autoclaved prior to being wound into yarn and finally into a clutch facing.

Production levels for clutch facings are not reported but a breakdown of the value of asbestos bearing friction materials, including clutch facings, is given in Table 10.

TABLE 15. ASBESTOS EXPOSURE LEVELS IN REBUILDING BRAKE AND CLUTCH ASSEMBLIES[21]

| Facility | Fibers/cm$^3$ TWA | | | |
|---|---|---|---|---|
| | Receiving and cleaning | Bonding and riveting | Cutting and grinding | Inspection and packaging |
| A | | | | |
| Mean | 1.1 | 0.6 | 1.1 | 0.9 |
| 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 | |

Secondary and Consumer Use

Clutch facings are used mainly in the transportation industry, although they can be used for any application that has the potential of switching gears. In an automotive application, the engaging of a clutch transfers the kinetic energy of a rotating crankshaft to the transmission and wheels. Any slippage results in the generation of heat, which is absorbed and eventually dissipated to the atmosphere by the clutch.[3] The clutch friction material is considered to be expendable.

The wear of a clutch depends on the amount of slippage since the clutch is basically a static friction couple which momentarily slides during gear shifts. Once the clutch cannot hold a continuous couple, it must be replaced.

Environmental Release

Specific asbestos fiber concentration monitoring studies have not been reported for clutch repair or replacement work. Fiber release levels, however, are expected to be lower than those reported for brake lining repair and replacement because the clutch facings are normally covered with a lubricating transmission fluid. The fluid would effectively suppress the release of asbestos fibers during handling.

## REFERENCES


1. Drislane, E. W. Written Response to U.S. Environmental Protection Agency's ANPRM on Asbestos. Submitted in behalf of the Friction Materials Standards Institute, Inc. to be included in the Office of Toxic Substances' Docket No. OTS-61005.

2. Clifton, R. A., Asbestos, A Chapter from Mineral Facts and Problems. 1980 Edition. Washington, D.C., U.S. Bureau of Mines. 1981.

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

4. Krusell, N., and D. Cogley. Asbestos Substitute Performance Analysis. Prepared by GCA/Technology Division for the U.S. Environmental Protection Agency, Office of Toxic Substances, Washington, D.C. May 1981.

5. FMSI Issues Review of Asbestos Handling Procedure for Brake and Clutch Repairs. Brake and Front End. July 1977. pp. 22-23.

6. Rohl, A. N., et al. Asbestos Content of Dust Encountered in Brake Maintenance and Repair. Proceedings of Royal Society Medical J. Vol. 70. January 1977.

7. Burnell, J. T., 1957. Wear. Vol. 1, p. 119.

8. Mizutani, Y., H. Ohara, and K. Nakajima. 1973. Wear, Vol. 23, p. 387.

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

10. Holt, P. F., and D. K. Young. 1973. Asbestos Fibers in the Atmosphere of Towns. Atmospheric Environment, 7:481-483; 669-670.

11. Alste, J., D. Watson, and J. Bagg. 1976. Airborne Asbestos in the Vicinity of a Freeway. Atmospheric Environment. Vol. 10. pp. 583-589.

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

13. 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.

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

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

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

17. 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.

18. 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.

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

20. Lemmons, T. Method of Cleaning Debris from Brake Drums Study of Asbestos Exposures. Environmental Protection Agency, Research Triangle Park, North Carolina. 1980.

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

## SECTION 5

## FLOORING PRODUCTS

### INTRODUCTION

The manufacturing of floor products is the second largest industrial use of asbestos, consuming 76,589 metric tons in 1980.[1] Floor products can be divided into two separate subgroupings, flooring felts and floor tiles. The production of flooring felts consumed 40,509 metric tons of asbestos while the rest (36,080 metric tons) is used for the production of tile flooring. Flooring felts have already been discussed in Section 3 under Paper Products.

The tile flooring industry produces two major product lines: vinyl-asbestos floor tile and asphalt-asbestos floor tile. Vinyl-asbestos floor tile consumes up to 95 percent of the asbestos used by the floor tile industry.[2] Both types of asbestos tile utilize grades 5 and 7 chrysotile fibers to obtain the desired properties; strength, dimensional stability, and resistance to the cold.[3] Production methods for both are similar except for the high processing temperature required to flux and process the vinyl copolymer.

### VINYL-ASBESTOS FLOOR TILES

#### Product Manufacturing and Composition

As stated above, within this category vinyl-asbestos floor tile production consumes 95 percent of the asbestos fibers, or an estimated 34,275 metric tons in 1980. Specific ingredient formulations vary with manufacturer and the type of tile. Reported asbestos contents range from 5 to 30 percent by weight or up to 635 grams of asbestos per square meter (0.13 pounds per square foot) of tile.[4,5] Polyvinyl chloride (PVC) resin serves as the binder and constitutes from 15 to 25 percent by weight of the tile.[3] Fillers, such as limestone and color pigments, make up the remainder of the ingredients.

Ingredients are usually dry mixed in a Banbury mixer, then are dispersed through the vinyl mass along with any required liquids. The temperature of the batch is raised to 149°C (300°F), and the mixture is fed to the mill where it is shaped to the desired size, decorated, and cooled. After cooling, the tile is waxed, cut to size, inspected, and packaged. Tiles are usually produced in sizes 23 x 23 cm (9 x 9 in.) or 30 x 30 cm (12 x 12 in.) with thicknesses varying from 0.08 to 0.24 cm (1/32 to 3/32 in.).[4]

After a period of a marked decrease in asbestos consumption during the 70's, the market share of all forms of vinyl flooring is now believed to be well established and is not expected to change in the foreseeable future. The 20-year forecast predicts a range for annual asbestos consumption at 110,000 to 220,000 metric tons, with the probable amount being 170,000 metric tons.[1,6] A large percentage of tile production, an estimated 40 to 60 percent, is intended as flooring replacement.[2]

Secondary and Consumer Use

Vinyl-asbestos tile flooring is used for protective and decorative covering of floors in industrial, commercial, and residential applications. New floor covering may be installed on concrete, prepared wood floors, or over old tile floors if they are in relatively good shape. In some cases, an old floor may require repairing rough spots or gouges using a patching material or may actually require a totally new surface whereby fiberboard or masonite underlayment is laid on top of the old floor.[7] For industrial and commercial installations, the tiles are commonly affixed to the underlayment using a tacky adhesive. Most tile sold for consumer application is normally coated on the back with a layer of pressure-sensitive adhesive,[8] which by itself minimizes potential fiber release.

During installation, some cutting with scissors or shears may be involved to fit the flooring to the size of the room. Other than following manufacturer's recommended installation procedures, no control measures are used during the cutting and installing of the floor covering. Manufacturers of resilient floor coverings that contain asbestos fibers have made it their policy to warn their wholesalers and distributors against sanding old floor coverings.[7] Similar warning messages are packaged with floor coverings sold directly to "do-it-yourself" homeowners.[7]

Environmental Release

During floor tile manufacturing, asbestos fibers are mixed with other ingredients such that the fibers become locked in the product matrix. From this point on, the fibers remain securely bound within the vinyl resin compound. In addition, the wear surface of floor coverings is usually coated with an abrasive-resistant urethane finish which increases the isolation of the asbestos from the external environment.[8] The following presents a summary of available monitoring data and release estimates reported in the literature for vinyl-asbestos tile installation, use, maintenance, and removal. The fiber concentrations reported were determined by the NIOSH method; i.e., fibers as long or longer than 5 μm with as aspect ratio of 3 to 1 or greater were counted by phase contrast analysis using optical light microscopy.

Installation of vinyl-asbestos floor tiles results in minimal fiber release. As stated above, the asbestos fibers are locked-in, therefore, any release is expected to occur only if the asbestos fibers were sheared away from the encapsulating material. Monitoring of fiber release during installation of vinyl-asbestos floor tile has been performed for the Resilient Floor Covering Institute (RFCI) by SRI International.[9,10] The results of the SRI study are presented in Table 16. As shown in the table, asbestos fiber levels associated with tile installation are well below the OSHA TWA limit of 2 fibers/cm$^3$.

The service life of a vinyl-asbestos floor is estimated to be between 10 and 30 years.[3] During this time, various forces act upon the flooring which may result in the release of asbestos fibers. Monitoring of fiber release during use and maintenance has also been performed by SRI for RFCI.[9,10] As shown in Table 16, no fibers were detected from mopping and buffing vinyl-asbestos floor tile in an office building's copy center and snack shop.

Asbestos fiber release from everyday wear and cleaning of vinyl-asbestos flooring has also been estimated by researchers based on calculated material wear.[2] The calculated releases ranged from 0.008 to 0.08 f/cm$^3$.[2] Four assumptions were made before these fiber release levels were calculated:

- Each square meter of floor tile contains 635 grams of asbestos,
- The average service life of the floor is 20 years,
- Approximately 10 percent of the flooring is worn away during the service life by use and cleaning, and
- About 1 percent of the worn-away floor becomes airborne.[2]

The greatest potential for asbestos fiber release during floor tile use occurs during removal. At the end of the floor's lifetime, usually when the surface design is worn away, the flooring may be ripped up or covered with a new surface underlayment. If the flooring is ripped up, pieces of tile may remain affixed to the floor which have to be scraped up or sanded down to level off the subflooring. Various monitoring studies have been performed during floor tile removal.[9,10,11,12] SRI's results[9,10] are presented in Table 16. The results of another study[11] revealed a fiber concentration range of 0.02 to 0.10 f/cm$^3$ during vinyl-asbestos floor tile removal. The fourth study,[12] performed under a laboratory setting, reports asbestos fiber release during sanding to remove old asbestos floor tile. The results showed that sanding can cause the release of 1.2 to 1.3 fibers/cm$^3$ into the worker environment.[12] The experiment was performed in a 3 x 3.7 x 2.1 meter (10 x 12 x7 ft) walk-in chamber. Room ventilation involved four air changes per hour. A belt sander with coarse paper was used to remove a section of old vinyl-asbestos floor tile.

ASPHALT-ASBESTOS FLOOR TILES

Asphalt-asbestos floor tiles represent only 5 percent of the asbestos floor tile industry.[2] The differences between asphalt-asbestos and vinyl-asbestos floor tiles are only minor; therefore, the discussion above on vinyl-asbestos floor tile applies directly to asphalt-asbestos floor tile use.

TABLE 16. ASBESTOS FIBER RELEASE FROM VINYL-ASBESTOS FLOOR TILE INSTALLATION, USE, MAINTENANCE, AND REMOVAL[9,10]

| Site description | Age of tile (years) | Operation | TWA fiber count range ($f/cm^3$) |
|---|---|---|---|
| Residential home | 6 | Old tile preparation for new installation | 0 |
| Residential home | New | Installation | 0.0046 to 0.0092 |
| Residential home | New | Installation | 0.008 to 0.027 |
| Residential home | New | Installation | 0.016 to 0.032 |
| Office building copy center | 5 | In-use | 0 |
| Office building snack shop | 5 | In-use | 0 |
| Office building copy center | 5 | Maintenance - mopping | 0 |
| Office building snack shop | 5 | Maintenance - mopping | 0 |
| Office building copy center | 5 | Maintenance - buffing | 0 |
| Office building snack shop | 5 | Maintenance - buffing | 0 |
| Residential home | NR | Removal | 0.006 to 0.015 |
| Residential home | 6 | Removal[a] | 0.12 to 0.38 |

[a]Removal deviated from recommended procedures that include removal without sanding, use of a flat-bladed wall scraper instead of equipment that would unduly shatter the tile, and not breaking the tile by hand before placing in a disposal bag.

NR = Not reported.

## REFERENCES


1. Clifton, R. A., Asbestos. A Chapter from Mineral Facts and Problems, 1980 Edition. U.S. Bureau of Mines, Washington, D.C. 1981.

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 1981.

3. Cogley, D. et al. Life Cycle of Asbestos in Commercial and Industrial Use Including Estimates of Releases to Air, Water, and Land. Draft final report prepared by GCA/Technology Division for the U.S. Environmental Protection Agency, Office of Toxic Substances, Washington, D.C., January 1981.

4. Chapman, J. H. et al. Asbestos Dust Technological Feasibility Assessment and Economic Impact Analysis of the Proposed Federal Occupational Standard: Part 1. U.S. Department of Labor, OSHA. September 1978.

5. Daly, A. R. et al. Technological Feasibility and Economic Impact of OSHA Proposed Revision of Asbestos Standard (Construction Excluded). Prepared by R. F. Weston for the Asbestos Information Association/North America. March 26, 1976.

6. Clifton, R. A., Asbestos: Mineral Commodity Profiles. U.S. Bureau of Mines, Washington, D.C. 1979.

7. The Resilient Floor Covering Institute. Comments on the Advance Notice of Proposed Rulemaking on the Commercial and Industrial Use of Asbestos Fibers. Washington, D.C. February 18, 1980.

8. Blecher, L. GAF Corporation. Comments on Advance Notice of Proposed Rulemaking on Commercial and Industrial Use of Asbestos Fibers. EPA Docket No. OTS-61005, February 1980.

9. SRI International. Monitoring for Airborne Asbestos Fibers: Vinyl Asbestos Floor Tile. Prepared for Resilient Floor Covering Institute. December 1979. SRI Project 7988.

10. SRI International. Comparison Testing Monitoring for Airborne Asbestos Fibers: Vinyl Asbestos Floor Tile. Prepared for Resilient Floor Covering Institute. December 1979. SRI Project 7988.

11. Roy, N. et al. Asbestos Product Test Results. Draft Final Report, Prepared by GCA/Technology Division for the U.S. Environmental Protection Agency, Office of Toxic Substances, Washington, D.C. February 1980.

12. Murphy, R. L. et al. Floor Tile Installation as a Source of Asbestos Exposure. American Review of Respiratory Disease, Vol. 104. 1971.

SECTION 6

GASKETS AND PACKING

## INTRODUCTION

This category, gaskets and packing, is ranked sixth in annual consumption of asbestos fibers, consuming 12,300 metric tons of asbestos or 3 percent of the total U.S. consumption in 1980.[1] Asbestos is used for gaskets and packing because of its resilience, strength, chemical inertness and heat resistant properties.[2] A variety of other materials may be used in the manufacturing process to give a gasket specific use qualities. With respect to packing material, it is typically made of asbestos yarn saturated with a grease-based lubricant.

Gaskets and packing are used to prevent leakages; gaskets for static applications and packing for dynamic applications. Gaskets are needed to obtain tight nonleaking connections for piping and other joints such as the covers and opening on all types of industrial and commercial equipment. Packing is used as a type of bearing for revolving or moving parts, preventing leakage of the contained fluid along the bearing surface.

## GASKETS

### Product Manufacturing and Composition

Gaskets are made from compressed sheet or beater-add asbestos paper. Compressed sheet gaskets will be discussed in this section. Beater-add gaskets have been previously discussed under the paper products category (Section 3). Compressed sheet gaskets are formed from a plastic mixture consisting of asbestos fibers, an elastomeric binder, and a solvent. The process consists of mixing the ingredients, rolling them out to a specific thickness, drying, cutting to size, and packaging. Packages of compressed sheet are normally shipped to a secondary manufacturer who cuts out the gaskets as needed, usually by die-cutting.

The amount of asbestos used in producing gaskets is approximately 66 percent[2] of the total amount consumed by this category or 8120 metric tons of asbestos based on 1980 data.[1] Commercial grade gasket sheet contains 75 to 80 percent asbestos; specialty grades may contain as much as 100 percent asbestos. For the specialty gaskets both chrysotile and crocidolite asbestos fibers are used, whereas for the others chrysotile is predominantly used.

The consumption of asbestos in the production of gaskets and packing has decreased only slightly, 4 percent, since 1976. Between 1974 and 1976 it had decreased 25 percent because of newly developed products, the use of substitute materials, and recognized health hazards. Use of asbestos is expected to continue near current levels due to the advantages of the fiber compared to substitutes and because the hazardous fiber form of the material is not employed.[3] The 20-year forecast indicates that asbestos consumption will range from 0 to 30,000 metric tons, with a probable value somewhere around 25,000 metric tons annually.[1]

## Secondary and Consumer Use

Asbestos gaskets are used to obtain a tight nonleaking connection between piping and other joints. It is used on all types of industrial and commercial equipment with specialty items such as impregnated millboard being used in small motors for things like snowblowers and lawnmowers. The primary product, the asbestos sheets, are usually sold to secondary fabricators, who size cut, package, and sell the gaskets wholesale or retail.

Installation is simple once the gasket is cut to size; it consists of setting the gasket in place between two rigid surfaces and sealing the joints with pressure. In service, the faces are completely isolated from the outside environment. After installation, the gasket's life span is dependent on the severity of use and maintenance practices. It has been estimated[3] that 25 percent of gasket materials have less than a 1-year lifespan, 60 percent are used for maintenance and long-time replacement, and 15 percent for new installation.

## Environmental Release

Following manufacture, asbestos fibers are considered to be locked in the gasket sheeting material. Consequently, only minimal fiber release is expected during secondary fabrication and product end use. Studies have been conducted to monitor asbestos fiber concentrations associated with various asbestos sheet gasket handling, fabricating, installation, and removal activities.[4,5,6] These studies were performed under actual conditions. Asbestos fiber concentrations recorded during these activities are presented in Table 17. Except in two cases, hand punching and machine punching, fiber levels were all below the current OSHA 8-hour TWA standard of 2 f/cm$^3$. It is noted that the relatively high fiber levels recorded for hand and machine punching occurred when no controls were employed. When control measures were applied to these two operations, resultant fiber concentrations were reduced to levels well below the 2 f/cm$^3$ standard.

Another study[7] reported fiber levels during cutting and packaging of asbestos gasket sheeting at 0.1 to 0.5 f/cm$^3$. Fiber release during use is expected to be less than that measured during cutting because at no time is the asbestos-containing material acted upon with a force that would cause the release of fibers from the product matrix.

TABLE 17. ASBESTOS FIBER CONCENTRATIONS ASSOCIATED WITH VARIOUS COMPRESSED ASBESTOS SHEET GASKET HANDLING ACTIVITIES[4,5,6]

| Study | Activity performed | Measured fiber concentrations (f/cm$^3$) | Date of tests | Duration of activity/ sample time (min) | Analytical method | Comments |
|---|---|---|---|---|---|---|
| A | Punch press operation | 0.04 to 0.67 | 1980 | 80 to 211 | Fibers were counted by phase contrast with PLM verification | Monitoring performed at a major gasket fabricator located in Wisconsin |
| | Power shear operation | 0.17 | 1980 | 188 | Fibers were counted by phase contrast with PLM verification | Monitoring performed at a major gasket fabricator located in Wisconsin |
| | Shear press operation | 0.23 to 0.81 | 1980 | 50 to 76 | Fibers were counted by phase contrast with PLM verification | Monitoring performed at a major gasket fabricator located in Wisconsin |
| | Roussel press | 0.04 to 0.08 | 1980 | 100 to 192 | Fibers were counted by phase contrast with PLM verification | Monitoring performed at a major gasket fabricator located in Wisconsin |
| | Picking operation | 0.10 to 0.31 | 1980 | 93 to 206 | Fibers were counted by phase contrast with PLM verification | Monitoring performed at a major gasket fabricator located in Wisconsin |
| | Tumbling operation | 0.42 to 0.60 | 1980 | 77 to 141 | Fibers were counted by phase contrast with PLM verification | Monitoring performed at a major gasket fabricator located in Wisconsin |
| | Materials handling | 0.11 to 0.34 | 1980 | 91 to 216 | Fibers were counted by phase contrast with PLM verification | Monitoring performed at a major gasket fabricator located in Wisconsin |
| | Platen press operation | 0.05 to 0.29 | 1980 | 52 to 256 | Fibers were counted by phase contrast with PLM verification | Monitoring performed at a major gasket fabricator located in Wisconsin |
| B | Platen press operation | 0.03 to 0.15 | 1980 | 63 to 238 | Phase contrast | Monitoring performed at an asbestos-using gasket operation in Wisconsin |
| | Hydraulic beam press | 0.02 to 0.05 | 1980 | 61 to 178 | Phase contrast | Monitoring performed at an asbestos-using gasket operation in Wisconsin |
| | Hand picking and packaging | 0.06 to 0.20 | 1980 | 45 to 176 | Phase contrast | Monitoring performed at an asbestos-using gasket operation in Wisconsin |

(continued)

TABLE 17 (continued)

| Study | Activity performed | Measured fiber concentrations (f/cm³) | Date of tests | Duration of activity/ sample time (min) | Analytical method | Comments |
|---|---|---|---|---|---|---|
| | Platen press picking operator | 0.09 to 0.12 | 1980 | 67 to 140 | Phase contrast | Monitoring performed at an asbestos-using gasket operation in Wisconsin |
| | Reeves punch press operator | 0.12 | 1980 | 124 | Phase contrast | Monitoring performed at an asbestos-using gasket operation in Wisconsin |
| C | Storage for receipt and issue | <0.01 to 0.05 | 1978 | 60 to 132 | Phase contrast | Housekeeping[a] performed, monitoring conducted under actual work conditions |
| | Storage for use | <0.01 to 0.12 | 1978 | 97 to 122 | Phase contrast | No control,[b] monitoring conducted under actual work conditions |
| | Hand punching | 3.00 | 1978 | NR | Phase contrast | No control, monitoring conducted under actual work conditions |
| | Hand punching | <0.05 to 0.15 | 1978 | 28 to 31 | Phase contrast | Housekeeping performed, monitoring conducted under actual work conditions |
| | Hand operated mechanical punching | <0.05 | 1978 | 30 | Phase contrast | No control, monitoring conducted under actual work conditions |
| | Machine punching | 5.0 | 1978 | NR | Phase contrast | No control, monitoring conducted under actual work conditions |
| | Machine punching | <0.03 to 0.7 | 1978 | 20 to 30 | Phase contrast | Housekeeping performed, monitoring conducted under actual work conditions |
| | Machine punching | <0.05 to 0.06 | 1978 | 23 to 31 | Phase contrast | Housekeeping and ventilation,[c] monitoring conducted under actual conditions |
| | Hand shaping | <0.03 to 0.3 | 1978 | 7 to 31 | Phase contrast | No control, monitoring conducted under actual work conditions |

(continued)

## TABLE 17 (continued)

| Study | Activity performed | Measured fiber concentrations (f/cm$^3$) | Date of tests | Duration of activity/ sample time (min) | Analytical method | Comments |
|---|---|---|---|---|---|---|
| | Machine shearing | 0.5 to 1.3 | 1978 | 6 | Phase contrast | No control, monitoring conducted under actual work conditions |
| | Machine shearing | 0.05 to 0.15 | 1978 | 31 to 38 | Phase contrast | Housekeeping performed, monitoring conducted under actual work conditions |
| | Machine nibbling | <0.08 to 0.46 | 1978 | 8 | Phase contrast | No control, monitoring conducted under actual work conditions |
| | Machine nibbling | 0.08 to 0.8 | 1978 | 24 to 31 | Phase contrast | Housekeeping performed, monitoring conducted under actual work conditions |
| | Installation of flange gasket | <0.03 | 1978 | 30 | Phase contrast | No control, monitoring conducted under actual work conditions |
| | Removal and concurrent installation (boiler header gaskets) | 0.02 to 0.3 | 1978 | 21 to 95 | Phase contrast | Housekeeping performed, monitoring conducted under actual work conditions |
| | Clean-up following removal by hand scraping | <0.05 | 1978 | 33 to 37 | Phase contrast | No control, monitoring conducted under actual work conditions |
| | Removal and hand scraping | <0.06 to 0.39 | 1978 | 15 to 28 | Phase contrast | No control, monitoring conducted under actual work conditions |
| | Removal and wire brushing | <0.03 to 0.18 | 1978 | 25 to 33 | Phase contrast | Housekeeping performed, monitoring conducted under actual work conditions |

[a]Housekeeping - high efficiency vacuum cleaners were used to clean areas (area kept clean and free of debris accumulation), waste material placed in sealed containers.

[b]No control - no specific controls were used, i.e., no wetting, enclosing, or ventilation.

[c]Ventilation - filtered local exhaust ventilation provided to operation.

NR - Not Reported

With respect to removal, gaskets are generally treated so that they will release from the equipment face when it is necessary to replace them.[8] Should any portion stick to the support surface, it may be removed using a scraping tool. As shown in Table 17, gasket removal by hand scraping or wire brushing resulted in fiber releases ranging from 0.03 to 0.39 $f/cm^3$. The high level of 0.39 $f/cm^3$, however, was recorded when no control measures were taken. Wetting down the gasket remnants with oil or water prior to removal with an abrasive tool should substantially reduce the potential for fiber release.

Westinghouse has reported that asbestos-containing gaskets are used in residential air conditioners.[9] The gasket material is used in a hermetically sealed unit which is normally not repairable and thus totally discarded after use. Gasketing materials containing asbestos fibers are also used in larger air conditioning units that are not hermetically sealed, but because of their size and cost, they are replaced by skilled personnel and therefore should not be a source of significant release.[9]

## PACKING

### Product Manufacturing and Composition

In 1980 approximately 4180 metric tons of asbestos were consumed in the production of packing.[1] The most common type of packing is made by impregnating asbestos-containing yarn with a lubricant.[10] The impregnated yarns are braided into a continuous length of packing which is in turn calendered to a specific size and cross sectional shape. The formed product may be coated again with more lubricant. The packing is then pressed into desired shapes for use or sold to a secondary fabricator who forms it to customer specifications before he sells it.[10]

### Secondary and Consumer Use

Asbestos packings are used in dynamic situations to prevent fluid leakage. They form a bearing for revolving or moving parts in stationary supporting members that prevent leakage of the contained fluid along the bearing surface. Lubricated asbestos packings are employed in a variety of industrial, commercial, and residential applications, as well as in motor vehicles. Dry asbestos packing is used to seal furnace doors, rotary kilns and high-temperature refractory equipment.

Installation of the packing is easy once the packing is molded to form. Once in place the packing is enclosed by the supporting members of the unit. The life span of packing material, after installation, has been estimated to be less than 1 year for 90 percent the packing applications, while the rest wear much more rapidly after installation.[3]

### Environmental Release

Release of asbestos fibers to the atmosphere is considered to be minimal or nonexistent during packing handling and use. During installation the fibers are completely saturated with lubricants which inhibit the release of asbestos fibers. When the packing is in use, it is intermittently or continually coated with lubricants. Asbestos fibers released during wear should be captured by the lubricants or carried away in the process fluid system. Removal of packing should cause minimal fiber release since the free fibers are wetted and captured by the lubricant or process fluid.

Johns-Manville Corporation has conducted a study[11] to determine airborne fiber concentrations associated with the installation and removal of asbestos- containing mechanical packing. The simulated installation activity, performed in an open building, involved unrolling the packing material, wrapping it around the metal shaft of a mechanical pump, cutting the material flattening it with a hammer, and finally pushing it into the pump. Fiber levels recorded during these activities ranged from <0.1 to 0.1 $f/cm^3$. Similar fiber levels were recorded during removal of the packing from the pump after the pump had been run for a while. Although it was not reported, phase contrast analysis employing optical light microscopy was assumed to be used to determine fiber concentrations.

REFERENCES


1. Clifton, R. A., Asbestos, A Chapter from Mineral Facts and Problems. 1980 Edition. Washington, D.C. U.S. Bureau of Mines. 1981.

2. Cogley, D., et al. Life Cycle of Asbestos in Commercial and Industrial Use Including Estimates of Releases to Air, Water, and Land. Draft Final Report. Prepared by GCA/Technology Division for the U.S. Environmental Protection Agency, Office of Toxic Substances, Washington, D.C. January 1981.

3. Meylan, W. M., et al. Chemical Market Input/Output Analysis of Selected Chemical Substances to Assess Sources of Environmental Contamination, Task III - Asbestos. Report prepared for U.S. Environmental Protection Agency. EPA-560/6-78-005. August 1978.

4. Liukonen, L. R. et al. Asbestos Exposure From Gasket Operations. Report prepared by Industrial Hygiene Branch, Naval Regional Medical Center, Bremerton, Washington. May 1978.

5. Hager Laboratories, Inc. Report on Service Number 3910, For Johns-Manville Corp., August 21, 1980. Published in Health and Safety Facts: Mechanical Packings and Gasketing Materials Containing Asbestos Fibers, Johns-Manville Corp., Denver, Colorado.

6. Johns-Manville Corporation: Health, Safety, and Environment Department. Industrial Hygiene Survey Conducted July 1980 in Wisconsin. Results published in Health and Safety Facts: Mechanical Packings and Gasketing Materials Containing Asbestos Fiber, Johns-Manville Corp., Denver, Colorado.

7. Chapman, J. H., et al. Asbestos Dust Technological Feasibility Assessment and Economic Impact Analysis or the Proposed Federal Occupational Standard: Part 1. U.S. Department of Labor, OSHA. September 1978.

8. Blecher, L., GAF Corporation, Comments on Advance Notice of Proposed Rulemaking on Commercial and Industrial Use of Asbestos Fibers. February 7, 1980. U.S. EPA Docket No. OTS 61005.

9. Gormley, J. F. Submittal of Westinghouse Electric Corporation to U.S. Environmental Protection Agency's Office of Toxic Substances for Inclusion into Docket No. OTS 61005: Commercial and Industrial Use of Asbestos Fibers; Advance Notice of Proposed Rulemaking.

10. Krusell, N., and D. Cogley. Asbestos Substitute Performance Analysis. Draft Final Report prepared by GCA/Technology Division for U.S. Environmental Protection Agency, Office of Toxic Substances, Washington, D.C. May 1981.

11. Johns-Manville Corporation: Health, Safety, and Environment Department. Industrial Hygiene Survey of Simulated Field Installation of Asbestos-Containing Packings. Results of study published in Health and Safety Facts: Mechanical Packings and Gasketing Materials Containing Asbestos Fiber, Johns-Manville Corporation, Denver, Colorado.

## SECTION 7

## COATINGS AND SEALANTS

### INTRODUCTION

Asbestos-containing coatings and sealants can be divided into two basic categories; those which are of a tar or asphalt base and those which have a water soluble latex or gypsum base. Asphalt or tar-based sealants include products such as: roofing tar, flashing material, automobile undercoatings, waterproofing and floor mastics.[1] These products are put into final use by construction contractors, small businesses (such as for auto undercoating and private roofers) and often the "do-it-yourself" homeowner. The products are applied by brush, spray gun, roller, or trowel depending upon its consistency and intended use. Asbestos fibers contained within coatings and sealants are bound in the asphalt or tar matrix. The fibers have an affinity for the petroleum base materials and thus are totally wetted by the asphalt or tar in the mixture. Consequently, no fibrous asbestos dust is expected to be released during the use of these products.[2]

Water soluble asbestos-containing coatings and sealants include products such as spackling compounds, drywall patching and taping compounds, and textured paints. These products are used by building contractors both large and small as well as do-it-yourself homeowners. The latex products often come in premixed containers whereas the gypsum based materials come dry and must be mixed by the user. Significant fiber release can occur from mixing of dry materials, sanding, and cleanup.

### ASPHALT/TAR-BASED SEALANTS

#### Product Manufacturing and Composition

Asphalt or tar-based sealants which contain asbestos fibers as a filler and strengthener are composed of 5 to 10 percent asbestos, 50 percent volatile solvents, and various amounts of tars, rust proofing chemicals, pigments, heat reflecting metallic paints, and other fillers such as cork, emulsifiers, and resins. The solvents are added to reduce product viscosity and thus facilitate application of the material. The asbestos fibers used are nearly all (98 percent) grade 7 chrysotile, which become totally wetted in the mixture.[2]

Sealants are produced in batches under a controlled production cycle. Initially, the fibers are fluffed prior to being charged to a batch blending tank where they are mixed with asphalt or tar and other additives as required for an even dispersion. After blending, the liquid product is pumped to dispersing operations, and finally shipped out to market.

The batch sizes produced will 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.[3] The batch sizes also vary with company size, type of product, method of containerization, type of production equipment, and size of order. Sealant products are shipped out ready for distribution and use. Consequently, no secondary producers are involved.

The Bureau of Mines reports that 1980 usage of asbestos fibers for coatings and sealants production was approximately 10,900 metric tons.[4] The expected trend for asbestos consumption is not to decline or increase, but to remain stable.

Secondary and Consumer Use

The asphalt and tar-based sealants and coatings which contain asbestos are used by various tradesmen and contractors as well as the individual homeowner. Sealants sold for consumer use generally come packaged in 5 gallon or smaller size containers. As a roofing product the material is applied as a thick tar commercially spread by large brushes and trowels. It is most often applied to large, level top buildings, although due to its adhesive, nonrunning characteristics (which in part is attributed to the presence of the asbestos fibers), it can be spread on nonhorizontal surfaces as well. Flashing materials are also applied by trowel. As a thicker material, it is primarily applied to small areas such as joints and seams in the roofing.

Water proofing and rust proofing sealants are applied by brush or spray, and may need to be applied in several coats to achieve the desired protection.[1]

Environmental Release

In general, asphalt and tar-based sealants which contain asbestos are considered safe for use with respect to asbestos exposure. The U.S. EPA, under the authority of the National Emission Standards for Hazardous Air Pollutants (NESHAPs)[5], has banned the use of all spray-applied asbestos-containing coatings and sealants except those that are made from a petroleum-based compound. The level of ambient fiber release during the use of these products is not considered harmful. In response to EPA's notice of proposed rulemaking concerning the ban of spray-applied asbestos-containing coating materials various studies[6] were conducted to demonstrate the minimal health effects associated with the use of such petroleum-based products.

Asbestos fiber concentrations recorded during the spray application of different types of asbestos-containing petroleum-based coatings are presented in Table 18. As shown, across a wide range of products and product applications, worker exposure to asbestos fibers were well below the 2 $f/cm^3$ TWA OSHA standard. These findings support EPA's decision not to ban the use of such products.

WATER SOLUBLE LATEX OR GYPSUM-BASED SEALANTS*

Product Manufacturing and Composition

There are two principal types of joint compounds. One uses a latex or water soluble glue as a binder and sets by evaporation of the water. The other uses dehydrated gypsum as the binder (and principal dry ingredient) and sets by chemical reaction as the gypsum takes up waters of hydration. The first type is mainly limestone with lesser amounts of mica and 3 to 5 percent asbestos. This type is used in about 80 percent of the market, and is mostly sold in the ready-mixed, wet form. The gypsum-based material, with roughly 20 percent of the market, also usually contains asbestos and must naturally be sold dry and wetted just before use. The worker mixes the compound with water in the field. Wet-mix products are manufactured and packaged in a can for ready use.[3]

Manufacture of both these products involves the usual handling of raw asbestos fibers where bags are stored, moved, split, dumped and fluffed. After dry blending, the latex-based products are wet mixed, binding the fibers in the matrix. The dry mixed gypsum-based product, which is not wetted during manufacture, maintains the potential for fiber release throughout the manufacturing process, as well as during packaging, distribution, and consumer use.[3]

Secondary and Consumer Use

The use of these products and thus their manufacture is declining primarily because of the high potential for exposure to hazardous levels of asbestos during manufacturing and end use. A major impact on product use has resulted from the Consumer Product Safety Commission's (CPSC) ban of consumer patching compounds containing respirable free form asbestos.[7] Some asbestos-containing products are still used by commercial dry wallers but the health safety factors will most likely drive these users towards alternative materials as well.

Certain decorative textured paints have also contained asbestos in the past, but manufactures say they have ceased making these products with asbestos, using other fibrous materials instead.[8,9]

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*Joint compounds, patching plaster, spackle, drywall taping and finishing compounds.

TABLE 18. ASBESTOS FIBER CONCENTRATIONS ASSOCIATED WITH THE SPRAY APPLICATION OF ASBESTOS-CONTAINING PETROLEUM-BASED COATING PRODUCTS[6]

| Asbestos-containing product | Activity performed | Measured fiber concentration ($f/cm^3$) | Date of tests | Duration of activity/ sampling time (min) | Analytical method | Comments |
|---|---|---|---|---|---|---|
| Spray-applied asphaltic roof coating | | | | | | |
| Cutback asphalt | Spraying | 0.003 to 0.15 | 1974 | 342 to 432 | Phase contrast[a] (assumed) | Percent weight of asbestos as sprayed ranged from 5.8 to 7.7, after curing 9.7 to 12.8 |
| Asphalt-emulsion | Spraying | 0.01 to 0.3 | 1974,1976 | NR | Phase contrast (assumed) | Percent weight of asbestos as sprayed was 2.8, after curing 5.1 |
| Built-up roofing | Tear-off | 0.1 to 0.4 | 1974 | NR | Phase contrast (assumed) | Monitoring performed in Indiana |
| | Tear-off and replace (spray) | 0.0 to 0.3 | 1974,1976 | NR | Phase contrast (assumed) | Monitoring performed in Pennsylvania and Indiana |
| | New application (spray) | 0.0 to 0.6 | 1974,1975,1976 | NR | Phase contrast (assumed) | Monitoring performed in Wisconsin, Colorado, and Indiana |
| Resin coatings | Ship coating by spray application | 0.2 | 1974 | 8 to 33 | Phase contrast (assumed) | Operator spraying outside and under a ship with asbestos-containing epoxy resin. Percent asbestos as sprayed 1.5 |
| | Dry dock coating by spray application | 0.0 to 0.2 | 1974 | 11 to 38 | Phase contrast (assumed) | Operator spraying dock with an asbestos-containing epoxy and coal tar mixture. One percent asbestos as sprayed |
| | Coating pipe interior - spray application | 0.1 | 1974 | 37 | Phase contrast (assumed) | Operator spraying interior of 7.6, 15 and 30 cm diameter pipe with an asbestos-containing (1 percent) epoxy and coal tar mixture |
| | Fiber-glass pipe [illegible] (Mandrel coating) | 0.1 to 0.4 | 1974 | 14 to 23 | Phase contrast (assumed) | Operators monitored were involved in running automatic spray machine and wiping mandrel. A 1.4 percent asbestos chemical resistant resin was sprayed-applied |
| | Ship coating below waterline (spray application) | 0.0 to 0.4 | 1974 | 23 to 65 | Phase contrast (assumed) | Chemical resistant resin containing 0.7 percent asbestos applied |
| | Painting building exterior (commercial) | 0.0 to 0.06 | 1974,1977 | 5 to 16 | Phase contrast (assumed) | Alkyd resin containing 6 percent asbestos or vinyl-acrylic latex containing 0.6 percent asbestos applied |

(continued)

## TABLE 18 (continued)

| Asbestos-containing product | Activity performed | Measured fiber concentration ($f/cm^3$) | Date of tests | Duration of activity/ sampling time (min) | Analytical method | Comments |
|---|---|---|---|---|---|---|
| Resin coatings (continued) | Painting building interior (commercial) | 0.03 to 0.06 | 1977 | 23 | Phase contrast (assumed) | Vinyl-acrylic latex containing 0.6 percent asbestos applied |
| | Wall and roof spraying | 0.0 to 0.2 | 1974 | 12 to 15 | Phase contrast (assumed) | Operator spraying 2.8 to 3.7 percent asbestos vinyl latex on vertical wall panel |
| | Roof spraying | 0.0 | 1974 | 14 to 28 | Phase contrast (assumed) | Operator spraying 0.7 percent asbestos acrylic latex |
| | Boat MFG - spraying surface coatings | 0.0 to 0.6 | 1972,1974,1975 | 4 to 55 | Phase contrast (assumed) | Operator spraying 0.5 percent asbestos general purpose polyester resin |
| | Sawing pipe coated with polyester resin | 0.04 to 0.1 | 1973 | 19 to 49 | Phase contrast (assumed) | Operator sawing reinforced fiberglass pipe coated with polyester resin containing 2 to 3 percent asbestos |
| | Grinding FRP tanks and pipe | 0.3 to 0.4 | 1974 | 5 to 25 | Phase contrast (assumed) | Operator grinding fiberglass reinforced plastic parts containing 1.5 asbestos |
| | Handsanding interior building panels | 0.0 to 0.3 | 1977 | 1 to 16 | Phase contrast (assumed) | Operator handsanding panel surfaces covered with vinyl latex paint containing 1.1 percent asbestos |
| | Sand blasting high performance exterior coating | 0.2 to 0.3 | 1978 | 5 to 27 | Phase contrast | Operators sandblasted 12 meter diameter by 7.6 meter high steel tank spray coated in 1973 with a 2.1 percent asbestos resin coating. |

a Fibers 5 μm long or longer with a length to width aspect ratio of 3 or greater were counted by phase contrast analysis using optical light microscopy.

NR - Not Reported

The following describes a common product end use for dry wall spacklers who apply asbestos-containing patching compounds in a finishing operation.[10] In the construction of a commercial building, wallboards are fixed to metal studs with screws, while in residential houses the gypsum wallboards are nailed into the wooden studs.[10] The resulting joints, as well as screw and nail indentations, are finished by taping and spackling.

The dry joint compound powder is normally contained in paper bags. The bag is slit open with a knife and the powder dumped into a container. Water is then added according to the manufacturer's directions and the compound mixed by means of a portable electric drill equipped with a mud or paint mixe· bit. Some joint compound is sold as a paste (referred to as "premix") and only a small amount of water is required. The prepared mixture in its putty-like form after wetting is referred to as mud. The time spent mixing in a working day is short. It usually takes 5 to 10 minutes to mix a batch and in most instances one to three batches are required daily.[10]

The joint compound (mud) is placed on the bottom side of a paper tape and is applied to cover the joints between the gypsum boards and allowed to dry. Subsequently, this compound is also applied on the front side of the tape and to screw and nail indentations. A major portion (65 to 70 percent) of the working day is spent in this operation.[10]

The joints and indentations are sanded between each application of mud, with the major amount of sanding being carried out after the final coat. Three to four coats of mud are usually applied. Sanding operations normally involve either hand sanding or pole sanding. Hand sanding is carried out with a hand-held, abrasive paper, covered sanding block. In pole sanding, the sanding block is at the end of long pole. Generally speaking, most of the sanding is carried out by pole sanding. It is estimated that 25 to 30 percent of total time is spent in this operation.[10]

The debris and the dust accumulated on the floor resulting from the mixing, application and sanding operations is generally cleaned up by dry sweeping. In many instances, especially in cases of commercial building and large projects, this operation is carried out by general laborers. However, it was generally found to be part of the work responsibilities of employees of small companies working on residential construction projects.[10]

Environmental Release

The asbestos release potential of these products is relatively high. A summary of airborne asbestos concentrations is given in Table 19. The table breaks down exposure levels into the various steps of product use and handling. Even though the CPSC has banned the use of these materials, a fair amount may still be in circulation in the marketplace. Consequently, the following discussion presents suggested recommendations to minimize worker contamination.

Verma and Middleton[10] reached the following conclusions based on the data they recorded:

TABLE 19. SUMMARY OF AIRBORNE ASBESTOS FIBER CONCENTRATIONS ENCOUNTERED IN THE DRYWALL TAPING PROCESS[10,11]

| Asbestos-containing product | Activity performed | Measured fiber concentration (f/cm³) | Date of tests | Duration of activity/ sampling time (min) | Analytical method | Comments |
|---|---|---|---|---|---|---|
| Water soluble gypsum-based drywall compound (Study A) | Application | 0.4 to 1.3 | 1978 | 39 to 65 | Phase contrast[a] | Commercial operation |
| | Mixing (dry powder) | 9.0 to 12.4 | 1975 to 1977 | 10 to 12 | Phase contrast | Residential setting |
| | Mixing (pre-mix) | 1.2 to 3.2 | 1978 | 4 to 5 | Phase contrast | Commercial operations |
| | Hand sanding | 2.1 to 24.2 | 1975 to 1977 | 10 to 80 | Phase contrast | Residential setting |
| | Pole sanding | 1.2 to 10.1 | 1975 to 1977 | 10 to 38 | Phase contrast | Residential setting |
| | Pole sanding | 1.2 to 10.0 | 1978 | 4 to 21 | Phase contrast | Commercial operation |
| | Sweeping | 4.0 to 26.5 | 1975 to 1977 | 9 to 30 | Phase contrast | Residential setting |
| | Sweeping | 14.5 to 25.4 | 1978 | 10 to 20 | Phase contrast | Commercial operation |
| Water soluble gypsum-based drywall compound (Study B) | Dry mixing (0.9 to 1.5 m) | 35.4 to 59.0 | 1974 | NR | Phase contrast | Commercial operation. Fiber range reported is not less background levels, which for the same room ranged from 0.5 to [illegible] f/cm³ |
| | Hand sanding (0.9 to 1.5 m) | 1.3 to 16.9 | 1974 | NR | Phase contrast | Commercial operation. Fiber range reported is not less background levels, which for the same room ranged from 2.1 to 2.5 |
| | Pole sanding (0.9 to 1.5 m) | 1.2 to 19.3 | 1974 | NR | Phase contrast | Commercial operation. Fiber range reported is not less background levels, which for the same room ranged from 3.5 to 19.8 |
| | Sweeping hose (3.0 to 15) | 41.4 (mean) | 1974 | NR | Phase contrast | Due to heavy loading during sweeping, sampling occurred 15 minutes after sweeping stopped. After 35 minutes, the measured fiber level was 26.4 f/cm³. |

[a] Fibers 5 μm long or longer with a length to width aspect ratio of 3 or greater were counted by Phase Contrast Analysis using optical microscopy.

1. The tapers are occupationally exposed to potentially hazardous asbestos dust concentrations in their work. The asbestos hazard can be eliminated by the use of asbestos free joint compound. Although asbestos-free joint compound is available and most manufacturers are actively working towards the reduction and/or elimination of asbestos in their material, most of the taping compounds used still contain asbestos. The use of an asbestos-free compound is the only feasible method of total control of asbestos exposure and is therefore strongly recommended. However, a person engaged in mixing, sanding, and sweeping, of an asbestos-containing compound should wear an approved protective respiratory device.

2. The use of a pre-mix compound is preferable over a dry powder joint compound because it eliminates potential high exposure during mixing. It is recommended that the amount of joint compound used should be the minimum necessary to complete the job.

3. Sanding is the most hazardous operation of the taping process because the concentrations of asbestos encountered are high and a large portion of total time is spent in this operation. To reduce the exposure potential, various control measures should be considered, including the effective use of respirators and rotation of workers.

4. The short-term hazard associated with sweeping and cleanup operations could be reduced by employing an industrial type vacuum cleaner. If a broom must be employed, a dust suppressant compound should be used.

5. Tapers who work with asbestos-containing compounds should be included in the medical surveillance program for asbestos workers. Additional epidemiological studies of this group of workers are also recommended. Furthermore, tapers should be familiarized with the potential health hazards, especially the greatly elevated lung cancer risks for asbestos workers who smoke.

6. The unnecessary exposure of tradesmen not directly involved in taping, can be avoided by proper job scheduling and restricting their entry to exposure areas. Contamination of the home environment can be minimized by careful handling of workclothes and good personal hygiene.

REFERENCES


1. Cogley, D., et al. Life Cycle of Asbestos in Commercial and Industrial Use Including Estimates of Releases to Air, Water, and Land. Prepared for the U.S. Environmental Protection Agency, Office of Toxic Substances by GCA/Technology Division, January 1981.

2. Meylan, W. M., et al. Chemical Market Input/Output Analysis of Selected Chemical Substances to Assess Sources of Environmental Contamination: Task III. Asbestos. Prepared for the U.S. Environmental Protection Agency, Office of Toxic Substances, EPA-560/6-78-005. August 1978.

3. Daly, A.P., et al. Technological Feasibility and Economic Impact of OSHA Proposed Revisions to the Asbestos Standard (Construction Excluded). Prepared for the Asbestos Information Association/North America by R. F. Weston Environmental Consultants. March 26, 1976.

4. Clifton, R. A., Asbestos, A Chapter from Mineral Facts and Problems. 1980 Edition. Prepared for the U.S. Department of the Interior, Bureau of Mines. Preprint from Bulletin 671.

5. 40 CFR Part 61, National Emission Standards for Hazardous Air Pollutants. 38 FR 8820, April 6, 1973, as amended.

6. Testimony Prepared for A Public Hearing Before the California Occupational Safety and Health Standards Board. November 8, 1978. Source of testimony unknown. Information supplied to GCA by Johns-Manville Corporation, Denver, Colorado.

7. Consumer Product Safety Commission, 16 CFR Part 1304 - Ban of Consumer Patching Compounds Containing Respirable Free Form Asbestos - 42FR 63362. December 15, 1977. pp. 203-207.

8. Telecon. Charles Spector, Everseal Manufacturing Co., Inc., with David Cook, GCA/Technology Division, January 17, 1980.

9. Telecon. Jack Fleming, Bondex International, with David Cook, GCA/Technology Division, January 16, 1980.

10. Verma, D. K., and C. G. Middleton. Occupational Exposure to Asbestos in the Drywall Taping Process. Presented in the Journal of American Industrial Hygiene Association, Vol. 41, April 1980. pp. 264-265.

11. Fischbein, A., et al. 1979. Drywall Construction and Asbestos Exposure. J. American Industrial Hygiene Association. Vol. 40, pp. 402-407.

## SECTION 8

## ASBESTOS-CEMENT SHEET

### INTRODUCTION

Asbestos-cement (A/C) sheet, which is the only product in this category, is used mainly in construction applications, such as roofing and sidings of both industrial and residential buildings.[1] Constituting approximately 2.2 percent (7,900 metric tons) of the 1980 U.S. market consumption for asbestos-containing material, A/C sheet is categorized into four distinct product lines:[2]

- flat sheets
- corrugated sheets
- siding shingles
- roofing shingles

Flat sheet has a variety of construction applications. Density variations generally determine the product's end use. Ordinary or high density sheets may be used for external cladding applications, while special, low density panels, containing a larger portion of asbestos fibers, are designed for use as infill panels for curtain wall systems, fire-resistant partitions, ducting, fume hoods and doors.[1] Other uses include laboratory bench tops, electrical equipment mounting panels, components in vaults, ovens and safes, and cooling tower fill sheets. Corrugated sheets are used primarily in industrial and agricultural applications whereas roofing and siding products are used in building construction. Other sheeting uses include lining of waterways and canal bulkheads, and end paneling for cooling towers.[3]

### PRODUCT MANUFACTURING AND COMPOSITION

A/C sheet products typically contain 30 to 40 percent asbestos, by weight, with chrysotile grades 6 and 7 most commonly used.[1,2] Primary manufacturing of A/C sheet and shingles include dry, wet, or wet mechanical processes. Wet processed A/C sheet production closely parallels A/C pipe manufacturing; dry processing is used to make certain shingle type products.[4]

Secondary processing of A/C sheet products is generally performed at central fabricating shops. Material is cut and shaped into specific sizes for sale to a distributor or the consuming public. Fabricating processes, which include sawing, trimming, drilling, and grinding, are generally conducted under controlled conditions.[4]

Today the use of A/C sheet is narrowing toward applications where its special properties of durability and heat and chemical resistances are not duplicated by other steel materials. Demand for asbestos use in the construction industry is expected to remain at present levels; approximately 70 percent of all asbestos-containing material usage.[2] However, substitution is currently being actively investigated in many of the product uses, particularly in asbestos-cement products where a variety of alternative ceramic and new plastic materials are available.[2] The most apparent opportunities for market increases appear to be asbestos-cement products which compete with lumber and other building products, many of which are increasing rapidly in price.[2] The extended forecasted growth rate for asbestos-cement products is estimated to average 0.6 percent per year.[2]

## SECONDARY AND CONSUMER USE

Almost all A/C sheet consumption is for a construction-related application. Some field fabrication of A/C sheet products may be necessary, specifically in shingle applications. 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 are performed.[1] Hand tools (without controls) may also be used in the field, but the extent of use is not accurately known. 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.[1]

Life expectancy of A/C sheet products vary with use. A/C roofing shingles are thought to last 20 to 25 years, while laboratory table tops and textured architectural construction lasts until the building of which they are a part of is torn down.[1]

## ENVIRONMENTAL RELEASE

Asbestos fiber release, and subsequent exposure to asbestos material, is a function of material age and condition, mechanical forces applied, and the degree of area ventilation. Generally, asbestos fibers are embedded firmly in shingle tiles (or sheets) such that handling or installation (where hammering is the mechanical force applied) are not major sources of asbestos fiber exposure. Installation of A/C sheet material is generally performed outdoors where direct exposure to asbestos fiber takes on a lesser magnitude[5] due to ambient air dilution. Removal of A/C sheet by building demolition, however, constitutes a greater potential for asbestos fiber exposure.

Published data on asbestos fiber release from both simulated tests and actual field applications are available. Fiber release tests of Transite®, an A/C sheet product manufactured by Johns-Manville, were performed in a nonventilated glove box chamber.[6] Commonly used as an insulating panel in wood stove installations, the A/C material was subjected to four test activities routinely performed in construction applications. Asbestos fibers in this product may be characterized by unsorted fibers and bundles embedded in an irregular orientation in the cement matrix.[6] The test results appear in Table 20.

TABLE 20. FIBER[a] RELEASE CONCENTRATIONS ASSOCIATED WITH ASBESTOS-CEMENT SHEET PRODUCT USE ACTIVITIES[6]

| Operation | Time (min) | Phase contrast ($f/cm^3$) | SEM[b] ($f/cm^3$) |
|---|---|---|---|
| Drill | 1 | 2.3 | 2.3 |
| Score | 4 | 3.2 | 1.1 |
| Hammer[c] | 1 | 12.7 | 16.5 |
| Hammer[c] | 4 | 6.4 | 10.2 |
| Saw | 1 | 195.8 | 258.8 |

[a]Fibers as long as or longer than 5 µm having a length to width aspect ratio of 3 to 1 or greater were counted by optical microscopy analysis.

[b]SEM - Scanning Electron Microscopy analysis.

[c]Unclear whether this operation simulated installation with nails (fasteners).

An epidemiological study conducted in West Germany has estimated construction worker exposure to asbestos fine dusts.[7] Worker activity monitoring occurred at approximately 40 building sites where roofing and siding work was being performed. Onsite tests of asbestos fiber release from grinding operations performed on corrugated asbestos-cement sheets revealed that near the breathing zone of the workers, fiber concentrations ranged from 0.6 to 41 $f/cm^3$ of length greater than 5 microns with a mean value of 20 $f/cm^3$.[7] Scanning electron microscopy analysis revealed that the mean values of fiber length ranged from 1 to 5 μm and fiber diameter from 0.1 to 0.4 μm. The ratio of fibers with a length greater than 5 μm to the total number of free fibers ranged from 4 to 60 percent, with a median value of 25 percent. The authors state that on the average, grinding accounts for only 6 percent of the working time.[7] As such, the daily mean value reaches only 1.2 fibers/$cm^3$. According to the study, roofing operations involving the grinding of corrugated asbestos-cement sheets are carried out up to 125 days per year. The study goes on to explain that, based on a sampling of 61 roofers, the frequency of handling corrugated sheets, shingles, and front plate asbestos-cement building products, where the grinding machine is not used, are 34, 30 and 25 days per year, respectively. It is noted that workers may handle more than one type of asbestos-cement product on any given day.

Although it is beyond the scope of this study, researchers in Belgium have shown that asbestos-cement dust behaves more like cement dust (Portland cement P300) than like pure asbestos fibers.[8] The results of their study reveal that respirable asbestos-cement dust particles are physiochemically different from respirable pure asbestos dust. Asbestos-cement products tested (machining) were autoclaved sheeting, not autoclaved sheeting, and A/C pipe. The authors do conclude, however, that the results obtained from their study cannot be used to assess whether asbestos-cement dust is as hazardous to human health as pure asbestos dust.

Continuing, a simulated product use demonstration[9] conducted by Nilfisk of America, a leading manufacturer of HEPA filtered industrial vacuum cleaners for toxic materials, revealed that fiber releases can be minimized using power tools equipped with dust control apparatus. Phase contrast microscopy analysis of air samples taken during the drilling and cutting of asbestos-cement board ranged from 0.04 to 0.15 f/$cm^3$. Sampling periods ranged from 12 to 17 minutes using a power circular saw, drill and saber saw. Dust capture was achieved using hooded tools that vented to a Nilfisk filtered vacuum cleaner. No visible emissions were observed from the operation while the vacuum cleaner was activated.

Another simulated A/C sheet monitoring study was performed by the Johns-Manville Corporation.[10] The results of J-M's tests using dust controlled construction tools indicate little or no fiber release during the drilling and sawing of 0.64 cm thick (0.25 in.) flat A/C sheet. Measured fiber levels are presented in Table 21.

Table 22 shows the typical exposure levels occuring during primary and secondary manufacturing of A/C sheet. Primary and secondary manufacturing operations are generally controlled.

In summary, asbestos fibers embedded in the cement matrix will generally remain so for the life of the product, with the exception of when mechanical forces are applied during handling. It has been estimated that 0.1 percent of asbestos in roof products can become detached by weathering.[11] Other environmental releases include landfill disposal of manufacturing wastes or old, worn-out product.

TABLE 21. AIR MONITORING TEST[a] RESULTS USING A CIRCULAR SAW AND DRILL ON FLAT A/C SHEET[10]

| Operation | Time (min) | Equipment | Fiber concentration[b] ($f/cm^3$) |
|---|---|---|---|
| Drilling holes (163 holes) | 40 | Drill with dust pick-up shroud; operated at full speed | 0.1 |
| Sawing (18.3 meters) | 40 | Circular saw with dust pick-up shroud; totally enclosed masonry blade | 0.0 |

[a]All tests conducted in an open room.

[b]NIOSH's phase contrast analysis assumed, counting fibers 5 μm long or longer with a length to width aspect ratio of 3 or greater.

TABLE 22. EXPOSURE TO AIRBORNE ASBESTOS FIBERS DURING A/C SHEET MANUFACTURING[5]

| | Asbestos concentrations (Time-weighted average in $fibers/cm^3$)[a] | | | | |
|---|---|---|---|---|---|
| | Most operations | | Operations with highest levels | | |
| Operation | Typical | Range | Typical | Range | Name of operation |
| Primary manufacturing | 2.0 | 0.3-8.7 | 3.0 | 0.9-8.4 | Dry mixing |
| Secondary manufacturing | - | 1.0-6.0 | 2.5 to 3.0 | - | Trimming, sanding |

[a]NIOSH's Phase Contrast Analysis performed counting fibers 5 um long or longer with a length to width aspect ratio of 3 or greater.

## REFERENCES


1. Cogley, D., et al. Life Cycle of Asbestos in Commercial and Industrial Use Including Estimates of Releases to Air, Water, and Land. Draft Final Report, prepared by GCA/Technology Division for the U.S. Environmental Protection Agency, Office of Toxic Substances, Washington, D.C. October 1979.

2. Clifton, R. A., Asbestos 1980. U.S. Department of the Interior, Bureau of Mines. 1980.

3. Krusell, N., et al. Asbestos Substitute Performance Analysis. Final Report, prepared by GCA/Technology Division for the U.S. Environmental Protection Agency, Office of Toxic Substances, Washington, D.C. May 1980.

4. Chapman, J. H., et al. Asbestos Dust Technology Feasibility Assessment and Economic Impact Analysis of the Proposed Federal Occupational Standard. Part 1. U.S. Department of Labor, OSHA. September 1978. NTIS No. RTI/1270/02-01-F.

5. Levine, R. J. (ed.). Asbestos: An Information Source. DHEW Pub. No. (NIH)79-1681. May 1978.

6. Cogley, D., et al. The Experimental Determination of Asbestos Fiber Size Distribution During Simulated Product Use. Final Report prepared by GCA/Technology Division for the U.S. Environmental Protection Agency, Office of Toxic Substances, Washington, D.C. May 1981.

7. Rodelsperger, K., et al. Estimation of Exposure to Asbestos-Cement Dust on Building Sites. Study supported by the Umwelfbundesant, Berlin, Project No. 10401023/11, by the Commission of the European Community, Project No. 298-781 ENVD, and by the Bau-Berufsgenossenschaften, Frankfurt.

8. Baeten, J., J. Helsen, and A. Deruyttere. 1980. Nature, Structure, and Properties of Asbestos Cement Dust. British Journal of Industrial Medicine. Vol. 37, pp. 33-41.

9. Intra-laboratory Memo, Argonne National Laboratory. Asbestos Fiber Measurements During the Nilfisk Power and Vacuum Demonstration. August 30, 1979. Memo received from Bruce Newman, Nilfisk of America, Inc., King of Prussia, Pa. December 7, 1981.

10. Asbestos Information Association/North America, Recommended Work Practice Procedures for Asbestos-Cement Sheet. Submittal to U.S. Environmental Protection Agency, Office of Toxic Substances, in response to Commercial and Industrial Use of Asbestos Fibers: Advance Notice of Proposed Rulemaking. Docket Number OTS 61005.

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

## SECTION 9

## TEXTILES

### INTRODUCTION

Because asbestos fibers, after a minimal amount of conditioning, are processable on conventional textile manufacturing equipment, they are available in all conventional textile forms including: lap, roving, yarn, cord, thread, cloth, tape, tubing, wick, rope and felt.[1] Approximately two-thirds of all manufactured asbestos-containing textiles are used as an intermediate product to produce other materials such as friction products, insulation, packings and gaskets.[2] Long asbestos fibers which are processed into various intermediate textile forms are generally worked into protective clothing, insulating materials, filters or diaphragms.

### TEXTILE MANUFACTURING AND COMPOSITION

Asbestos-containing textile products typically contain from 75 to 100 percent asbestos fiber. Small percentages of cotton, rayon and other natural or synthetic fibers are blended with asbestos to improve spinnability and to impart the desired serviceability to the end product.[3]. Approximately 1,900 metric tons of asbestos or about 0.5 percent of the total U.S. fiber consumption went into textile manufacturing in 1980.[4] Long, spinning grade chrysotile fibers, grades 1, 2, and 3, are predominantly used.

Primary manufacturing of asbestos textile products include the conventional process and the wet process. Most textiles are made by the conventional process by either the dry or damp methods.[2] Both methods are identical except that during damp processing, yarn is moistened to reduce fiber emissions. The conventional dry process produces a small volume of highly specialized yarn without absorbing any water.[2]

The more newly developed wet process yields a product that tends to hold asbestos fibers better than those produced by the conventional processes, thus reducing workplace fiber levels. The yarn formed, however, tends to have poor absorption and impregnation characteristics.[5] Raybestos-Manhattan Inc. has been involved in the development of this new wet process.[6] Their process, referred to as the Novatex® method, mixes asbestos fibers with hot, soapy water in a hydropulper. Researchers found that the asbestos fibers, with positively charged surfaces, are readily dispersed in water treated with certain soaps.[6] The process yields a dense yarn by extruding the dispersion slurry and passing the material through spinnerettes. Similar with respect to viscose rayon processing, the Novatex process eliminates the carding operation; the segment of the conventional process that generates a great deal of airborne fibrous dust.

Primary asbestos textile products are typically fabricated into industrial, commercial and consumer products by secondary manufacturers. Table 23 identifies the end products made using primary asbestos-containing textile materials. In 1975, the market shares of asbestos textiles used for friction materials, packing and jointing material, protective clothing, thermal and electrical insulation, layer felts, and conveyor belts were 30, 27, 17, 13, 7 and 6 percent, respectively.[1] In most cases, asbestos textile materials are bound or coated with resins or elastomers before becoming the final product.[7] Asbestos material can also be aluminized forming a heat reflecting surface. The metallic layer can be sprayed on or bonded to the cloth by a thermosetting resin.

TABLE 23. FORMS OF ASBESTOS TEXTILES USED IN ASBESTOS PRODUCTS[7]

| Fire-resistant clothing | 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 | | | |

The demand for asbestos in textile manufacture is estimated to fall to zero tons in the year 2000.[4] The performance of high temperature application substitute materials has proven comparable with and often exceeds the performance characteristics of asbestos.[7] Large producers of fire-resistant materials are currently manufacturing substitutes containing fiberglass and ceramics along with their asbestos products as government specifications for fire-resistant materials are being revised for health reasons, thus encouraging the sale and use of substitute materials.[7]

SECONDARY AND CONSUMER USE

As discussed previously, primary asbestos-containing textile materials are further processed by secondary manufacturers. As an example, electrical wire manufacturers may use asbestos tubing as insulating material. The consumer product is the electric wire itself or the fixture or appliance the electric wire may be a part of.

The following paragraphs describe asbestos textile product uses and potential consumer exposure. It is important to remember that asbestos-containing textile materials are generally bound or coated with resins or elastomers before becoming the final product; this minimizes consumer exposure during product use.

Fire-Resistant Materials

Whenever the properties of incombustibility and thermal stability are required, asbestos-containing cloth is generally used. Woven from asbestos yarn, the variety of asbestos cloth applications include welding curtains, draperies, blankets, protective clothing, hot conveyor belts, furnace shields and molten metal splash protection aprons.[7] All of these are industrial applications and do not represent general consumer uses.

With respect to consumer uses, the Consumer Product Safety Commission has banned general use of garments containing asbestos.[8] However, the use of asbestos in special garments, such as fire-fighting protective clothing, is permitted if the materials are made so that asbestos fibers are not released under normal use. Asbestos cloth is generally treated during processing such that direct exposure to asbestos fiber will not occur until the product wears out or becomes torn.

Thermal Insulation

Asbestos textiles, such as cloth, tubing, and tape, are used as thermal insulation. Applications include pipe wraps for safety protection, stress relieving pads in welding operations, protective coverings for hot glassware utensils, coverings for diesel engine exhaust lines, and braided walls in the construction of steam hoses.[7] Again these are primarily industrial and commercial uses, not consumer applications which would affect a greater population.

Exposure to asbestos fibers can occur during installation when the textile product may be cut or torn for proper application. "Rip-outs" or removal of unuseable or worn-out asbestos material generates the highest concentrations of asbestos fibers encountered by insulation workers.[8]

## Electrical Insulation

Asbestos tubing, tape, and cloth have a wide variety of applications in the electrical industry providing insulation and heat resistance.[1] As a conductor covering, braided tubing or tape may be wrapped on wire (or cables), or plastic laminated and pressed onto wire. Generally, asbestos textiles are employed for the insulation of wires and cable which are designed for low voltage, high current use under severe temperature conditions.[7]

Under proper use, direct exposure to asbestos fibers from insulated electrical products is expected to be minimal. However, electrical appliance cords may become frayed (cloth covering) under abnormal use, in which case asbestos fibers could become airborne.

## Packing Material

Asbestos textile packing is manufactured from dry asbestos yarn which is impregnated with a lubricant and braided into continuous lengths. Varying amounts of binder and lubricant may be added depending on the application. The most common type of rotating shaft seal consists of packing composed of woven, twisted or braided textile yarns and threads which are formed into coils, spirals or rings.[9] Similar packing material may be used in slip-type expansion joints. In both cases, asbestos fiber release is related to the lack of lubricant which causes packing material to become hard and lose its resiliency. Lubrication fittings are generally provided on pumps and slip joints so that adequate quantities of lubricant can be supplied regularly.

## Friction Material

Asbestos textile materials in the form of woven asbestos brake lining or clutch facings are mainly found in industrial applications where long periods of heavy load conditions exists. Molded asbestos brake materials, developed in the 1950's, are replacing woven textile products because they offer superior frictional properties.[1] Woven asbestos brakes are reinforced with brass wire or impregnated with phenolic resin. Exposure to asbestos fibers during use is expected to be similar to other friction materials.

## Specialty Textiles

Carded fiber is the main form of asbestos that can be used in specialty products.[7] Carded asbestos fiber (100 percent asbestos) is used as a filtering media in the clarification of beer, wine, oils and chemicals. Carded asbestos fiber can be furnished in many degrees of fineness to provide exactly the right screening for the liquid to be filtered.[3] The life span of this material is dependent upon its application, but usually lasts only one cycle.[9] Carded asbestos fiber is packaged by the manufacturer in cartons and boxes. Use of this material is generally associated with a large scale brewery or distillery operation.

ENVIRONMENTAL RELEASE

Asbestos fiber release monitoring data associated with textile use are scant. A few studies have been performed, covering a limited number of textile products. The following presents the monitoring results that have been obtained from the literature.

Tests to determine fiber release while wearing asbestos garments were performed at a blast furnace and a phosphorous plant where asbestos coats, hoods and mittens are worn. Personal monitors were used to measure the concentration of asbestos fibers at the breathing zone level. Asbestos fiber concentrations of 0.3 to 5.0 fibers/$cm^3$ were recorded for a blast furnace worker with an 8-hour TWA concentration of 0.1 to 1.1 fibers/$cm^3$.[10] At the phosphorous plant, asbestos fiber levels were considerably higher; 9 to 26.2 fibers/$cm^3$, with an 8-hour TWA concentration of 4.7 fibers/$cm^3$.[10] No reason was given for the difference in concentrations recorded at the two plants.

The garments tested were made of an untreated fabric. However, hoods were aluminized on the outside. The age of the garments was also examined in the study. Generally, asbestos fiber release increased with product age, however, no firm correlation could be developed.

Measurements of asbestos fiber release from fire-fighting helmets during use were made in another study.[11] Testing of a new helmet with an unlined asbestos cover, an identical older helmet, and a helmet with an aluminized cover on the inside and outside surfaces, showed breathing zone concentrations of 2.30, 1.38, and 0.0 fibers/$cm^3$, respectively.[11]

With respect to worker exposure during the handling and use of thermal insulation, the highest concentration of asbestos fiber exposure occurred during "rip-out" or removal of old asbestos insulation.[8] Asbestos air levels monitored on a ship during the removal of sprayed asbestos coatings, removal of 100 percent asbestos lagging, and clean-up operations averaged 248, 62 to 159, and 353 fibers/$cm^3$, respectively.[8] The high levels of asbestos fiber exposure are probably attributable to: (1) percent of asbestos content in the insulating material, (2) the untreated nature of asbestos material that becomes exposed to the atmosphere during removal operations, and (3) poorly ventilated conditions existing during installation and removal operations (shipbuilding). A study investigating the installation of pipe lagging containing 15 percent asbestos, reported asbestos fiber exposure levels of 5 to 60 fibers/$cm^3$.[12] It should be noted that the above data are relatively old and that substantially more effective control measures are now implemented during insulation removal.

A more recent study[13] has shown that asbestos-containing gloves release asbestos fibers during use. Asbestos gloves, which are manufactured from asbestos-containing textiles, are commonly used in hospital, industrial and university laboratories where sterilization is done and in the molten metal industry where worker protection from handling hot items is required. These types of gloves contain from 80 to 85 percent asbestos and 15 to 20 percent rayon. The cloth of the gloves tested was treated with an acrylate-based compound which enables the manufacturer to market them as "lint free."

Three tests were performed as part of the referenced study. The fiber release monitoring experiments included testing in a ventless isolation chamber (glove box), a well-ventilated (five air changes per hour) biology preparation room and in University laboratories under conditions of actual glove use. The researchers examined the potential difference in fiber release from new and worn gloves, the latter varying from clean to heavily soiled.

The glove use activities included the following: (1) picking the gloves up from a table top and putting them on; (2) opening an autoclave or oven door; (3) removing a tray containing laboratory growth media or glassware and setting the tray on a table top; (4) closing the door; and (5) taking the gloves off and tossing them onto a table top. The results of the three test cases are summarized in Table 24.

In all cases, fiber release was found to be directly related to the condition of the gloves. Under the nonventilated isolation chamber conditions, the well-worn/clean gloves emitted almost three times as many fibers as did the brand-new gloves, although the number of fibers released from the well-worn gloves decreased with increased surface soiling.

TWA values recorded for the well-ventilated biology preparation room were considerably lower than those obtained in the ventless isolation chamber. The authors postulate that the lower levels result from dispersion of fibers within the room by the ventilation system. The findings of the biology preparation room testing concur with those of the ventless isolation chamber whereby the well-worn/clean gloves emitted a significantly higher number of asbestos fibers into the atmosphere than the brand-new gloves did. Fiber concentrations also increased with work load, as one would expect.

Monitoring tests conducted in various University laboratories revealed a wide range of fiber levels. The researchers state that exposure levels depended more on the particular laboratory than on glove condition or usage (work load). The range in values reported are thought to be attributed to differences in room size and configuration, efficiency of the ventilation system and amount of moisture on the gloves. In summary, the researchers conclude from their tests that the use of asbestos-containing gloves expose the wearer to potentially hazardous levels of asbestos and suggest gloves made from asbestos substitute material be used whenever possible.

Asbestos fiber release during primary and secondary manufacturing processes have been widely documented. Table 25 presents the exposure levels measured during asbestos textile manufacturing. Asbestos dust levels from primary and secondary manufacturing of wet-processed asbestos textile are

TABLE 24. AIRBORNE ASBESTOS FIBERS[a] RESULTING FROM THE USE OF ASBESTOS-CONTAINING GLOVES[13]

| Sampling environment | Condition of gloves and work load | Mean TWA ± SD ($f/cm^3$) |
|---|---|---|
| Isolation chamber (nonventilated) | Brand new | 2.25 ± 0.57 |
| | Well-worn/clean | 7.97 ± 3.14 |
| | Well-worn/lightly soiled | 5.08 ± 1.27 |
| | Well-worn/heavily soiled | 0.95 ± 0.16 |
| Biology preparation room (well ventilated) | | |
| Breathing zone | Brand new - normal[b] | 0.07 ± 0.02 |
| | Well-worn/clean-normal | 0.49 ± 0.11 |
| | Brand new - heavy[c] | 0.51 ± 0.21 |
| | Well-worn/clean-heavy | 0.99 ± 0.22 |
| Work area | Brand new - normal | 0.06 ± 0.02 |
| | Well-worn/clean-normal | 0.40 ± 0.09 |
| | Brand new - heavy | 0.26 ± 0.08 |
| | Well-worn/clean-heavy | 0.60 ± 0.12 |
| University Laboratories | | |
| Breathing zone | Well-worn/clean | 0.07 to 2.93[d] |
| | Well-worn/lightly soiled | 0.10 to 0.71 |
| Work area | Well-worn/clean | 0.04 |
| | Well-worn/lightly soiled | 0.30 to 0.74 |

[a]Asbestos fibers counted were 5 μm long or longer with a length to width aspect ratio of 3 to 1. Phase contrast optical microscopy analysis was performed.

[b]Normal usage of gloves two times per hour.

[c]Heavy usage of gloves six times per hour.

[d]Values reported are not means; ranges are from tests performed at five different laboratories.

generally lower than levels for dry-processed materials. Dust level measurements in the manufacture of insulation mattresses with wet-processed "Fortex" asbestos cloth showed asbestos fiber concentrations during cloth preparation and mattress making of 0.28 to 0.58 and 0.29 to 0.6 fibers/cm$^3$, respectively.[14]

TABLE 25. EXPOSURE TO AIRBORNE ASBESTOS FIBERS DURING PRIMARY AND SECONDARY TEXTILE MANUFACTURING[8]

| Manufacturing operation | Asbestos concentrations (Time-weighted average in fibers/cm$^3$)[a] | | | | |
|---|---|---|---|---|---|
| | Most operations | | Operations with highest level | | |
| | Typical | Range | Typical | Range | Operation |
| Primary | 4 | 0.25-10 | 4 | 2.0-10 | Carding |
| Secondary | - | 2.0 - 6.0 | - | - | - |

[a]Fibers 5 um long or longer, having a length to width aspect ratio of 3:1 were counted by Phase Contrast Optical Microscopy Analysis.

In summary, all testing has shown that surface treatment of asbestos-containing textile material, whether it be during processing or prior to consumer use, generally lessens the danger of asbestos fiber exposure. All tests with asbestos garments suggest that the safety provided may outweigh the risk of asbestos-related diseases, however, the tests also show that proper treatment of asbestos garment materials, such as aluminization of cloth surfaces, can eliminate the risk entirely.

## REFERENCES


1. 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.

2. Cogley, D., et al. Life Cycle of Asbestos in Commercial and Industrial Use Including Estimates of Releases to Air, Water, and Land. Draft Final Report prepared by GCA/Technology Division for U.S. Environmental Protection Agency, Office of Toxic Substances, Washington, D.C. October 1979.

3. Anon. Handbook of Asbestos Textiles. American Textile Institute. 3rd Edition. 1967.

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

5. Meylan, W. M., et al. Chemical Market Input/Output Analysis of Selected Chemical Substances to Assess Sources of Environmental Contamination: Task III - Asbestos. EPA Report No. EPA-560/6-78-005. August 1978.

6. Scott, S. W. Produce Asbestos Yarn, Safely. Textile World. 131:69. March 1981.

7. Krusell, N., et al. Asbestos Substitute Performance Analysis. Final Report prepared by GCA/Technology Division for U.S. Environmental Protection Agency, Office of Toxic Substances, Washington, D.C.. May 1981.

8. Levine, R. J. (ed.). Asbestos: An Information Source. DHEW Pub. No. (NIH)79-681, May 1978.

9. Perry, R. H., and C. H. Chilton. Chemical Engineer's Handbook. Fifth Edition. McGraw-Hill, New York, 1973.

10. Gibbs, G. W. Fibre Release from Asbestos Garments. Ann. Occup. Hyg. 18:143. 1975.

11. Lumley, K. P. S. Asbestos Dust Levels Inside Firefighting Helmets with Chrysotile Asbestos Covers. Ann. Occup. Hyg. 14:285. 1971.

12. Harries, P.G. Asbestos Hazards in Naval Dockyards. Ann. Occup. Hyg. 11:135-145. 1968.

13. Samini, B. S., and A. M. Williams. Occupational Exposure to Asbestos Fibers Resulting from Use of Asbestos Gloves. Am. Ind. Hyg. Assoc. J. 42:870-875. 1981.

14. Schneider, T. Asbestos Dust Levels During Work with Cloths Made from Liquid Dispersed Chrysotile. Ann. Occup. Hyg. 15:425. 1972.

## SECTION 10

## ASBESTOS-REINFORCED PLASTICS

### INTRODUCTION

Asbestos fibers are used to reinforce high grade plastics for many applications where precision and specialty plastics are called for. The asbestos content of these materials is generally quite low.[1]

Asbestos reinforced plastics are extremely versatile. They can be applied for many uses which call for impact resistance, dimensional stability, heat resistance, dielectric strength, insulation resistance, arc-trac resistance, and ability to retain electrical properties at elevated temperature and humidity.[2]

Products manufactured from asbestos reinforced plastics include:[3]

- automotive parts
- communications products
- drafting tools
- precision engineered parts formerly made from metals
- electrical components
- appliance components

Once the plastic products are fabricated and ready for use, the potential for asbestos fiber release is highly unlikely; the fibers are bound tightly in the product's polymer matrix. A great deal of energy needs to be applied to the plastic in order to release any amount of fiber.[1]

### PRODUCT MANUFACTURING AND COMPOSITION

Two processing steps are involved in the manufacture of asbestos-reinforced plastic products. The two steps are primary manufacturing using commercial asbestos fibers and secondary manufacturing or fabricating. Primary manufacturers produce molding resin compounds in pellet or flake form, package it, and sell this granulated material to secondary manufacturers where the final product is shaped (molded) and finished. The primary manufacturing steps consist typically of: (1) fiber receiving and storage, (2) fiber introduction, (3) dry blending, (4) resin formation, and (5) packaging and shipping.[4] The secondary manufacturing steps usually are at a facility remote from the primary processor 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.[4]

It is extremely difficult to determine the entire scope of the secondary market for asbestos-reinforced plastics. There are industry estimates of some 3,000 secondary fabricators of reinforced plastics and perhaps 5,000 separate end users of the product.[4] Also, 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 decided not to process compounds containing asbestos fibers in their operations and have already converted to asbestos-free compounds.[5]

The volume of asbestos used in the plastics industry is declining rapidly according to Bureau of Mines estimates. In 1976, 19,500 metric tons of asbestos were reported to be consumed by the plastics molding industry; by 1978 this figure declined to 4,900.[4,6] The 1980 figures indicate a further reduction to only 1,500 metric tons of asbestos.[7] This decline can be attributed to the use of a large variety of asbestos substitutes in the industry. The asbestos that is used, however, consists primarily of crocidolite and chrysotile grades 1, 2, 5, and 7.[7]

SECONDARY AND CONSUMER USE

Asbestos-reinforced plastics are used in a great number of diverse applications. Most of the applications are related to commercial or industrial operations, few represent consumer uses. Molded asbestos-reinforced plastic products are predominantly used in the electronic, automotive and printing industries. Such product applications include 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; and commutators for electrical motors, switches and circuit breakers.[4]

The life span of many of these items vary, most are less than 35 years.[8] Some, such as automotive parts, may have a very short useful life. However, even during handling and replacement there is no significant exposure hazard from the asbestos content of the products. The asbestos is safely bound in the polymer matrix. Eighty to ninety percent of the asbestos-containing plastics produced are for replacement components.[8] In 1978, annual wasting of asbestos-containing plastics was estimated to be around 18,000 tons.[8]

ENVIRONMENTAL RELEASE

Molded reinforced plastic products are usually finished to a form where installation for use generates negligible dusting. Secondary finishing operations include drilling, filing, grinding and some riveting. Tests performed under laboratory conditions have shown that asbestos fibers are released during secondary finishing operations.[9] Grinding, filing and drilling tests resulted in fiber levels ranging from 0.0 to 7.1 $f/cm^3$ as shown in Table 26. Asbestos fibers identified occurred in short bundles and were encapsulated in the plastic matrix. Free individual fibers were also detected.

TABLE 26. ASBESTOS FIBER[a] CONCENTRATIONS ASSOCIATED WITH REINFORCED PLASTIC SECONDARY FINISHING OPERATIONS[9]

| Operation | Time (min) | SEM[b] analysis ($f/cm^3$) | Phase contrast analysis ($f/cm^3$) |
|---|---|---|---|
| File | 1 | 0 | 0 |
| File (repeat) | 3 | 1.6 | 2.8 |
| Drill | 3 | 0 | 7.1 |
| Grind | 3 | 1.6 | 2.8 |

[a]Fibers 5 μm long or longer with a length to width aspect ration of 3 to 1 were counted.

[b]Scanning electron microscopy analysis.

Asbestos fibers are also contained in insulators of electrical transformers. During assembly, the transformers are varnish-impregnated which serves as additional protection from fiber release.[10] During normal use, including some reasonably expected misuse, fibers are not expected to be released.[10] The bonded asbestos material is sealed by the varnish and the entire section containing asbestos is removed during repair or disposal.

## REFERENCES


1. Daly, A. R., et al. Technological Feasibility and Economic Impact of OSHA Proposed Revision of Asbestos Standard (construction excluded). Prepared by R. F. Weston for Asbestos Information Association/North America. March 26, 1976.

2. Durez/Hooker. Durez Thermosetting Molding Compounds Bulletin 328 MPIOM878. Durez Division, Hooker Chemicals and Plastics Corp., N. Tonowanda, New York.

3. General Electric, Genal® F7000 Series, New High-Performance Engineering Plastics to Replace Metal. G. E. Plastics Division, Pittsfield, Massachusetts.

4. Cogley, D., et al. Life Cycle of Asbestos in Commercial and Industrial Use Including Estimates of Releases to Air, Water and Land. Prepared by GCA/Technology Division under EPA Contract No. 68-02-2607 for U.S. Environmental Protection Agency, Office of Toxic Substances, Washington, D.C. November 1981.

5. Swanson, R. C., Sales Representative, Colt Industries, Garlock Inc. Mechanics Packing Division, Charlotte, North Carolina. Meeting with Mr. T. Curtin, GCA/Technology Division, Chapel Hill, North Carolina. February 21, 1980.

6. Clifton, R. A., Asbestos: A Chapter from Mineral Facts and Problems, 1980 Edition. Bureau of Mines Preprint from Bulletin 671. 9 pp.

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

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

9. Cogley, D., et al. The Experimental Determination of Asbestos Fiber Size Distribution During Simulated Product Use. Prepared by GCA/Technology Division for the U.S. Environmental Protection Agency, Office of Pesticides and Toxic Substances, Washington, D.C. October 1981.

10. Gormley, J. F. Submittal of Westinghouse Electric Corporation to U.S. Environmental Protection Agency's Office of Toxic Substances for Inclusion Into Docket OTS 61005: Commercial and Industrial Use of Asbestos Fibers; Advance Notice of Proposed Rulemaking.

## SECTION 11

## CONCLUSION AND RECOMMENDATIONS

### SUMMARY OF FINDINGS

This study was undertaken to provide an analysis of asbestos fiber release concentrations resulting from routine activities performed on asbestos-containing products and to prioritize products for subsequent laboratory testing. Products to be tested under this program are those for which data is insufficient or lacking in quality. Routine activities to be reenacted are those which are commonly or most frequently performed and those which are most likely to release free form asbestos fibers.

Product category profiles were developed to provide the information required to select the products to be tested under this program and to identify candidate products to be tested under future monitoring programs sponsored by EPA. Fiber concentration data reported were obtained from technical reports, trade journals, and contacts with environmental regulatory agencies and industry representatives.

As summarized in Table 27, the quantity and quality of the asbestos fiber release data varies greatly between product categories and among products within each category. In addition, measured fiber concentrations even vary among tests performed on similar products. These latter variances are attributable to monitoring in a glove box versus monitoring in a well-ventilated room or out of doors; employing dust control measures during some tests but not during others; differences in sampling location and analytical techniques; and differences in product composition. Consequently, meaningful comparative analysis of the test results is restricted.

The magnitude and severity of human exposure during asbestos product handling and use depends upon the releasibility of the fibers, strength of the exertion or force of agitation, fiber sizes released, and duration of the activity. During normal handling and intended use, many asbestos-containing products will not release asbestos fibers. Only during maintenance or replacement will the product be acted upon such that it may pose a potential health hazard. Furthermore, due to their rigid physical structure, many asbestos-containing products are used in stationary or static applications. Once in place, the material is subjected to little or no direct physical force or abrasion.

TABLE 27. MEASURED ASBESTOS FIBER CONCENTRATIONS RESULTING FROM SECONDARY AND END USE PRODUCT TESTING ACTIVITIES

| Asbestos product category | Asbestos product | Activity performed | Measured fiber concentration ($f/cm^3$) | Date of tests | Duration of activity/sampling time (min) | Analytical method | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|
| Asbestos-cement pipe | A/C sewer pipe | Cutting Operations | | | | | | |
| | | Hack saw | 0.18 | 1979-1980 | ≤15 | NIOSH Method[a] | Personal monitor on operator. | 1 |
| | | Snap cutting | <0.10 | 1979-1980 | ≤15 | NIOSH Method | Personal monitor on operator. | 1 |
| | | Abrasive disc, wet | 42.10 | 1979-1980 | ≤15 | NIOSH Method | Personal monitor on operator. | 1 |
| | | Abrasive disc, dry | 35.50 | 1979-1980 | ≤15 | NIOSH Method | Personal monitor on operator. | 1 |
| | | Chisel, hammer, and rasp | 0.30 | 1979-1980 | ≤15 | NIOSH Method | Personal monitor on operator. | 1 |
| | | Machining Operations | | | | | | |
| | | Manual lathe | 0.15 | 1979-1980 | ≤15 | NIOSH Method | Personal monitor on operator. | 1 |
| | | Power lathe | <0.10 | 1979-1980 | ≤15 | NIOSH Method | Personal monitor on operator. | 1 |
| | | Doty machine dry | 3.83 | 1979-1980 | ≤15 | NIOSH Method | Personal monitor on operator. | 1 |
| | | Dry shroud | 0.23 | 1979-1980 | ≤15 | NIOSH Method | Personal monitor on operator. | 1 |
| | | Wet shroud | 0.20 | 1979-1980 | ≤15 | NIOSH Method | Personal monitor on operator. | 1 |
| | | Tapering tool with airduct pipe | 0.18 | 1979-1980 | ≤15 | NIOSH Method | Personal monitor on operator. | 1 |
| | | Hole Cutting | | | | | | |
| | | Power hole cutter | 0.44 | 1979-1980 | ≤15 | NIOSH Method | Personal monitor on operator. | 1 |
| | | Hole cutting with drill, hammer and rasp | 0.23 | 1979-1980 | ≤15 | NIOSH Method | Personal monitor on operator. | 1 |
| | | Dry tap with Mueller J tool | <0.10 | 1979-1980 | ≤15 | NIOSH Method | Personal monitor on operator. | 1 |
| | | Tapping operations with Mueller B-100 | <0.10 | 1979-1980 | ≤15 | NIOSH Method | Personal monitor on operator. | 1 |
| | | Coupling Removal | | | | | | |
| | | Removal of coupling with hammer and chisel | <0.10 | 1979-1980 | ≤15 | NIOSH Method | Personal monitor on operator. | 1 |
| | A/C water (pressure) pipe | Cutting Operations Hack saw | <0.10 | 1979-1980 | ≤15 | NIOSH Method | Personal monitor on operator. | 1 |

(continued)

## TABLE 27 (continued)

| Asbestos product category | Asbestos product | Activity performed | Measured fiber concen-tration (f/cm³) | Date of tests | Duration of activity/ sampling time (min) | Analytical method | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|
| Asbestos-cement pipe (continued) | A/C water (pressure) pipe | Snap cutting | <0.10 | 1979-1980 | ≤15 | NIOSH Method | Personal monitor on operator. | 1 |
| | | Abrasive disc, wet | 65.00 | 1979-1980 | ≤15 | NIOSH Method | Personal monitor on operator. | 1 |
| | | Abrasive disc, dry | 20.30 | 1979-1980 | ≤15 | NIOSH Method | Personal monitor on operator. | 1 |
| | | Chisel, hammer, and rasp | 1.99 | 1979-1980 | ≤15 | NIOSH Method | Personal monitor on operator. | 1 |
| | | Machining Operations | | | | | | |
| | | Manual lathe | 0.51 | 1979-1980 | ≤15 | NIOSH Method | Personal monitor on operator. | 1 |
| | | Power lathe | 0.29 | 1979-1980 | ≤15 | NIOSH Method | Personal monitor on operator. | 1 |
| | | Cutting and machining on Doty machine dry | 1.90 | 1979-1980 | ≤15 | NIOSH Method | Personal monitor on operator. | 1 |
| | | Dry shroud | 1.29 | 1979-1980 | ≤15 | NIOSH Method | Personal monitor on operator. | 1 |
| | | Wet shroud | 0.21 | 1979-1980 | ≤15 | NIOSH Method | Personal monitor on operator. | 1 |
| | | Hole Cutting | | | | | | |
| | | Powerhole cutter | 1.65 | 1979-1980 | ≤15 | NIOSH Method | Personal monitor on operator. | 1 |
| | | Hole cutting with drill, hammer and rasp | 0.22 | 1979-1980 | ≤15 | NIOSH Method | Personal monitor on operator. | 1 |
| | | Dry tap with Mueller J tool | <0.10 | 1979-1980 | ≤15 | NIOSH Method | Personal monitor on operator. | 1 |
| | | Tapping operations with Mueller B-100 | 0.11 | 1979-1980 | ≤15 | NIOSH Method | Personal monitor on operator. | 1 |
| | | Coupling Removal | | | | | | |
| | | Removal of coupling with hammer and chisel | 0.30 | 1979-1980 | ≤15 | NIOSH Method | Personal monitor on operator. | 1 |
| | A/C sewer pipe | Sawing | 56.6-59.4 | 1981 | 1 | NIOSH Method | Testing performed in glove box. | 2 |
| | | Hammering | 12.2-19.8 | 1981 | 1 to 3 | NIOSH Method | Testing performed in glove box. | 2 |
| [illegible] | [illegible] wrap | Cut | 0 | 1981 | 1 | NIOSH Method | Testing performed in glove box. | 2 |

(continued)

## TABLE 27 (continued)

| Asbestos product category | Asbestos product | Activity performed | Measured fiber concentration (f/cm³) | Date of tests | Duration of activity/ sampling time (min) | Analytical method | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|
| Asbestos paper (continued) | Asbestos pipeline wrap | Tear | 0-0.9 | 1981 | 1 to 3 | NIOSH Method | Testing performed in glove box. | 2 |
| | | Crumple | 1.9-14.5 | 1981 | 3 to 4 | NIOSH Method | Testing performed in glove box. | 2 |
| | Millboard | Score | 8.4 | 1980 | 10 | SEM[b] | Testing performed in glove box. | 3 |
| | | Hammer | 1.4 | 1980 | 10 | SEM | Testing performed in glove box. | 3 |
| | | Saw | 6.2 | 1980 | 10 | SEM | Testing performed in glove box. | 3 |
| | 25% asbestos household paper roll | Cutting | 2.0-2.2 (13.8-23.3)[b] | 1980 | 10 | NIOSH Method (SEM) | Testing performed in glove box. | 3 |
| | 25% asbestos household paper roll | Tearing | 2.3 (8.9) | 1980 | 10 | NIOSH Method (SEM) | Testing performed in glove box. | 3 |
| | 25% asbestos household paper roll | Tearing and cutting | 4.8 (27.6) | 1980 | 10 | NIOSH Method (SEM) | Testing performed in glove box. | 3 |
| | 75% asbestos commercial paper | Tearing and crumpling | 7.3 (58.9) | 1980 | 10 | NIOSH Method (SEM) | Testing performed in glove box. | 3 |
| | 20% asbestos paper tape | Cutting, tearing and crumpling | 49.0 (262) | 1980 | 10 | NIOSH Method (SEM) | Testing performed in glove box. | 3 |
| | 70% to 80% asbestos shelf paper | Cutting, rubbing, rolling, tearing | 24 | 1979 | 10 | Polarized light microscopy[c] | Tests performed inside 30.5x43.2x43.2 cm glove box. | 4 |
| | 70% to 80% asbestos tape | Cutting, rubbing, rolling, tearing | 18 | 1979 | 10 | Polarized light microscopy | Tests performed inside 30.5x43.2x43.2 cm glove box. | 4 |
| | Electrical insulating paper and boards[d] | Sterling magna ply package operator | <0.016 | 1980 | 43 | Phase contrast | Results from monitoring electrical insulating paper products manufactured by Quin-T Corporation. | 5 |

(continued)

TABLE 27 (continued)

| Asbestos product category | Asbestos product | Activity performed | Measured fiber concentration (f/cm$^3$) | Date of tests | Duration of activity/sampling time (min) | Analytical method | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|
| Asbestos paper (continued) | Electrical insulating paper and boards[d] | Paper machine rewind operator, 0.008 cm thick paper | <0.004 | 1980 | 178 | Phase contrast | Results from monitoring electrical insulating paper products manufactured by Quin-T Corporation. | 5 |
| | | Paper machine rewind operator, 0.04 cm thick paper | <0.006 | 1980 | 112 | Phase contrast | Results from monitoring electrical insulating paper products manufactured by Quin-T Corporation. | 5 |
| | | Millboard cutter operator 0.08 cm thick paper | <0.005 | 1980 | 141 | Phase contrast | Results from monitoring electrical insulating paper products manufactured by Quin-T Corporation. | 5 |
| | | Winding operator, 0.03 cm thick paper | <0.008 | 1980 | 90 | Phase contrast | Results from monitoring electrical insulating paper products manufactured by Quin-T Corporation. | 5 |
| | | Slitting operator, 0.03 cm thick paper | <0.008 | 1980 | 90 | Phase contrast | Results from monitoring electrical insulating paper products manufactured by Quin-T Corporation. | 5 |
| | | Highlander, band saw operator | 12.3 | 1978 | 30 | Phase contrast | Reference cites release as excessive. | 5 |
| | | Highlander, slitter operator | 0.53 | 1978 | 42 | Phase contrast | Results from monitoring electrical insulating paper products manufactured by Quin-T Corporation. | 5 |

(continued)

TABLE 27 (continued)

| Asbestos product category | Asbestos product | Activity performed | Measured fiber concentration (f/cm³) | Date of tests | Duration of activity/ sampling time (min) | Analytical method | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|
| Asbestos paper (continued) | Electrical insulating paper and boards | Coil cutter operator | 0.094 | ND | 118 | Phase contrast | Results from monitoring electrical insulating paper products manufactured by Quin-T Corporation. | 5 |
| | | Coil cutter operator | 0.015 | ND | 94 | Phase contrast | Results from monitoring electrical insulating paper products manufactured by Quin-T Corporation. | 5 |
| | | Acme paper cutter | <0.008 | 1979 | 91 | Phase contrast | Results from monitoring electrical insulating paper products manufactured by Quin-T Corporation. | 5 |
| | | Acme coil cutter | <0.013 | 1979 | 53 | Phase contrast | Results from monitoring electrical insulating paper products manufactured by Quin-T Corporation. | 5 |
| | | Acme conv. winding | <0.008 | 1979 | 87 | Phase contrast | Results from monitoring electrical insulating paper products manufactured by Quin-T Corporation. | 5 |
| | | Winding operator, 0.008 cm thick paper | <0.008 | 1980 | 90 | Phase contrast | Results from monitoring electrical insulating paper products manufactured by Quin-T Corporation. | 5 |
| | | Slitting operator, 0.008 cm thick paper | 0.031 | 1980 | 90 | Phase contrast | Results from monitoring electrical insulating paper products manufactured by Quin-T Corporation. | 5 |

(continued)

## TABLE 27 (continued)

| Asbestos product category | Asbestos product | Activity performed | Measured fiber concentration ($f/cm^3$) | Date of tests | Duration of activity/ sampling time (min) | Analytical method | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|
| Asbestos paper (continued) | Electrical insulating paper and boards | Electrical insulating paper-punch press operator (TV BORD) | 0.097 | ND | 298 | Phase contrast | Results from monitoring electrical insulating paper products manufactured by Quin-T Corporation. | 5 |
| | | Electrical insulating paper--shear operator (TV BORD) | 0.064 | ND | 153 | Phase contrast | Results from monitoring electrical insulating paper products manufactured by Quin-T Corporation. | 5 |
| | | Electrical insulating paper--assembly dept. operator (TV BORD) | 0.006 | ND | 165 | Phase contrast | Results from monitoring electrical insulating paper products manufactured by Quin-T Corporation. | 5 |
| | | NECO, shear machine operator | 0.033 | 1978 | 120 | Phase contrast | Results from monitoring electrical insulating paper products manufactured by Quin-T Corporation. | 5 |
| | | NECO, winding area operator | 0.038 | 1978 | 180 | Phase contrast | Results from monitoring electrical insulating paper products manufactured by Quin-T Corporation. | 5 |
| | | Acme heavy handwinding | <0.006 | 1979 | 108 | Phase contrast | Results from monitoring electrical insulating paper products manufactured by Quin-T Corporation. | 5 |
| | | Acme coil pulling | <0.008 | 1979 | 87 | Phase contrast | Results from monitoring electrical insulating paper products manufactured by Quin-T Corporation. | 5 |

(continued)

## TABLE 27 (continued)

| Asbestos product category | Asbestos product | Activity performed | Measured fiber concen-tration (f/cm³) | Date of tests | Duration of activity/sampling time (min) | Analytical method | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|
| Asbestos paper (continued) | Electrical insulating paper and boards | Acme compound pourer | <0.012 | 1979 | 60 | Phase contrast | Results from monitoring electrical insulating paper products manufactured by Quin-T Corporation. | 5 |
| | | Resinite band saw operator | 0.034 | ND | 372 | Phase contrast | Results from monitoring electrical insulating paper products manufactured by Quin-T Corporation. | 5 |
| | | Square D saw operator | 0.062 | 1980 | 111 | Phase contrast | Results from monitoring electrical insulating paper products manufactured by Quin-T Corporation. | 5 |
| | Asbestos-containing flooring felt attached to vinyl sheet flooring | Installation | 0.0 to 0.102 (TWA) | 1978-1979 | 44 to 179 | Phase contrast | Installation covered four adhering and one nonadhering applications. | 6 |
| | | Partial removal by recommended procedures[e] | 0.019 to 0.041 (TWA) | 1979 | 44 to 62 | Phase contrast | Material removed had been adhered to subflooring. | 6 |
| | | Complete removal by recommended procedures | 0.037 to 0.04 | 1979 | 121 to 123 | Phase contrast | Material removed had been adhered to subflooring. | 6 |
| | | Complete removal by recommended procedures | 0.007 to 0.01 (TWA) | 1979 | 74 to 76 | Phase contrast | Material removed had not been adhered to subflooring. | 6 |
| | | Complete removal | | | | | | |
| | | Wear layer removal | 0.08 to 0.16 (TWA) | 1979 | 70 to 75 | Phase contrast | Material removed had been adhered to subflooring. | 7 |
| | | Dry scraping of flooring felt | 0.83 to 2.0 (TWA) | 1979 | 40 to 63 | Phase contrast | Material removed had been adhered to subflooring. | 7 |
| | | Wet scraping of flooring felt | 0.41 (TWA) | 1979 | 55 | Phase contrast | Material removed had been adhered to subflooring. | 7 |

(continued)

## TABLE 27 (continued)

| Asbestos product category | Asbestos product | Activity performed | Measured fiber concen-tration (f/cm$^3$) | Date of tests | Duration of activity/sampling time (min) | Analytical method | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|
| Friction products | Brake and clutch assembly rebuilding | Receiving and cleaning | 0.4-7.6 | 1976-1977 | ND | NIOSH Method (assumed) | Not clear in reference how brake and clutch activities differ. | 8 |
| | | Bonding and riveting | 0.2-5.8 | 1976-1977 | ND | NIOSH Method (assumed) | Not clear in reference how brake and clutch activities differ. | 8 |
| | | Cutting and grinding | 0.8-9.3 | 1976-1977 | ND | NIOSH Method (assumed) | Not clear in reference how brake and clutch activities differ. | 8 |
| | | Inspection and packaging | 0.8-1.1 | 1976-1977 | ND | NIOSH Method (assumed) | Not clear in reference how brake and clutch activities differ. | 8 |
| | Automobile brakes | Blowing dust out of brake drums with compressed air | | | | | | |
| | | Monitoring distance 0.9-1.5 meters | 6.6-29.8 | 1976 | ND | NIOSH Method | | 9 |
| | | Monitoring distance 1.5-3.0 meters | 2.0-4.2 | 1976 | ND | NIOSH Method | | 9 |
| | | Monitoring distance 3.0-6.1 meters | 0.4-4.8 | 1976 | ND | NIOSH Method | | 9 |
| | Truck brakes | Renewing used linings by grinding | | | | | | |
| | | Monitoring distance [illegible]-1.5 meters | 1.7-7.0 | 1976 | ND | NIOSH Method | | 9 |
| | | Beveling new linings. | | | | | | |
| | | Monitoring distance 0.9-1.5 meters | 23.7-72.0 | 1976 | ND | NIOSH Method | | 9 |
| Flooring products (resilient flooring items which are covered under paper) | Vinyl-asbestos floor tile | Cut | 0 | 1981 | 5 | NIOSH Method | Testing performed in glove box. | 2 |
| | | Grind | 0 (0.5) | 1981 | 3 | NIOSH Method (SEM) | Testing performed in glove box. | 2 |
| | | Break | 0 | 1981 | 3 | NIOSH Method | Testing performed in glove box. | 2 |

(continued)

## TABLE 27 (continued)

| Asbestos product category | Asbestos product | Activity performed | Measured fiber concentration (f/cm$^3$) | Date of tests | Duration of activity/sampling time (min) | Analytical method | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|
| F. Flooring products (excluding flooring felts which are covered under paper) (continued) | Vinyl-asbestos floor tile | Drill | 0 | 1981 | 1 | NIOSH method | Testing performed in glove box. | 2 |
| | | Every-day wear and cleaning | 0.008 to 0.06 | 1976 | - | - | Calculated values reported. Not based on actual tests. | 10 |
| | | Flooring removal, ripping up tiles | 0.02-0.1 | 1980 | 165 | SEM | Monitoring performed during actual flooring removal. Results are more indicative of levels nearby the workplace than those actually experienced by the worker. | 3 |
| | | Flooring removal by sanding rough surfaces remaining | 1.2-1.3 | 1970-1971 | 20 | Phase contrast | Simulated testing in laboratory chamber 3x3.7x2.1 meters with four air changes/hr. Belt sander with coarse paper used. | 11 |
| | | Pedestrian traffic on floor tile | 0.0 | 1979 | 130 to 420 | Phase contrast | Monitoring occurred in an office setting, the areas examined were a photocopying room and a snack shop. | 12 |
| | | Floor covering maintenance, Mopping | 0.0 | 1979 | 15 to 21 | Phase contrast | Activity was performed on floor tiles located in photocopying room and snack shop. | 12 |
| | | Buffing | 0.0 | 1979 | 11 to 30 | Phase contrast | Activity was performed on floor tiles located in photocopying room and snack shop. | 12 |

(continued)

TABLE 27 (continued)

| Asbestos product category | Asbestos product | Activity performed | Measured fiber concentration (f/cm$^3$) | Date of tests | Duration of activity/sampling time (min) | Analytical method | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|
| Flooring products (continued) | Vinyl-asbestos floor tiles | Complete removal by recommended procedures[f] | 0.006 to 0.015 (TWA) | 1979 | 123 to 134 | Phase contrast | Testing was performed in laundry room, powder room, closet, and hallway of a private home. | 12 |
| | | Installation by recommended procedures | 0.008 to 0.027 (TWA) | 1979 | 220 to 232 | Phase contrast | Tiles, precoated with adhesive, were installed in laundry room, powder room, closet, and hallway of a private home. | 12 |
| | | Installation by recommended procedures | 0.005 to 0.01 (TWA) | 1979 | 113 to 114 | Phase contrast | Testing was performed in basement and small utility room of private home. | 12 |
| | | Old tile preparation for new installation | 0.0 (TWA) | 1979 | 10 | Phase contrast | Preparation include stripping and dry mopping of old tile surface. | 13 |
| | | Complete removal by a method that deviates from recommended procedures | 0.12 to 0.38 (TWA) | 1979 | 80 | Phase contrast | Dry scraping and sweeping occurred during removal. | 13 |
| | | Installation by recommended procedures | 0.016 to 0.032 (TWA) | 1979 | 65 | Phase contrast | Self-adhering tiles were installed following standard work procedures. Authors postulate that fiber levels recorded resulted from fiber release during preceding removal operation. | 13 |
| Gaskets and packing | Compressed asbestos sheet flange gaskets | Storage for receipt and issue | <0.01 to 0.05 | 1978 | 60 to 132 | Phase contrast | Housekeeping[g] performed, monitoring conducted under actual work conditions. | 14 |

(continued)

## TABLE 27 (continued)

| Asbestos product category | Asbestos product | Activity performed | Measured fiber concen-tration (f/cm$^3$) | Date of tests | Duration of activity/sampling time (min) | Analytical method | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|
| Gaskets and packing (continued) | Compressed asbestos sheet flange gaskets | Storage for use | <0.01 to 0.12 | 1978 | 97 to 122 | Phase contrast | No control.[h] Monitoring conducted under actual work conditions. | 14 |
| | | Hand punching | 3.00 | 1978 | NR | Phase contrast | No control. Monitoring conducted under actual work conditions. | 14 |
| | | Hand punching | <0.05 to 0.15 | 1978 | 28 to 31 | Phase contrast | Housekeeping. Monitoring conducted under actual work conditions. | 14 |
| | | Hand operated mechanical punching | <0.05 | 1978 | 30 | Phase contrast | No control. Monitoring conducted under actual work conditions. | 14 |
| | | Machine punching | 5.0 | 1978 | NR | Phase contrast | No control. Monitoring conducted under actual work conditions. | 14 |
| | | Machine punching | <0.03 to 0.7 | 1978 | 20 to 30 | Phase contrast | Housekeeping. Monitoring conducted under actual work conditions. | 14 |
| | | Machine punching | <0.05 to 0.06 | 1978 | 23 to 31 | Phase contrast | Housekeeping and ventilation.[i] Monitoring conducted under actual work conditions. | 14 |
| | | [illegible] | <0.03 to 0.3 | 1978 | 7 to 31 | Phase contrast | No control. Monitoring conducted under actual work conditions. | 14 |
| | | Machine shearing | 0.5 to 1.3 | 1978 | 6 | Phase contrast | No control. Monitoring conducted under actual work conditions. | 14 |
| | | [illegible] | 0.05 to 0.15 | 1978 | 31 to 38 | Phase contrast | Ho[illegible]. Monitoring conducted under actual work conditions. | 14 |

(continued)

## TABLE 27 (continued)

| Asbestos product category | Asbestos product | Activity performed | Measured fiber concentration (f/cm³) | Date of tests | Duration of activity/ sampling time (min) | Analytical method | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|
| Gaskets and packing (continued) | Compressed asbestos sheet flange gaskets | Machine nibbling | <0.08 to 0.46 | 1978 | 8 | Phase contrast | No control. Monitoring conducted under actual work conditions. | 14 |
| | | Machine nibbling | 0.08 to 0.8 | 1978 | 24 to 31 | Phase contrast | Housekeeping. Monitoring conducted under actual work conditions. | 14 |
| | | Installation of flange gasket | <0.03 | 1978 | 30 | Phase contrast | No control. Monitoring conducted under actual work conditions. | 14 |
| | | Removal and concurrent installation (boiler header gaskets) | 0.02 to 0.3 | 1978 | 21 to 95 | Phase contrast | Housekeeping. Monitoring conducted under actual work conditions. | 14 |
| | | Clean-up following removal by hand scraping | <0.05 | 1978 | 33 to 37 | Phase contrast | No control. Monitoring conducted under actual work conditions. | 14 |
| | | Removal and hand scraping | <0.06 to 0.39 | 1978 | 15 to 28 | Phase contrast | No control. Monitoring conducted under actual work conditions. | 14 |
| | | Removal and wire brushing | <0.03 to 0.18 | 1978 | 25 to 33 | Phase contrast | Housekeeping. Monitoring conducted under actual work conditions. | 14 |
| | Gasket-compressed asbestos sheet | Punch press operation | 0.04 to 0.67 | 1980 | 80 to 211 | Fibers were counted by phase contrast with PLM verification | Monitoring performed at major gasket fabricator located in Wisconsin. | 15 |
| | | Power shear operation | 0.17 | 1980 | 188 | Fibers were counted by phase contrast with PLM verification | Monitoring performed at major gasket fabricator located in Wisconsin. | 15 |

(continued)

## TABLE 27 (continued)

| Asbestos product category | Asbestos product | Activity performed | Measured fiber concentration (f/cm³) | Date of tests | Duration of activity/sampling time (min) | Analytical method | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|
| Gaskets and packing (continued) | Gasket-compressed asbestos sheet | Shear press operation | 0.23 to 0.61 | 1980 | 50 to 76 | Fibers were counted by phase contrast with PLM verification | Monitoring performed at major gasket fabricator located in Wisconsin. | 15 |
| | | Roussel press | 0.04 to 0.08 | 1980 | 100 to 192 | Fibers were counted by phase contrast with PLM verification | Monitoring performed at major gasket fabricator located in Wisconsin. | 15 |
| | | Picking operation | 0.10 to 0.31 | 1980 | 93 to 206 | Fibers were counted by phase contrast with PLM verification | Monitoring performed at major gasket fabricator located in Wisconsin. | 15 |
| | | Tumbling operation | 0.42 to 0.60 | 1980 | 77 to 141 | Fibers were counted by phase contrast with PLM verification | Monitoring performed at major gasket fabricator located in Wisconsin. | 15 |
| | | Materials handling | 0.11 to 0.34 | 1980 | 91 to 216 | Fibers were counted by phase contrast with PLM verification | Monitoring performed at major gasket fabricator located in Wisconsin. | 15 |
| | | Platen press operation | 0.05 to 0.29 | 1980 | 52 to 256 | Fibers were counted by phase contrast with PLM verification | Monitoring performed at major gasket fabricator located in Wisconsin. | 15 |
| | Gasket-compressed asbestos sheet | Platen press operation | 0.03 to 0.15 | 1980 | 63 to 238 | Phase contrast | Monitoring performed at an asbestos-using gasket operation in Wisconsin. | 16 |

(continued)

TABLE 27 (continued)

| Asbestos product category | Asbestos product | Activity performed | Measured fiber concentration (f/cm$^3$) | Date of tests | Duration of activity/ sampling time (min) | Analytical method | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|
| Gaskets and packing (continued) | Gasket-compressed asbestos sheet | Hydraulic beam press | 0.02 to 0.05 | 1980 | 61 to 178 | Phase contrast | Monitoring performed at an asbestos-using gasket operation in Wisconsin. | 16 |
| | | Hand picking and packaging | 0.06 to 0.20 | 1980 | 45 to 176 | Phase contrast | Monitoring performed at an asbestos-using gasket operation in Wisconsin. | 16 |
| | | Platen press picking operator | 0.09 to 0.12 | 1980 | 67 to 140 | Phase contrast | Monitoring performed at an asbestos-using gasket operation in Wisconsin. | 16 |
| | | Reeves punch press operator | 0.12 | 1980 | 124 | Phase contrast | Monitoring performed at an asbestos-using gasket operation in Wisconsin | 16 |
| | Packing - mechanical packings for pumps | Simulated field installation | <0.1 to 0.1 | 1979 | NR | Phase contrast (assumed) | Simulated activity was performed in open building and involved unrolling, wrapping, cutting, flattening with a hammer and pushing the material into a pump. | 17 |
| | | Simulated removal of packing from pump | <0.1 to 0.1 | 1979 | NR | Phase contrast (assumed) | Simulated removal occurred in open building, details of removal not reported. | 17 |
| | Gaskets and packing (in general) | Cutting/packaging | 0.1 to 0.5 (TWA) | NR | NR | Phase contrast (assumed) | General fiber ranges are reported, specifics about the activities monitored not available from reference. | 18 |

(continued)

TABLE 27 (continued)

| Asbestos product category | Asbestos product | Activity performed | Measured fiber concentration (f/cm³) | Date of tests | Duration of activity/ sampling time (min) | Analytical method | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|
| Coatings and sealants | Asphalt and tar-based sealants | Application | 0 | | | | Zero release as stated in cited reference - statement is not documented by test data however. | 10 |
| | Spray-applied asphaltic roof coating | | | | | | | |
| | Cutback asphalt | Spraying | 0.003 to 0.15 | 1974 | 342 to 432 | Phase contrast (assumed) | Percent weight of asbestos as sprayed ranged from 5.8 to 7.7, after curing 9.7 to [illegible] percent asbestos. | 19 |
| | Asphalt-emulsion | Spraying | 0.01 to 0.3 | 1974,1976 | NR | Phase contrast (assumed) | Percent weight of asbestos as sprayed was 2.8, after curing 5.1 percent asbestos. | 19 |
| | Built-up roofing | Tear-off | 0.1 to 0.4 | 1974 | NR | Phase contrast (assumed) | Monitoring performed in Indiana. | 19 |
| | | Tear-off and replace (spray) | 0.0 to 0.3 | 1974,1976 | NR | Phase contrast (assumed) | Monitoring performed in Pennsylvania and Indiana. | 19 |
| | | New application (spray) | 0.0 to 0.6 | 1974,1975, 1976 | NR | Phase contrast (assumed) | Monitoring performed in Wisconsin, Colorado, and Indiana. | 19 |
| | Resin coatings | Ship coating by spray application | 0.2 | 1974 | 8 to 33 | Phase contrast (assumed) | Operator spraying outside and under a ship with asbestos-containing epoxy resin. Percent asbestos as sprayed 1.5. | 19 |

(continued)

## TABLE 27 (continued)

| Asbestos product category | Asbestos product | Activity performed | Measured fiber concen-tration (f/cm³) | Date of tests | Duration of activity/ sampling time (min) | Analytical method | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|
| Coatings and sealants (continued) | Resin coatings | Dry dock coating by spray applications | 0.0 to 0.2 | 1974 | 11 to 38 | Phase contrast (assumed) | Operator spraying dock with an asbestos-containing epoxy and coal tar mixture. One percent asbestos as sprayed. | 19 |
| | | Coating pipe interiors - spray application | 0.1 | 1974 | 37 | Phase contrast (assumed) | Operator spraying interior of 7.6, 15, and 30 cm diameter pipes with an asbestos-containing (1 percent) epoxy and coal tar mixture. | 19 |
| | | Fiber glass pipe MFG (mandrel coating) | 0.1 to 0.4 | 1974 | 14 to 23 | Phase contrast (assumed) | Operators monitored were involved in running automatic spray machine and wiping mandrel. A 1.4 percent asbestos chemical resistant resin was spray-applied. | 19 |
| | | Ship coating below waterline (spray application) | 0.0 to 0.4 | 1974 | 23 to 65 | Phase contrast (assumed) | Chemical resistant resin containing 0.7 percent asbestos applied. | 19 |
| | | Painting building exterior (commercial) | 0.0 to 0.06 | 1974,1977 | 5 to 16 | Phase contrast (assumed) | Alkyd resin contain-ing 6 percent asbes-tos or vinyl-acrylic latex containing 0.6 percent asbestos applied. | 19 |
| | | Painting building interior (commercial) | 0.03 to 0.06 | 1977 | 23 | Phase contrast (assumed) | Vinyl-acrylic latex containing 0.6 percent asbestos applied. | 19 |

(continued)

## TABLE 27 (continued)

| Asbestos product category | Asbestos product | Activity performed | Measured fiber concentration (f/cm$^3$) | Date of tests | Duration of activity/sampling time (min) | Analytical method | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|
| Coatings and sealants (continued) | Resin coatings | Wall and roof spraying | 0.0 to 0.2 | 1974 | 12 to 15 | Phase contrast (assumed) | Operator spraying 2.8 to 3.7 percent asbestos vinyl latex on vertical wall panel. | 19 |
| | | Roof spraying | 0.0 | 1974 | 14 to 28 | Phase contrast (assumed) | Operator spraying 0.7 percent asbestos acrylic latex. | 19 |
| | | Boat MFG - spraying surface coatings | 0.0 to 0.6 | 1972, 1974, 1975 | 4 to 55 | Phase contrast (assumed) | Operator spraying 0.5 percent asbestos general purpose polyester resin. | 19 |
| | | Sawing pipe coated with polyester resin | 0.04 to 0.1 | 1973 | 19 to 49 | Phase contrast (assumed) | Operator sawing reinforced fiber glass pipe coated with polyester resin containing 2 to 3 percent asbestos. | 19 |
| | | Grinding FRP tanks and pipe | 0.3 to 0.4 | 1974 | 5 to 25 | Phase contrast (assumed) | Operator grinding fiber glass reinforced plastic parts containing 1.5 asbestos. | 19 |
| | | Handsanding interior building panels | 0.0 to 0.3 | 1977 | 11 to 16 | Phase contrast (assumed) | Operator handsanding panel surfaces covered with vinyl latex paint containing 1.1 percent asbestos. | 19 |
| | | Sand blasting high performance exterior coating | 0.2 to 0.3 | 1978 | 5 to 27 | Phase contrast (assumed) | Operators sandblasted 12 meter diameter by 7.6 meter high steel tank spray coated in 1973 with a 2.1 percent asbestos resin coating. | 19 |

(continued)

TABLE 27 (continued)

| Asbestos product category | Asbestos product | Activity performed | Measured fiber concentration (f/cm$^3$) | Date of tests | Duration of activity/sampling time (min) | Analytical method | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|
| Coatings and sealants (continued) | Water soluble gypsum-based drywall compound (Study A) | Application | 0.4 to 1.3 | 1978 | 39 to 65 | Phase contrast | Commercial operation. | 20 |
| | | Mixing (dry powder) | 9.0 to 12.4 | 1975-1977 | 10 to 12 | Phase contrast | Residential setting. | 20 |
| | | Mixing (pre-mix) | 1.2 to 3.2 | 1978 | 4 to 5 | Phase contrast | Commercial operation. | 20 |
| | | Hand sanding | 2.1 to 24.2 | 1975-1977 | 10 to 80 | Phase contrast | Residential setting. | 20 |
| | | Pole sanding | 1.2 to 10.1 | 1975-1977 | 10 to 38 | Phase contrast | Residential setting. | 20 |
| | | Pole sanding | 1.2 to 10.0 | 1978 | 4 to 21 | Phase contrast | Commercial operation. | 20 |
| | | Sweeping | 4.0 to 26.5 | 1975-1977 | 9 to 30 | Phase contrast | Residential setting. | 20 |
| | | Sweeping | 14.5 to 25.4 | 1978 | 10 to 20 | Phase contrast | Commercial operation. | 20 |
| | Water soluble gypsum-based drywall compound (Study B) | Dry mixing (0.9 to 1.5 m) | 35.4 to 59.0 | 1974 | NR | Phase contrast | Commercial operation. Fiber range reported is not less background levels, which for the same room ranged from 0.5 to 13.1 f/cm$^3$. | 21 |
| | | Hand sanding (0.9 to 1.5 m) | 1.3 to 16.9 | 1974 | NR | Phase contrast | Commercial operation. Fiber range reported is not less background levels, which for the same room ranged from 2.1 to 2.5 f/cm$^3$. | 21 |
| | | Pole sanding (0.9 to 1.5 m) | 1.2 to 19.3 | 1974 | NR | Phase contrast | Commercial operation. Fiber range reported is not less background levels, which for the same room ranged from 3.5 to 19.8 f/cm$^3$. | 21 |

(continued)

## TABLE 27 (continued)

| Asbestos product category | Asbestos product | Activity performed | Measured fiber concentration (f/cm$^3$) | Date of tests | Duration of activity/ sampling time (min) | Analytical method | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|
| Coatings and sealants (continued) | Water soluble gypsum-based drywall compound (Study B) | Sweeping floor (3.0 to 15 m) | 41.4 (mean) | 1974 | NR | Phase contrast | Due to heavy loading during sweeping, sampling occurred 15 minutes after sweeping stopped. After 35 minutes, the measured fiber level was 26.4 f/cm$^3$. | 21 |
| Asbestos-cement sheeting | Flat sheeting | Drill | 2.8 | 1981 | 5 | NIOSH Method | Testing performed in glove box. | 2 |
| | | Score | 3.2 | 1981 | 4 | NIOSH Method | Testing performed in glove box. | 2 |
| | | Hammer | 6.4, 12.7 | 1981 | 4,1 | NIOSH Method | Based on two repetitions in glove box. | 2 |
| | | Saw | 195.8 | 1981 | 1 | NIOSH Method | Testing performed in glove box. | 2 |
| | Corrugated sheeting | Grinding to cut stack of sheeting in open air; Grinding to cut sheeting while on roof | 0.6 to 41 | 1980 | ND | Phase contrast | Testing performed on job site. | 22 |
| | 0 64 cm (0 25 in.) thick flat sheeting | Drilling holes (163) | <0.1 | 1979-1980 | 40 | Phase contrast (assumed) | Drill was equipped with dust pickup shroud. | 23 |
| | | Sawing (18.3 meters) | 0.0 | 1979-1980 | 40 | Phase contrast (assumed) | Saw was equipped with dust pickup shroud that totally enclosed masonry blade. | 23 |
| | Asbestos-cement board | Sawing with a circular saw (carbide blade) | 0.04 | 1979 | 12 | Phase contrast | Saw was equipped with dust pickup shroud that vented to a Nilfisk HEPA filtered vacuum cleaner. | 24 |

(continued)

## TABLE 27 (continued)

| Asbestos product category | Asbestos product | Activity performed | Measured fiber concentration (f/cm$^3$) | Date of tests | Duration of activity/sampling time (min) | Analytical method | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|
| Asbestos-cement sheeting (continued) | Asbestos-cement board | Sawing, drilling, and scrolling (sabre saw) | 0.15 | 1979 | 17 | Phase contrast | Power tools were equipped with dust pickup shrouds that vented to a Nilfisk HEPA filtered vacuum cleaner. | 24 |
| Textiles | Fireproof clothing | Wearing asbestos fireproofing clothing: (untreated material) Steel mill- | | | | | | |
| | | Blast furnace workers | 0.3-5.0 (TWA 0.1 to 1.1) | 1975 | 52 (average) | Phase contrast | Actual sampling in plant. | 25 |
| | | Phosphorus plant- Reduction furnace | 9.9-26.2 (TWA 4.7) | 1975 | 35 (average) | Phase contrast | Actual sampling in plant. | 25 |
| | Firefighting helmets. | | | | | | | |
| | New helmet with unlined asbestos cloth cover | Naval firefighting personnel wearing helmets | 2.3 | 1971 | 22.4 | Phase contrast | | 26 |
| | Old helmet with unlined asbestos cloth cover | Naval firefighting personnel wearing helmets | 1.38 | 1971 | 20.6 | Phase contrast | | 26 |
| | helmet with aluminized asbestos | Naval firefighting personnel wearing helmets | 0 | 1971 | 20.5 | Phase contrast | | 26 |
| | Asbestos gloves | Putting on, handling hot tray, taking off | 0.95 to 7.97 | 1981 | <10 | NIOSH Method | Range of fiber levels monitored in ventless isolation chamber (glove box). | 27 |

(continued)

## TABLE 27 (continued)

| Asbestos product category | Asbestos product | Activity performed | Measured fiber concentration (f/cm$^3$) | Date of tests | Duration of activity/ sampling time (min) | Analytical method | Comments | Ref. |
|---|---|---|---|---|---|---|---|---|
| Textiles (continued) | Asbestos gloves | Putting on, handling hot tray, taking off | 0.07 to 0.99 | 1981 | 10 | NIOSH Method | Range of fiber levels monitored in well ventilated biology preparation room. Range encompasses breathing zone and work area. | 27 |
| | | Using gloves in laboratory | 0.04 to 2.93 | 1981 | 10 | NIOSH Method | Range of fiber levels monitored during normal use in university laboratories. Range encompasses breathing zone and work area. | 27 |
| [illegible] | Ph[illegible] molded electrical components | File | 0 to 2.8 | 1981 | 3 | Phase contrast | Testing performed in glove box. | 2 |
| | | Drill | 7.1 | 1981 | 3 | Phase contrast | Testing performed in glove box. | 2 |
| | | Grind | 2.8 | 1981 | [illegible] | Phase contrast | Testing performed in glove box. | 2 |

[illegible] optical microscopy counting fibers 5 µm long or longer having a length to width aspect ratio of 3 to 1 or greater.

[illegible] electron microscopy.

[illegible] polarized light microscopy.

[illegible] recorded were found to be no more than ambient levels.

[illegible] sanding the existing floor covering or the residual felt, and wet-scraping [illegible]

[illegible] installation, and removal without sanding, use of a flat-bladed wall scraper instead of equipment that [illegible] the tile and not breaking the tile by hand before placing in a disposal bag.

[illegible] vacuum cleaners were used to clean areas, area kept clean and free of debris accumulation, waste material placed in [illegible]

[illegible] controls were used, i.e., no wetting, enclosing, or ventilation.

Ventilation [illegible] – filtered local exhaust ventilation provided to operation.

ND – No data.

[illegible]

– Not reported.

Table 28 summarizes, by asbestos product type, the number of fiber release monitoring studies that have been identified in this report. The data have been compiled from the information provided in Table 27. As expected, the majority of the studies have been performed on products that are suspected to release high fiber levels based upon how they are acted upon and their method of construction (e.g., asbestos-cement products and paper products), or on products with widespread use such as friction products and floor tiles.

PRODUCT TESTING RECOMMENDATIONS

In accordance with the data reported, experimental limitations, and reenactment equipment use limitations, asbestos-containing products are prioritized for testing as follows:

- The following products are candidates for testing based on suspected high fiber release potential, widespread application, and expected future use:
  - millboard
  - commercial and household paper
  - flat asbestos-cement sheet
  - uncoated textiles
  - paper pipeline wrap.
- Products having low testing priority because (1) they have been adequately examined, (2) the likelihood of harmful exposure during use is low or (3) product distribution is limited are:
  - vinyl-asbestos floor tile
  - reinforced molded plastic components
  - asbestos-containing packings
  - petroleum-based surface coatings, sealants and adhesives
  - flooring felt
  - compressed sheet gaskets
  - coated textiles
  - beverage or pharmaceutical filters
  - asphalt-asbestos floor tiles

TABLE 28. NUMERICAL SUMMARY OF MONITORING STUDIES PERFORMED ON ASBESTOS-CONTAINING PRODUCTS[a]

| Asbestos product category | Asbestos product | Number of studies performed on product as presented in this report |
|---|---|---|
| Asbestos-cement pipe | Water transfer pipe | 1 |
| | Sewage transfer pipe | 2 |
| | Other (electrical conduit, chemical process piping) | 0 |
| Asbestos paper | Flooring felt | 2 |
| | Roofing felt | 0 |
| | Beater-add gaskets | 1 |
| | Pipeline wrap | 1 |
| | Millboard | 1 |
| | Electrical insulation | 1 |
| | Commercial papers | 2 |
| | Specialty papers (e.g., tape) | 2 |
| | Beverage and pharmaceutical filters | 0 |
| Friction products | Brake linings | 2 |
| | Disc pads | 0 |
| | Clutch facings | 1 |
| | Other | 0 |
| Floor tile | Vinyl-asbestos tiles | 5 |
| | Asphalt-asbestos tiles | 0 |
| Gaskets and packings | Compressed sheet gaskets | 4 |
| | Impregnated millboard | 0 |
| | Impregnated yarn | 2 |
| Coatings, sealants, and adhesives | Asphalt and tar-based coatings and sealants | 1 |
| | Latex or gypsum-based coatings | 2 |
| | Adhesives | 0 |
| Asbestos-cement sheets | Roofing shingles | 0 |
| | Siding shingles | 0 |
| | Flat sheet | 3 |
| | Corrugated sheet | 1 |
| Textiles | Protective clothing | |
| | Firefighting helmets | 1 |
| | Outer garments | 1 |
| | Gloves | 1 |
| | Tubing-wire and pipe insulation | 0 |
| | Clutch-transmission components | 0 |
| Reinforced plastic | Electrical insulators | 1 |
| | Molded product components for high strength/weight uses | 0 |

[a]Some studies investigated fiber release from more than one product.

- Products to be excluded from testing under this program because their normal use activity is performed out of doors or with specialized equipment which this project is not designed to obtain nor operate are:

  - asbestos-cement pipe

  - asbestos-cement sheet (roofing shingles, siding shingles, corrugated sheet)

  - friction materials

  - roofing felt.

# REFERENCES


1. Association of Asbestos Cement Pipe Producers, Recommended Standard for Occupational Asbestos Exposure in Construction and Other Non-Fixed Work Operations. Internal Report. Cosponsored by the Asbestos Information Association of North America. February 1980.

2. Cogley, D., et al. The Experimental Determination of Asbestos Fiber Size Distribution during Simulated Product Use. Prepared by GCA/Technology Division for the U.S. Environmental Protection Agency, Office of Pesticides and Toxic Substances, Washington, D.C. October 1981.

3. Roy, N., et al. Asbestos Product Test Results. Prepared by GCA/Technology Division for the U.S. Environmental Protection Agency, Office of Pesticides and Toxic Substances, February 1980.

4. Unilab Research, Berkeley, California, Asbestos Paper Product Testing Results. Testing Performed for Channel 7 KGO TV, San Francisco, CA. November/December 1979.

5. Wardley, F. L., President Quin-T Corporation-Electrical Insulation, Written Correspondence to Mr. Richard Guimond, U.S. Environmental Protection Agency, Office of Toxic Substances, Washington, D.C. October 30, 1980.

6. SRI International. Monitoring for Airborne Asbestos Fibers: Sheet Vinyl Floor Covering. Prepared for Resilient Floor Covering Institute. December 1979. SRI Project 7988.

7. SRI International. Comparison Testing Monitoring for Airborne Asbestos Fibers: Sheet Vinyl Floor Covering, Wet Versus Dry Scraping. December 1979. SRI Project 7988.

8. Unpublished NIOSH Data Presented at American Industrial Hygiene Conference, New Orleans, Louisiana. May 1977.

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

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

11. Murphy, R. L., et al. Floor Tile Installation as a Source of Asbestos Exposure. American Review of Respiratory Disease, Vol. 104. 1971.

12. SRI International. Monitoring for Airborne Asbestos Fibers: Vinyl Asbestos Floor Tile. Prepared for Resilient Floor Covering Institute. December 1979. SRI Project 7988.

13. SRI International. Comparison Testing Monitoring for Airborne Asbestos Fibers: Vinyl Asbestos Floor Tile. Prepared for Resilient Floor Covering Institute. December 1979. SRI Project 7988.

14. Liukonen, L. R., et al. Asbestos Exposure from Gasket Operations. Report prepared by Industrial Hygiene Research, Naval Regional Medical Center, Bremerton, Washington. May 1978.

15. Hager Laboratories, Inc. Report on Service Number 3910 for Johns-Manville Corp. August 21, 1980. Published in Health and Safety Facts: Mechanical Packings and Gasketing Materials Containing Asbestos Fiber, Johns-Manville Corporation, Denver, Colorado.

16. Johns-Manville Corporation, Health, Safety, and Environment Department, Industrial Hygiene Survey conducted July 1980 in Wisconsin. Results published in Health and Safety Facts: Mechanical Packings and Gasketing Materials Containing Asbestos Fiber, Johns-Manville Corporation, Denver, Colorado.

17. Johns-Manville Corporation, Health, Safety, and Environment Department, Industrial Hygiene Survey of Simulated Field Installation of Asbestos-Containing Packings. Results of study published in Health and Safety Facts: Mechanical Packings and Gasketing Materials Containing Asbestos Fiber, Johns-Manville Corporation, Denver, Colorado.

18. Chapman, J. H., et al. Asbestos Dust; Technology Feasibility Assessment and Economic Impact Analysis of the Proposed Federal Occupational Standard: Part 1, U.S. Department of Labor, Occupational Safety and Health Administration.

19. Testimony Prepared for a Public Hearing Before the California Occupational Safety and Health Standards Board. November 8, 1978. Source of testimony unknown. Information provided to GCA/Technology Division by the Johns-Manville Corporation, Denver, Colorado.

20. Verma, D. K., and C. G. Middleton. Occupational Exposure to Asbestos in the Drywall Taping Process. Presented in the Journal of American Industrial Hygiene Association. Vol. 41. April 1980.

21. Fischbein, A., et al. 1979. Drywall Construction and Asbestos Exposure. J. American Industrial Hygiene Association, Vol. 40, pp. 402-407.

22. Rödelsperger, K., et al. Estimation of Exposure to Asbestos-Cement Dust on Building Sites. Study supported by the Umwelfbundesant, Berlin, Project No. 10401023/11, by the Commission of the European Community, Project No. 298-781 ENVD, and by the Bau-Berufsgenossenschaften, Frankfurt.

23. Asbestos Information Association/North America. Recommended Work Practice Procedures for Asbestos-Cement Sheet. Submittal to U.S. Environmental Protection Agency, Office of Toxic Substances, in response to Advance Notice of Proposed Rulemaking: Commercial and Industrial Use of Asbestos Fibers. Docket Number OTS 61005.

24. Intra-Laboratory Memo, Argonne National Laboratory. Asbestos Fiber Measurements During the Nilfisk Power Tool and Vacuum Demonstration, Nilfisk of America Inc., King of Prussia, PA, December 7, 1981.

25. Gibbs, G. W. 1975. Fibre Release From Asbestos Garments. An.. Occup. Hyg., Vol. 18, pp. 143-149.

26. Lumley, K. P. S. 1971. Asbestos Dust Levels Inside Firefighting Helmets With Chrysotile Asbestos Covers. Ann. Occup. Hyg., Vol. 14, pp. 285-28[illegible].

27. Samini, B. S., and A. M. Williams. 1981. Occupational Exposure to Asbestos Fibers Resulting from Use of Asbestos Gloves. Am. Ind. Hyg. Assoc. J. 42:870-875.