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APPENDIX A

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EXPOSURE TO ASBESTOS

Prepared for,

Richard J. Guimond (TS-794)
Office of Toxic Substances
U.S. Environmental Protection Agency
Washington, D.C. 20460

Prepared by,

Paul K. Ase
Harsh Dev
David R. Jones
Donald L. Krystof
George Yamate

IIT RESEARCH INSTITUTE
Chicago, Illinois 60616

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1. PROBLEM ANALYSIS

1.1 Introduction

Between 2,000 and 3,000 asbestos containing commercial and consumer products are presently identified. The use of these products has resulted in the consumption of 550,000 to 800,000 metric tons per year (MT/yr) of asbestos in the United States in recent years. Also, asbestos is present naturally with other minerals in many parts of the country. Thus, it is not surprising that asbestos can be found almost everywhere in the air, in the drinking water, and even in some foods.

The purpose of this report is to gather together the available information on asbestos sources and estimate the extent of the overall exposure to the general population. These estimates are mainly based on currently available data and information on asbestos which are discussed at length in several recently published reports (ref. 1, 3, 4, 5, 6, 8, 11). Four sources of exposure to asbestos can be recognized. These are: commercial and consumer use, asbestos presently in place, manufacturing and processing of asbestos products, and naturally occurring asbestos. An Exposure Index (EI) was prepared as a framework for estimating and ranking the exposure. The EI is defined in terms of the asbestos concentrations during exposure, the population involved, and the exposure time.

Due to the difficulties in measuring asbestos exposure and the use of engineering estimates where such measurements were lacking, the present Exposure Index ranking is necessarily imprecise.

The greatest amount of data is available for occupational exposure in industries for manufacturing and processing of asbestos products where levels of exposure are highest and exposures span over extended periods of time. Some measurements of in place asbestos concentration have also been made recently, but generally the levels are low and difficult to assess. A large number of people can be affected by in place asbestos and a potential exists for significant exposure from such uses as sprayed-on ceiling insulation and asbestos cement pipes used for potable water. Commerical use is very widespread. Most of the exposure accessment effort for commercial use has been devoted to activities of high exposure levels such as installation and removal of insulation and vehicular brake lining servicing and replacement. Less is known about routine exposure in commercial products industries in which asbestos is not a part of the end product of that industry but asbestos is nevertheless extensively used. Those without occupational contact or exposure can receive exposure from asbestos products manufacturing plants and other local sources. Also many low level sources such as automobile brake linings wear contribute to the general urban background. A variety of consumer products containing asbestos are readily available. Generally the exposure from the use of these is minimal due to limited use and low asbestos release. On occasion, however, levels comparable to that of occupational exposures are possible.

1.2 Constraints on Monitoring and Measuring Asbestos Levels

Although the role of asbestos as a cause of cancer and other diseases is clear (1), the mechanism underlying disease causation are not well understood, and this impedes efforts to measure, and subsequently to control human exposures to the substance. Besides the technical and economic difficulty of measuring asbestos concentrations, two other facts of the hazard are not clear: (1) the attribute(s) of asbestos that actually cause disease and which therefore can give reliable measures of exposure; and (2) the concentration and time period of exposure to asbestos that is hazardous.

The attributes of asbestos that have been implicated in various hypotheses on carcinogensis include:

- Size and shape of individual fibers
- Number of fibers

- Total mass of asbestos
- Type of asbestos
- Trace metal content
- Trace organic content
- Surface charge
- Surface adsorptive characteristics

"Because of the inordinate difficulties of separating the last four attributes from nonasbestos "background", these four are not suitable indices of exposure for routine monitoring situations. In addition, hypotheses based on trace metal or organic content have fallen out of favor. Because there is no consensus on the attribute(s) that cause cancer and, therefore, no consensus on the appropriate indicator of risk from environmental exposure to asbestos, the "best" monitoring and measuring method is that which permits the most detailed characterization of exposure through measurement of the first four variables -- size and shape of individual fibers; number of fibers; total mass of asbestos; and type of asbestos." (1) A single, reliable source of asbestos exposure is presently still unavailable.

1.3 Analysis of Samples

The most valid analytical methods for complete identification and characterization of asbestos are those methods based upon electron microscopy. This is particularly true for assessment of general community exposure from air or water. In some cases, where the fiber-size distributions of asbestos exposures are constant and already known from electron microscopy, the use of optical microscopy, or other methods of continuous monitoring may be justified for routine surveillance.

Complete fiber characterization and identification requires the following information:

- Size Distribution and Morphology
- Electron Diffraction Pattern
- Elemental Composition

It is not always possible to distinguish between the various different fiber types present in a sample by using phase-contrast optical microscopy. Therefore, in order to generate the complete information electron microscopy is used.

"With any of the analytical methods, compromises are necessary because of the relatively 'heroic' sample-preparation methods required, especially for transmission electronic microscopy. Many of these methods -- involving such techniques as ashing, multiple transfers of liquid resuspensions, and filtrations -- tend to subdivid fibers into fibrils." Thus, it is difficult to reconstruct the original size distribution and reliably estimate concentration. For samples in which the concentration of asbestos fibers is low the analysis of only a few fibers will be seen and this will thus add to the measurement uncertainty.(1)

1.4 Reproducibility of Measurements

Because of the difficulties of measuring asbestos-fiber concentration, there are large variations in the measurement of asbestos in samples of air and water, both within and among laboratories.

Several studies in which a series of round-robin tests by transmission electron microscopy on asbestos samples (collected from air and water) were conducted showed large intra and interlaboratory variations. It is not uncommon for results from duplicate samples analyzed by competent workers in independent laboratories to vary by much more than an order of magnitude.(1, 9, 25)

The reproducability of optical microscope measurements are more reliable. Measurements by experienced workers are within 20% of each other. However, it is important to recognize that the results of analysis obtained by phase-contrast microscopy are not strictly comparable to those from an electron microscope because the fraction of fibers in a sample of airborne asbestos that will be visible under an optical microscope will vary by type of asbestos and by the particular industrial process being evaluated and also, as mentioned earlier, the fiber characterization and identification which can be made by electron microscopy is not available from analyses by optical microscopy, alone.

Some conclusions drawn from results of various studies on the comparison of electron and optical microscopy are:

- The ratios of electron-microscope-visible to optical-microscope-visible fibers vary among plant emissions, the workplace, and the general environment, as well as within each of these categories.
- No universal ratios or factors for conversion of optical microscope results to electron microscope results exist. In this report, when needed, a factor of 50 has been used to convert occupational fiber levels from optical-microscope-visible to electron-microscope-visible fibers. The factor is based on a conservative estimate that 2% of total fibers are optical-microscope-visible.
- No single factor for conversion of mass emissions to fiber emissions exists.
- Fiber/mass ratios differ markedly from the occupational to the general environments, and they also differ markedly within each environment. The number of electron-microscope-visible fibers per nanogram might well range from 100-10,000.
- Based on the observed data available and for convenience sake, 1,000 fibers per nanogram has been used for calculations in this paper.

2. DEFINITIONS OF EXPOSURE INDEX AND POPULATION EXPOSURE

2.1 Exposure Index

An Exposure Index (EI) was prepared as a framework for estimating and ranking the asbestos exposure from the various sources. The Exposure Index (EI) is defined as:

$$EI_i = 1 + \log \left(\frac{PE_{max}}{PE_i} \right)$$

where PE_i is the overall population exposure from source i, and PE_{max} is the maximum Population Exposure value found by a comparison of all of the PE_i's. For the highest exposures, EI = 1. The EI values range from 1 to 11. These values were obtained by rounding off the logarithms of the corresponding Population Exposure values. The EI values for occupational exposure (see Tables 7, 8, 9, 10) rely on measured exposure levels and thus are more reliable estimates than the EI values in the Commerical and Consumer Use Table (Table 2 and 3), which are based on engineering estimates.

2.2 Population Exposure

Population Exposure (PE) is defined as the product of five factors. These are: Releasability (R), Duration (D), Frequency (F), Users (U), and Population Exposed (P). Levels for each factor have been quantified and coded in Table 1. Population Exposure can be formulated as:

$$PE = R \cdot D \cdot F \cdot U \cdot P \qquad \text{ng} \cdot \text{hr} \cdot \text{persons/m}^3 \cdot \text{yr}$$

Table 1 has five columns, headed Releasability, Duration, Frequency, Use, and Population Exposed. The numbers (1 through 4) in the first column are codes which denote for each use the level of use, releasability, duration and frequency of use, or population exposed. Table 1 gives quantities represented by each code number.

Table 1

POPULATION EXPOSURE CODES

Code	Releasability ng/m^3	Frequency Times/Year	Duration Hrs/Time	Population Exposed	User
1	10^5	365 (Daily)	12	10^3	10^6
2	2.15×10^3	26 (Biweekly)	1.2	10^2	10^5
3	4.6×10^1	12 (Monthly)	0.12 (7 mins.)	10^1	10^4
4	10^0	1 (Yearly)	0.012 (45 secs.)	10^0	10^3

These terms are explained below:

2.2.1 Releasability (R)

This refers to the degree of ease with which an asbestos-containing product is likely to release free fibers. Releasability ranking was reported on a qualitative basis in a CPSC memo (2), dated May 10, 1978. This scale is given below:

1. Free fibers. Not locked in at all.
2. Fibers locked in but are releasable in normal use or where handling is such that intentional abrasion, cutting, sanding, etc., is expected to occur. Fiber release may occur if there is a defect in the product's performance.
3. Fibers locked in and fibers not likely to be released in normal use but the potential for fiber release exists if a consumer engages in repair, accidental abrasion, modification, or if deterioration occurs because of aging or wearing out of the product.
4. Fibers locked in and are unlikely to be released under almost all foreseeable circumstances.

brake lining 5: 99.7% converted

In order to make some quantitative estimates, it was assumed that, as a first approximation, releasability may be represented as exposure concentration. Table 1 gives the range of asbestos fiber concentration in ng/m^3, represented by this code system. The range of concentrations was selected arbitrarily with the highest (100,000 ng/m^3) representing 2 fibers/cc as measured with an optical microscope. Codes 1 through 4 were assigned by making 3 logarithmic intervals in the range 1-10^5 ng/m^3.

2.2.2 Duration (D)

This refers to the exposure time for a person working with the asbestos-containing product. It estimates in gross terms the duration of each use.

2.2.3 Frequency (F)

This number gives an order of magnitude estimate of the number of times per year any product is likely to be used by a person.

2.2.4 User (U)

This refers to a gross order of magnitude estimate of the number of units of any particular asbestos-containing product which are currently in use. Table 1 gives the range denoted by the codes used in Table 2.

2.2.5 Population Exposed per User (P)

This number attempts to give an order of magnitude of the number of other people a person is likely to expose when using an asbestos-containing product.

3. COMMERCIAL AND CONSUMER USES OF ABESTOS

The exposure ranking for the general population due to major consumer and commercial uses of asbestos is given in Table 2. These use categories are taken directly from the Kearney Report (5). Several reported potential uses have never been realized and were not included.

A particularly high exposure risk is indicated for brake lining repair. Other products which may give potentially high exposure are appliance wiring, vinyl asbestos floor tiles, asbestos powder, textiles, and drilling fluids. This list of six uses represents all those asbestos-containing products available for commercial and consumer use which had an Exposure Index of 1, 2 or 3.

Table 2

COMMERCIAL AND CONSUMER USES (1)

AUTOMOTIVE REPAIR	USE	RELEASABILITY (2)	DURATION	FREQUENCY	POP. EXPOSURE	EXPOSURE INDEX
1. Automotive mufflers	1	2	2	4	4	6
2. Automotive undercoatings	2	4	3	4	4	11
3. Brake linings	1	2 3	1	1	2	1
4. Clutch facings	1	2	2	4	4	6
5. Custom auto body filler	2	1	3	4	4	6
6. Metal deadener	3	3	2	4	4	9
HOUSEHOLD MATERIALS						
1. Appliance wiring	1	3	1	1	3	3
2.* Components for erector set housing	3	3	2	3	4	8
3. Cord (electrical)	1	3	2	1	3	4
4. Dehumidifying apparatus	3	3	1	3	3	6
5. Filler for shoe soles	3	3	1	4	4	8
6.* Erector set parts	4	4	2	3	4	11
7. Floor tile (vinyl asbestos)	1	3	1	1	3	3
8. Hair dryers	2	3	2	1	4	6
9. Heater cord	3	3	1	3	3	6
10. Iron cords	2	3	2	2	4	7
11. Ironing board pads and covers	3	3	2	2	4	8
12. Kilns, potters (home hobby)	4	3	2	2	4	9
13.* Kitchen counter surfaces	2	4	1	1	3	5
14. Lamp mantles	4	3	1	3	3	7
15. Lamp sockets	2	3	2	3	3	6
16. Lining (radiator covers)	3	3	1	2	4	7
17.* Mats (for gas stove burners)	3	2	1	1	4	4
18. Radiator (home) insulation	3	3	1	4	3	7
19.* Slow cookers	3	3	1	2	3	6
20. Toasters	1	3	3	1	4	6

Table 2 (cont.)

1-3. SAFETY EQUIPMENT	USE	RELEASABILITY	DURATION	FREQUENCY	POP. EXPOSURE	EXPOSURE INDEX
1. Aprons	3	2	1	2	4	5
2. Arm protectors	3	3	1	2	4	7
3. Blankets	2	2	1	2	4	4
4. Boots	3	3	1	2	4	7
5. Caps	2	3	1	2	4	6
6. Clothing	2	2	1	2	4	4
7. Curtains	3	3	1	2	2	5
8. Draperies	3	3	1	2	2	5
9. Gloves	2	2	2	2	4	5
10. Hats	2	3	1	2	4	6
11. Helmets	2	4	1	2	4	7
12. Hoods	2	2	1	2	4	4
13. Mittens	3	2	2	2	4	6
14. Overgaiters	3	3	1	2	4	7
15. Sleeves	3	2	1	2	4	5
16. Suits	2	2	1	2	4	4
17. Umbrellas	3	3	2	2	4	8
1-4. RECREATIONAL ACTIVITY (OUTDOOR)						
1. Aerial distress flares	4	2	3	4	4	10
2. Ammunition shell wadding	2	2	2	3	4	5
3. Catalytic heater mantles	3	3	3	3	3	8
4. Mantles (lantern)	3	3	2	3	3	7
5. Sets & equipment; movie, theater, TV	3	3	1	2	2	5
6. Tent grommets	4	2	2	3	3	6
1-5. HOME BUILDING & REPAIRS						
1. Latex paints	2	3	1	4	3	6
2. Paints, texture	2	2	1	4	3	5

Table 2 (cont.)

1-6. COMMERCIAL APPLICATIONS	USE	RELEASABILITY	DURATION	FREQUENCY	POP. EXPOSURE	EXPOSURE INDEX
1. Aluminized cloth (asbestos)	3	3	3	2	4	9
2. Bags	3	2	1	4	3	6
3. Bearing	2	2	2	2	3	4
4. Belting (asbestos)	4	3	1	1	3	6
5. Blocks (shims)	3	3	3	1	4	8
6. Boards	3	3	2	4	3	8
7. Braid	3	3	2	4	4	9
8. Buffing and polishing compounds	2	2	3	3	4	6
9. Cloth (asbestos)	2	2	3	1	3	4
10. Plywood patch	4	2	3	4	4	10
11. Cord (asbestos)	2	3	3	4	4	9
12. Diaphragm	3	3	1	1	4	6
13. Drier felt (asbestos)	3	3	1	1	4	6
14. Fabrics	2	3	1	1	3	4
15. Felt	2	3	2	4	3	7
16.* Filtering materials, filters	2	3	3	3	1	5
18. Laboratory table tops	2	3	1	4	3	6
19. Metallic cloth	3	3	1	3	3	6
20. Millboard	3	3	2	4	3	8
21. Paper (asbestos)	2	2	1	4	3	5
22. Pipe and boiler coverings	3	3	2	4	4	9
23. Pottery clay	3	1	2	2	4	4
24. Powder (asbestos)	3	1	2	1	4	3
25. Sheet flooring	1	3	1	4	3	5
26. Stairs and vermisles	3	3	2	4	4	9
27. Tape	3	3	2	4	4	9
28. Textiles	2	2	1	2	3	3
29. Welding electrodes	3	4	2	2	4	9
30. Drilling fluids	3	2	1	1	3	3

Table 2 (cont.)

1-7. ASBESTOS/CEMENT PRODUCTS	USE	RELEASABILITY	DURATION	FREQUENCY	POP. EXPOSURE	EXPOSURE INDEX
1.**Asbestos cement pipe (water and sewer)	2	2	1	4	3	5
2. Asbestos cement pipe air duct	2	2	1	4	3	5
3. Asbestos cement sheet	2	3	1	4	3	6
4.* Baking sheets	4	2	2	1	3	5
5. Cement boards	2	3	1	4	3	6
6. Cement roofing	3	3	2	4	3	8
7. Cement tile	2	3	1	4	3	6
8. Clapboard	2	3	1	4	3	6
9. Corrugated roofing	2	3	1	4	3	6
10. Corrugated sheet	2	3	1	4	3	6
11. Plastic shingles	2	3	2	4	3	7
12. Shingles	2	3	1	4	3	6
13. Siding	2	3	1	4	3	6
1-8. MOLDED PRODUCTS						
1. Ash trays	3	4	1	1	3	6
2. Canal liners - pond liners	4	4	1	2	4	9
3. Filler and reinforcement in plastic	3	4	1	2	4	8
4. Gun grips	4	4	1	2	4	9
5. Molded plastics	3	4	1	1	3	6
6. Phenolic laminates	3	4	1	1	3	6
7. Resins	3	4	1	3	3	8
8. Rheostat backing	4	4	1	3	3	9

Table 2 (cont.)

1-9. ROOFING MATERIAL (COMMERCIAL INSTALLATION AND REPAIRS)	USE	RELEASABILITY	DURATION	FREQUENCY	POP. EXPOSURE	EXPOSURE INDEX
1. Aluminum roof coating	2	4	1	4	3	8
2. Roof patch	2	4	2	4	4	10
3.**Roofing felts	2	3	1	4	3	6
4. Roof preservative	3	4	1	4	4	10
1-10. SEALANTS AND MASTICS FOR CONSUMER AND COMMERCIAL USE						
1. A/C pipe joint sealant	3	4	2	4	3	10
2. Adhesives: glues and epoxies	3	3	2	4	3	8
3. Air duct joint sealing cement	3	4	2	4	3	10
4. Calking compounds and puttys	1	3	2	4	3	6
5. Flashing cement	2	4	2	4	4	10
6. Furnace cement	3	3	2	4	4	9
7. Glazing compound	2	3	2	4	4	8
8. Mastic	2	4	2	4	4	10
9. Roof coatings	2	4	1	4	3	8
10. Radiator sealant	3	3	3	4	4	10
11. Refrigerant cement	3	4	2	4	4	11
12. Varnish	4	3	2	4	4	10
13. Ceramic and quarry floor tile cement	2	4	1	4	3	8
14. Roof cement	2	4	1	4	3	8

* Fibers can be released to ingestible materials.
** Also reported under "Asbestos in Place"

(1) From Reference (3)
(2) Releasability ranking, Reference (2)

4. ASBESTOS PRESENTLY IN PLACE

A number of currently in place asbestos products are listed in Table 3, which gives a crude order of magnitude estimate of asbestos exposure of these products. Potential sources of high exposure risk with corresponding Exposure Index rankings, in parentheses, are: brakes in use (1), sprayed-on thermal and accoustical insulation (2), A.C. Pipe (3), and accoustical ceiling tiles (3).

In the following sub-sections an attempt is made to estimate the installed tonnage of various asbestos containing materials. These estimates are summarized in Table 4.

4.1 A.C. Pipe in Areas With Aggressive Water Supply

The exposure risk from aggressive water supplies using A.C. pipe is probably the easiest to quantify. From the results of a small sampling, it is estimated that up to 30 million persons in areas of aggressive water may be exposed to 20,000 ng/day of asbestos by ingestion. This is about 22 times more than the average inhalation exposure to air containing 46 ng/m^3 of asbestos fibers and strongly suggests that A.C. pipe carrying potable aggressive water may be a serious population exposure risk to asbestos.

The following information was used to develop estimates of population exposed to water piped in A.C. pipes.

About 448,000 kilometers of asbestos cement pipe is estimated to be in place (4). Asbestos pipe is used for water supply and sewage. About 70% of A.C. pipe is used for water supply with sewer pipe accounting for the rest. Further, almost 30% of all water supplies have water conveyed in A.C. pipes. If the water entering the pipe is acidic with low alkalinity and hardness, it is capable of dissolving the cementitious binder and releasing free fibers which enter the water supply.

An estimate of population exposure and mass of fibers ingested per day was made, based on the following assumptions:

Table 3

ASBESTOS PRESENTLY IN PLACE (1)

COMMERCIAL AND CONSUMER USES	USE	RELEASABILITY (2)	DURATION	FREQUENCY	POP. EXPOSURE	EXPOSURE INDEX
1. Acoustical ceiling tile	1	3	1	1	3	3
2. Acoustical material, sprayed	2	2	1	1	3	2
3. Tape joint cement	2	3	1	1	3	4
4. Blackboards A/C	2	3	2	1	2	4
5. Chalkboard	2	3	2	1	2	4
6. Linings for safes and filing cabinets	4	2	3	1	4	7
7. Ranges	4	3	2	1	3	7
8. Spackling	2	3	1	1	3	4
9. Thermal insulation	3	3	1	1	2	4
10. Thermal insulation, spray	2	2	1	1	2	1
11. Wallpaper	3	3	1	1	3	5
12.* A.C. pipe	2	3	1	1	2	3
13. Floor tile	2	2	1	4	3	5
14. Roofing felt	2	3	1	4	3	6
15. Brakes in use	1	2	1	1	3	1

* Release to water in water supply pipe.

(1) Same list as in reference (5)
(2) Same ranking as CPSC memo, reference (2)

Table 4

ESTIMATED TONNAGE OF ASBESTOS IN PLACE

RELEASE TO WATER

ASBESTOS PRODUCT	APPLICATION	ASBESTOS IN PLACE km	POPULATION EXPOSED	ESTIMATED INGESTION ng/day
A.C. Pipe	Water supply (aggressive water)	336,000 (2)	29.8×10^6 (1)	20,000
	Water supply (non-aggressive water)		46.2×10^6 (1)	100

RELEASE TO AIR

ASBESTOS PRODUCT	APPLICATION	ASBESTOS IN PLACE MT	EMISSIONS MT/YR
Asbestos roofing products	Roofing	2.19×10^6 (1)	2190 (1)
Asbestos cement sheet	Excluding sheet used for roofing	1.13×10^6 (1)	1130 (1)
Asbestos floor tile	Flooring	1.1×10^6 (1)	550 (1)
Insulation	All thermal, electrical & decorative sprays	0.4×10^6 (3)	200 (1)
Plastics (4)		0.14×10^6 (1)	-
Friction materials	Auto & truck brakes	0.17×10^6 (1)	20 (2)

(1) IITRI engineering estimate.
(2) Interpolated from data in Reference (5)
(3) Average of estimates from Reference (5) and (10).
(4) Excluding floor tile, packing, gasketing, friction material.

(1) 30% of the country's population live in areas with aggressive water supplies. This assumption was based on the observation that naturally occurring soft water tends to be corrosive (25). Further, from the distribution of naturally occurring waters (22), it was estimated that 30% of the country's population could be living in areas with aggressive water supplies.

(2) 30% of country's population receive water piped in A.C. pipe (ref. 4).

(3) Aggressive water supplies have 10^7 fibers/liter (4).

(4) Assume non-aggressive water supplies have 5×10^4 fibers/liter.

(5) Assume that on an average, an individual ingests 2 liters of water/day.

(6) Assume that 48% of the population is below 30 years (23).

(7) Assume that pipe is uniformly distributed.

(8) Total U.S. population 220×10^6.

Aggressiveness of water is measured by an index defined as

$$AI = pH + \log (AH)$$

where

AI = aggressiveness index

A = alkalinity of water, mg/liter $CaCO_3$

H = hardness of water, mg/liter $CaCO_3$

Water with aggressiveness index of 10.0 or less is considered to be aggressive.

4.2 Asbestos Roofing Products

Asbestos roofing products include asphaltic felts, patching compounds and sheets. It is difficult to envision release of fibers from installed asphaltic felts and patching compounds since the fibers are tightly held in the binder material. However, fibers may be released when a roof is being replaced or when the installed material becomes old and weathered. Population exposure is difficult to judge, but it is expected to be small because of immediate dilution of any fiber emissions.

The following assumptions were made to calculate total installed tonnage of asbestos roofing products.

Assumptions:

Repairs & maintenance	1.5%/yr of asbestos roofing installed
Replacement	5%/yr of asbestos roofing installed
Demolition	2.5%/yr of asbestos roofing installed
Net inventory increase	1.5%/yr of asbestos roofing installed
Current asbestos Consumption	229,522 MT/yr

Roofing Products release free fibers @ 0.1% by weight (4).

4.3 Asbestos Cement Sheet

It is widely used in industrial and roofing applications. It is difficult to estimate the population exposed to emissions from sheets used in industrial application. However, weathering and wear rates are expected to be low, about 0.1% per year of installed tonnage (4). A.C. sheets have been used for the construction of warehouses and bulk storage for corrosive materials and fertilizers. Under these conditions, it is envisaged that the asbestos fibers may be released if the cementitious binder material disintegrates in the corrosive atmosphere. Figures for asbestos tonnage installed in corrosive atmospheres are not available. Asbestos cement sheets installed as roofing are considered under the sub-section on roofing.

The following assumptions were made to calculate installed tonnage of A.C. sheets for purposes other than roofing.

Assumptions:

Maintenance & Repair	2%/yr of total installed sheets
Replacement	4%/yr of total installed sheets

Structural Demolition	2.5%/yr of total installed sheets
(assume all demolished material is replaced by new construction)	
Net Inventory Increase	2.5%/yr of total installed sheets
Installed Asbestos Sheets	1.13×10^6 MT

Wear & Release Rate:

Assume that normal wear, weathering, etc. amount to 0.1% per year.

Emission rate:

$$\frac{0.1 \times 1.13 \times 10^6}{100} = 1130 \text{ MT/yr}$$

4.4 Asbestos Floor Tile

Although widely used in apartments, commercial and public buildings, asbestos fibers in tiles are tightly held in the binder matrix and asbestos release at measureable rates under normal conditions of weathering and use is difficult to envision. However, there are no known attempts to quantify asbestos release from installed floor tiles.

An estimate of total installed tonnage of asbestos floor tiles was based on the following assumption.

Assumptions:

Maintenance & Repairs	2%/yr of asbestos flooring installed
Replacement	5%/yr of asbestos flooring installed
Demolition	2.5%/yr of asbestos flooring installed
Net Inventory Increase	0% of asbestos flooring installed
Asbestos Installed As Flooring	1.1×10^6 MT

Emission rate based on 1.0% over 20 years:

$$\frac{1.1 \times 10^6 \times 0.05}{100} = 550 \text{ MT/yr}$$

Wear rate for floor tiles was arbitrarily selected. Most floor tiles are sold in thicknesses of 1/8 and 1/16 inches. Assuming uniform wear, an 1/8" thick floor tile would lose approximately

6.25×10^{-5} inches per year, an amount so small that even after ten years of wear, its thickness would decrease by only 6.25×10^{-4} inches, an amount that commonly available instruments (e.g. vernier caliper, or micrometer gauge) would fail to read.

4.5 Insulation and Sprayed-On Materials

According to EPA estimates (10) about 4% of the schools in the U.S. have some indoor surface application of asbestos, either as accoustical tiles, decorative sprays, ceiling tiles or thermal insulation. If it is assumed that the percentage of children at risk from asbestos exposure is the same as percentage of schools having asbestos, then about 1.7 million students are currently being exposed to it.

This estimate indicates a potential for high releasability by these materials. The release of fibers into the building atmosphere has been found to be greatest from contact such as maintenance and reintrainment during custodial activities such as heavy dry dusting, sweeping and vacuuming. Asbestos emissions from these and other situations are compared in Table 5. Comparison of the optical microscope measurements in this table suggest that high optical microscope counts relative to the fiber concentrations on a weight basis may be largely due to the presence of non-asbestos fibers. More extensive measurements are needed to characterize the collected fibers and to determine the extent of this asbestos exposure risk.

Between 1950-1973 sprayed-on insulation was widely used in multi-storied multibuildings for fire proofing purposes.

In larger buildings, air condition return air flow through plenums which also contain the building structural members. These plenums are fire-proofed with sprayed asbestos insulation. It is conceivable that the movement of flowing air over the sprayed asbestos material can dislodge and entrain fibers to give a higher fiber concentration of ventilating air as compared to those buildings in which the air is returned through other means (e.g., through metal ductwork). To give an idea of potential exposure,

Table 5.

AIRBORNE ASBESTOS IN BUILDINGS[1]

Sampling conditions or situation	Mean counts (f/cm^3)[o.m]	Number of samples	Standard Deviation
1. University dormitory, UCLA Exposed friable surfaces, 98% amosite General student activities	0.1	-	0 to 0.8 (range)
2. Art and Architecture Building, Yale University . Exposed friable ceilings, 20% chrysotile			
Ambient air, City of New Haven	0.00	12	0.00
<u>Fallout</u>			
Quiet conditions	0.02	15	0.02
<u>Contact</u>			
Cleaning, moving books in stack area	15.5	3	6.7
Relamping light fixtures	1.4	2	0.1
Removing ceiling section	17.7	3	8.2
Installing track light	7.7	6	2.9
Installing partition	3.1	4	1.1
<u>Reentrainment</u>			
Custodians sweeping, dry	1.6	5	0.7
Dusting, dry	4.0	6	1.3
Proximal to cleaning (bystander exposure	0.3	-	0.3
General Activity	0.2	36	0.1
3. Office buildings, Eastern Connecticut Exposed friable ceilings, 5 to 30% chrysotile			
Custodial activities, heavy dusting	2.8	8	1.6
4. Private homes, Connecticut			
Remaining pipe lagging (dry) amosite and chrysotile asbestos	4.1	8	1.8 to 5.8 (range)
5. Laundry: contaminated clothing. Chrysotile	0.4	12	0.1 to 1.2 (range)
6. Office building, Connecticut. Exposed sprayed ceiling, 18% chrysotile.			
Routine activity	79[a]	3	40 to 110 (range)

Table 5 (cont.)

Sampling conditions or situation	Mean Counts (f/cm^3)	Number of samples	Standard Deviation
Under asbestos ceiling	99[a]	2	
Remote from asbestos ceiling	40[a]	1	
7. Urban Grammar School, New Haven. Exposed ceiling, 15% chrysotile asbestos			
Custodial activity: sweeping, vacuuming	643[a]	2	186 to 1100 (range)
8. Apartment Building: New Jersey, heavy housekeeping. Tremolite and chrysotile.	296[a]	1	
9. Office buildings, New York City,			
Asbestos in ventilation systems	2.5 to 200[a]		0 to 800 (range)
Quiet conditions and routine activity			

[a]Nanograms/cubic meter. Determined by electron microscope.

(1)Reference (7)

in 1973 there were 53 million employed (23) white collar and service workers in the labor force. Assuming that 4% of them were employed in buildings containing asbestos insulation, there were (2) million people who may have worked in situations with a potential exposure problem.

From figures in references (4) and (7) it is estimated that about 440,000 MT of installed insulation may be in place. Wear and Release of asbestos fibers from installed insulation were calculated at the rate of 0.05% per year of total installed tonnage (5).

4.6 Plastics

Asbestos fibers are tightly bound in the resin matrix of most molded plastic items. However, its use in common plastic items found in automobiles, homes, offices, and commercial environments is widespread. But, it is difficult to envision a fiber release under ordinary conditions of use, wear and tear. Based on the following assumptions, the quantity of asbestos in plastics currently in use was estimated:

Repair, Maintenance, and Replacement @ 12%/yr of asbestos-containing plastics currently in use.

Net growth of plastics inventory 1.5%/yr of existing inventory.

Annual consumption of asbestos for plastics -- 19,000 MT/yr

4.7 Brakes in Use

4.7.1 Estimate of Asbestos Installed in Brakes

It is estimated that in 1973 there were about 103 million passenger cars, trailers, motorcycles, and 20.90 million trucks and buses of all types (4). Assuming that the lighter vehicles (passenger cars, etc.) have 2 lbs of asbestos in their brakes and the heavier ones have 8 lbs of asbestos, the total amount of asbestos in brakes may be estimated to be about 0.17 million metric tons.

4.7.2 Brake Wear Emissions

A quantitative interpretation of asbestos emissions from automobile brake lining wear can be made by using urban dispersion model (21). Assuming that the density of automobiles in the United States is proportional to the population density, emission concentration can be estimated for New York City.

The total brake emissions in New York City have been calculated as 3.4×10^{14} ng/yr, based on a national average emission rate of 10 tons/year (4). This value corresponds to 1.1×10^{7} ng/sec. Since New York City has an area of roughly 300 sq. miles, the emission rate on an area basis can be calculated to be 1.4×10^{-7} ng/sec-m^2. Average asbestos emission concentrations of 0.15 to 0.36 ng/m^3 at ground level is calculated for wind speeds in the range of 1.5 to 5.5 m/sec. This can be compared to an average of 8 to 30 ng/m^3 of chrysotile asbestos which was found in various boroughs of New York City (9) and also to an average asbestos concentration range of 1 to 10 ng/m^3 found in the urban air of 48 U.S. cities (9). The source of the asbestos is uncertain since it may include much reentrained material from brake wear dropout as well as other possibly much larger inventories of asbestos emissions. Some of these are listed in Table 4. They are all sources which vary directly with population density.

117,000,000 / 2000
58,500 Tons (material)
x 0.70
= 41,000 (solids)

300 x x 41,000
1000 x 3600

120 / 30 = 4

5. ASBESTOS EXPOSURE DUE TO MANUFACTURING AND PROCESSING ACTIVITIES

The manufacturing industries were considered separately under three different categories:

- Primary Industries
- Secondary Industries
- Consumer Product Industries

Exposure ranks were assigned to each industry segment based on the definitions in Section 2 for exposure index, and population exposure. Population exposures were calculated as the product of exposed concentration (ng/m^3) exposure time (hrs/year) and number of people exposed.

5.1 Occupational Population Exposure

Exposure to asbestos in the work environment was estimated by assuming that in the primary industry, average exposure was 1.0 fibers/cc, 2.0 fibers/cc in secondary industries, and 0.1 fibers/cc in consumer industries. For the purpose of this calculation, these were assumed to be the same for all segments of any industry category. In Table 6, some typical concentration measurements for primary and some secondary industries are shown.

It was further assumed that the average occupational exposure is 2,000 hrs/year.

Occupational exposure figures reported by Daly (9) were used to develop the exposure ranks.

Based on these assumptions, the occupational population exposures are reported in Tables 8 through 10 and summarized in Table 7. Taken collectively, the occupational population exposure of the primary industry is dwarfed by the large sizes of the secondary industry, the consumer products, and brake service and repair category.

Table 6

EXPOSURE TO AIRBORNE ASBESTOS IN SELECTED ASBESTOS PRODUCT MANUFACTURING INDUSTRIES (1)

	Asbestos Concentrations (Time-Weighted Average in Fibers/ml) (2)	
	Typical	Range
Friction Products		
Primary	2	0.1 -15.0
Secondary		2.5 - 6.5
Asbestos Paper		
Primary	1	0.75- 2.7
Secondary		1.0 - 3.5
Asbestos-Reinforced Plastics		
Primary	1	0.2 - 2.5
Secondary		0.5 - 2.0
Cement Pipe	1.5	0.25- 3.5
Cement Sheet		
Primary	2	0.3 - 8.7
Secondary		1.0 - 6.0
Floor Tile	1	0.5 - 4.3
Textile		
Primary	4	0.25-10
Secondary		2.0 - 6.0
Paints, Coatings and Sealants	1	1.0 - 2.5

too high - violation of OSHA

(1) Reference (6).
(2) Optical microscope visible fibers, 5 μm long or longer.

Table 7

SUMMARY OF INDUSTRIAL OCCUPATIONAL POPULATION EXPOSURE

INDUSTRY CATEGORY	ASBESTOS CONC. OMV (1) fibers/cm^3	CUMULATIVE POPULATION EXPOSURE, ALL SEGMENTS ng-hr-Persons/m^3	EXPOSURE INDEX
1. Primary Asbestos Industry	1	149×10^{10}	3
2. Secondary Asbestos Industry	2	4440×10^{10}	1
3. Consumer Products, except brake service & repair	0.1	5860×10^{10}	1
4. Brake Service & Repair	0.8	7416×10^{10}	1

(1) Optical Microscope Visible

?

Table 8

OCCUPATIONAL EXPOSURE - PRIMARY INDUSTRY

INDUSTRY SEGMENT	ANNUAL ASBESTOS CONSUMPTION MT/YR(6)	PRODUCTION WORKERS (5)	OCCUPATIONAL POPULATION EXPOSURE (1) ng-hr-Persons/m^3-year	EXPOSURE INDEX
Roofing	229,522	EC (7)	EC	EC
A.C. Pipe	127,000	1,600	16×10^{10}	4
Flooring	103,000	2,900	29×10^{10}	4
Friction Products	57,900	4,900	49×10^{10}	3
Paper	28,100 (2)	1,100	11×10^{10}	4
A.C. Sheet	20,600 (2)	600	6×10^{10}	4
Plastics	19,500 (3)	900	9×10^{10}	4
Packing & Gaskets	18,200	600	6×10^{10}	4
Coating & Compounds	18,100	350	3.5×10^{10}	4
Insulation	8,100	400 (4)	4×10^{10}	4
Textiles	6,700	1,200 (4)	12×10^{10}	4
Other	18,700	360 (4)	3.6×10^{10}	4
TOTAL	655,422	14,910	149×10^{10}	

(1) Based on occupational exposure of 1.0 fiber/cc.
(2) Excluding roofing operations.
(3) Excluding flooring, packing & gaskets.
(4) IITRI engineering estimate.
(5) From Ref. (9).
(6) From Ref. (5).
(7) EC = elsewhere counted.

Table 9

OCCUPATIONAL EXPOSURE - SECONDARY INDUSTRY

INDUSTRY SEGMENT	ESTIMATED PRODUCTION WORKERS (1)	OCCUPATIONAL POPULATION EXPOSURE (2) ng-hr-Persons/m^3-year	EXPOSURE INDEX
Asbestos Paper	158,400	3168×10^{10}	1
Asbestos Cement Sheet	19,200	384×10^{10}	2
Gaskets & Packings	12,000	240×10^{10}	3
Asbestos Reinforced Plastics	8,400	168×10^{10}	3
Asbestos Textiles	6,000	120×10^{10}	3
Insulation	2,300 (3)	46×10^{10}	3
Other	15,700 (3)	314×10^{10}	2
TOTAL	222,000	4440×10^{10}	

(1) From Ref. (9).
(2) Based on occupational exposure of 2.0 fibers/cc.
(3) IITRI engineering estimate.

Table 10

OCCUPATIONAL EXPOSURE - CONSUMER INDUSTRIES

Consumer Products	Number of Employees Continuously Exposed	Population Exposure (1) ng-hr-Persons/m^3 x 10^{-10}	Exposure Index
Meat Products	720	0.72	5
Fluid Milk	1,500	1.50	5
Narrow Fabric Mills	5,710	5.72	4
House Furnishings N.E.C.	4,820	4.82	4
Fabricated Textile Products N.E.C.	760	0.76	5
Canned Fruits and Vegetables	2,480	2.48	5
Frozen Fuits and Vegetables	6,750	6.72	4
Flour and Cereal Preparations	4,120	4.12	4
Prepared Feeds for Animals and Fowls	7,840	7.84	4
Bakery Products	12,450	12.46	4
Sugar	7,590	7.60	4
Alcoholic Beverages	920	0.92	5
Bottled and Canned Soft Drinks	1,470	1.58	5
Soybean Oil Mills	590	0.60	5
Food Preparations N.E.C.	870	0.88	5
Paper Board Mills	860	0.86	5
Wallpaper & Building Paper & Board Mills	830	0.82	5
Converted Paper, Product N.E.C. (no Boxes)	12,460	12.46	4
Sanitary Paper Products	1,680	1.68	5
Industrial Inorganic & Organic Chemicals	11,470	11.48	4
Cleaning Preparations	1,950	1.94	5
Miscellaneous Chemical Products	32,490	32.50	3
Prefabricated Wood Structures	47,920	47.92	3
Logging Camps and Logging Contractors	N.D.	N.D.	N.D.
Wood Products N.E.C.	9,580	9.58	4
Saw Mills and Planing Mills General	13,420	13.42	4
Mill Work	12,200	1.20	5
Recaimed Rubber & Misc. Rubber Products	54,760	54.76	3
Miscellaneous Plastics Products	48,270	48.28	3
Glass Containers	8,410	8.42	4
Leather Tanning & Indust. Leather Products	7,540	7.54	4

Table 10 (continued)

Consumer Products	Number of Employees Continuously Exposed	Population Exposure(1) ng-hr-Persons/m^3 x 10^{-10}	Exposure Index
Glass and Glass Products (Not Containers)	6,980	7.00	4
Cement Hydraulic	9,810	9.82	4
Porcelain Electrical Supplies	32,850	32.86	3
Nonferrous Wire Drawing and Insulating	114,580	114.58	3
Copper Rolling and Drawing	7,580	7.60	4
Aluminum Rolling and Drawing	10,020	10.02	4
Paper Industries Machinery	2,010	2.00	5
Heating Equipment (Not Electric)	10,150	10.16	4
Farm Machinery	43,210	43.32	3
Industrial Trucks and Tractors	N.D.	N.D.	N.D.
Special Industry Machinery N.E.C.	N.D.	N.D.	N.D.
Sheet Metal Work	1,402,160	1402.16	2
Metal Stampings	9,780	9.80	4
General Industrial Machinery	11,240	11.24	4
Machine Shop Products	8,470	8.48	4
Motor Vehicles and Parts	2,214,560	2214.00	2
Pipe, Valves and Pipe Fittings	84,300	84.30	3
Fabricated Metal Products N.E.C.	92,570	52.56	3
Internal Combustion Engines N.E.C.	281,450	280.60	3
Machine Tools, Metal Forming Types	8,650	8.60	4
Service Industry Machines N.E.C.	15,870	15.88	4
Transformers	150,210	150.20	3
Electrical Industrial Appratus N.E.C.	154,780	154.78	3
Electrical House Wares and Fans	118,790	118.80	3
Wiring Devices	35,120	35.20	3
Electronic Components N.E.C.	87,490	87.50	3
Engine Electrical Equipment	67,080	67.08	3
Trailer Coaches	41,000	41.00	3
Transportation Equipment N.E.C.	45,120	45.12	3

Table 10 (continued)

Consumer Products	Number of Employees Continuously Exposed	Population Exposure(1) ng-hr-Persons/m^3 x 10^{-10}	Exposure Index
Ship Building and Repairing	323,010	323.02	2
Surgical Appliances and Supplies	21,890	21.90	4
Air Craft Equipment N.E.C.	43,000	43.00	3
Construction Machinery	93,000	93.00	3
N.E.C.	4,060	4.06	4
Friction Products			
Brake Service and Repair	927,000	7416 (2)	1
Total	6,800,000		

N.D. = not determined.
N.E.C. = not elsewhere counted.

(1) Based on occupational exposure of 0.1 fibers/cc.
(2) Brake service and repair exposure of 0.8 fibers/cc, Ref. (1).

5.2 Non-Occupational Population Exposure

The asbestos emissions to the general population surrounding a plant are a result of both process emissions and waste disposal emissions. Although they often occur together, they are treated separately here so that their individual contribution can be assessed. Process emissions were based on control efficiencies of 99.99% (20). Waste disposal emissions were based on field measured values (19). Non-occupational population exposure from process and disposal emissions were calculated by taking the product of population exposed, exposure time, and concentration. The number of people exposed to the emissions was found by assuming each disposal site and plant as point sources, and then applying Turner's Atmospheric Dispersion Model (12) to each individual source. The model was used to calculate the area of a circle in which the population would be exposed to an average concentration of 46 ng/m^3. This concentration level is given a code rank of 3 for Releasability in Table 1. This area was then multiplied by a population density and the number of emitting sites.

The following assumptions were made to estimate the population exposure.

Process emission rate is 0.01% of the baghouse waste collected

Disposal emission rate is 0.16% of waste per year

49

Plant operates for 50 weeks/yr x 8 hrs/shift x 2 shifts/day x 60 days/week

5

Disposal sites emit for 52 weeks/yr x 24 hrs/day x 7 days/week

Plant size: average for industry segment

Population density in the plant area - 1,931 people/km^2

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The number of persons exposed to an ave. of 46 ng/m^3 is determined using atmospheric diffusion estimation methods (12).

$$\bar{\chi} = \frac{2.03\ Q}{\sigma_z ux}$$

where $\bar{\chi}$ represents the average concentration at a receptor from a single point source at a distance x from the receptor.

Dispersion calculations are based on the following assumptions:

Emission rate, Q, ng/sec

Source is at ground level

Vertical dispersion rate @ distance $\bar{\chi}$ from source, σ_z

Wind velocity at 4.5 m/sec, u

Wind stability, D

Threshold concentration, $\bar{\chi}$ = 46 ng/m^3

With the above assumptions a graphical solution is used to determine the distance x at which $\bar{\chi}$ = 46 ng/m^3. This distance is used to determine the population exposed to significant asbestos concentrations.

The resulting Exposure Index rankings for process emissions and disposal emissions are summarized in Table 11. This table summarizes emissions for twelve manufacturing industries within the primary industry. The details are given in Table 12.

Process emissions to the non-occupational population are highly dependent on the emission controls used at a given plant. The effect of control efficiency on population exposure is demonstrated in Table 13 for the A.C. pipe primary industry. Wet scrubbers and electrostatic precipitators, which will give around 90% efficiency, are not very effective in reducing

Table 11

NON-OCCUPATIONAL POPULATION EXPOSURE -- PRIMARY INDUSTRY (SUMMARY)

INDUSTRY SEGMENT	EXPOSURE INDEX PROCESS EMISSIONS	EXPOSURE INDEX DISPOSAL EMISSIONS
1. Roofing	6	4
2. A.C. Pipe	7	4
3. Flooring	7	6
4. Friction Products	5	4
5. Paper	7	5
6. A.C. Sheet	7	5
7. Plastics	6	5
8. Packing & Gaskets	7	6
9. Coating & Compounds	6	N.D.
10. Insulation	6	6
11. Textiles	7	7
12. Other	9	7

N.D. = not determined.

Table 12

NON-OCCUPATIONAL POPULATION EXPOSURE - PRIMARY INDUSTRY

INDUSTRY SEGMENT	ANNUAL ASBESTOS CONSUMPTION MT/YR (4)	ASBESTOS EMISSIONS TO AIR, MT/YR (4)			POPULATION EXPOSED (1)		POPULATION EXPOSURE, (1) ng-hr-person/m³		EXPOSURE INDEX	
		FROM PROCESS	FROM DISPOSAL	TOTAL	TO EMISSIONS FROM PROCESS	TO EMISSIONS FROM DISPOSAL	FROM (5) PROCESS EMISSIONS	FROM (6) DISPOSAL EMISSIONS	PROCESS EMISSIONS	DISPOSAL EMISSIONS
Roofing	229,522	0.10	9.98	10.08	8,900	610,000	2.0×10^9	56.0×10^9	6	4
A.C. Pipe	127,000	0.067	17.24	17.31	5,300	1,080,000	1.2×10^9	99.0×10^9	6	4
Flooring	103,000	0.021	0.33	0.35	1,600	16,000	0.35×10^9	1.5×10^9	6	6
Friction Products	57,900	0.862	11.80	12.66	85,400	710,000	19.0×10^9	65.0×10^9	5	4
Paper	28,100 (2)	0.013	0.62	0.63	990	33,000	0.22×10^9	3.0×10^9	7	5
A.C. Sheet	20,600 (2)	0.010	2.48	2.49	780	149,000	0.17×10^9	14.0×10^9	7	5
Plastics	19,500 (3)	0.091	0.64	0.73	7,860	34,000	1.7×10^9	3.1×10^9	6	5
Packing & Gaskets	18,200	<0.01	0.24	<0.25	654	11,000	0.14×10^9	1.0×10^9	7	6
Coating & Compounds	18,100	<0.10	-	<0.10	9,400	-	2.1×10^9	-	6	-
Insulation	8,100	<0.018	0.174	<0.19	1,430	7,700	0.32×10^9	0.71×10^9	6	6
Textiles	6,700	<0.181	0.73	<0.91	1,200	740	0.27×10^9	0.07×10^9	7	7
Other	18,700	<0.009	<0.009	<0.018	1,200	442	0.001×10^9	0.04×10^9	9	7
TOTAL	655,422	1.482	44.243	45.73	124,714	2,643,000	27.47×10^9	242.71×10^9		

(1) IITRI engineering estimate.
(2) Excluding roofing applications.
(3) Excluding flooring, packing & gaskets.
(4) Reference (4)
(5) Process exposure at 2000 hrs/yr
(6) Disposal exposure at 8736 hrs/yr

Table 13

EFFECT OF CONTROL EFFICIENCY ON TOTAL POPULATION EXPOSURE TO ASBESTOS/ CEMENT PIPE MANUFACTURING PROCESS EMISSIONS

CONTROL EFFICIENCY %	TOTAL PROCESS EMISSIONS, MT/yr	POPULATION EXPOSURE	EXPOSURE INDEX
0	670	2.3×10^{13}	2
90	67	2.0×10^{12}	3
99	6.7	1.7×10^{11}	4
99.9	0.67	1.4×10^{10}	5
99.99	0.067	1.2×10^{9}	6

population exposure compared to a well-maintained baghouse system.

Table 14 shows the results of a survey (24) of process emission controls employed by asbestos users. Ninety percent of the control devices in use were baghouses.

The highest exposure from manufacturing and processing activities is among those who work with asbestos. Their large numbers make them an important group within the general population for special concern. One million persons now living in the United States either worked in the past or are currently working in the asbestos manufacturing industry (1). It is further estimated that in the consumer products industry, workers with continuous exposure to asbestos currently number 5.8 million persons. This figure does not include 900,000 persons who are continuously exposed to asbestos in their work related to the repair and servicing of automobile brakes (9).

Effluents from process waters are virtually non-existent and the plants are considered to have zero discharges (27).

From the existing data, only gross estimates of non-occupational exposure to primary manufacturing industries were possible. These estimates suggest that the population exposure in the area surrounding manufacturing plants from waste disposal may be comparable to the population exposure ~~to~~ of the occupational population. The population exposure from process emissions (assuming baghouse filtering is used) appears to be considerably less. Data were lacking for making even gross estimates of non-occupational population exposures from secondary and commercial products industries. Gross estimates of asbestos emissions from these industries are shown in Table 15.

Table 14

USE OF EMISSION CONTROL IN
ASBESTOS PRODUCTS MANUFACTURING PLANTS (1)

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

(1) Reference (24).

Table 15

ASBESTOS DISPOSED AS WASTE IN SECONDARY & CONSUMER INDUSTRIES

ASBESTOS PRODUCT CATEGORY	ASBESTOS CONSUMED MT/YR(4)	ASBESTOS TO WASTE MT/YR(5)	ASBESTOS EMISSIONS TO AIR, MT/YR FROM PROCESS	ASBESTOS EMISSIONS TO AIR, MT/YR FROM DISPOSAL(5)
Roofing	223,400	178,900	0.91	29
A.C. Pipe	116,200	20,300	-	3.3
Flooring	102,800	51,400	∿0	8.3
Friction Material	50,500	45,800	44.9 (1)	0.23
Paper (2)	27,731	21,800	<0.01	3.6
Plastics (3)	19,100	16,200	∿0	2.7
A.C. Sheet (2)	19,000	14,300	∿0	2.7
Packing & Gaskets	18,100	16,300	∿0	2.7
Coating & Compounds	18,100	12,800	∿0	1.5
Insulation	8,000	100	27.3 (4)	-
Textiles	6,300	6,900	<0.01	∿0
Other	18,700	9,500	45.4 (4)	1.52

(1) From Ref. (1).
(2) Excluding roofing applications.
(3) Including flooring, packing & gaskets.
(4) From Ref. (5).
(5) IITRI estimates.

2

6. NATURALLY OCCURRING ABESTOS

The geographic distribution of igneous metamorphic rock terrains and the population density by county, are shown in Figures 1 and 2 respectively. Asbestiform minerals are known to occur in these terrains or in the weathered sediments in close proximity to these rock types (11).

Comparison of Figures 2. and 1. indicates those regions of the U.S. having a high population density and also have a high potential for fugitive asbestos emissions. The most critical areas appear to be in eastern Pennsylvania, south eastern New York, south western Connecticut, the San Francisco area, and the Los Angeles area. However, there is little in the way of heavy mining in these areas. Most areas containing igneous and metamorphic rock which do support heavy mining activity tend to be sparsely populated.

One study (11) has shown, albeit inconclusively, that the ambient air concentration in the vicinity of mines containing 5% asbestos as gangue is about 0.3 - 10 ng/m^3. From this it would appear that substantial populations surrounding mine sites where asbestos is present as an accessory mineral are not exposed to significantly high concentration levels.

Natural waters from several rivers, lakes and creeks were analyzed in a study done in northern regions of Vermont and New Hampshire, southern Montana, the Washington Oregon region, northern California and the boundry regions of Georgia, Carolinas, and Tennessee.

Asbestos fiber have been found in the natural sites in Montana, California and along the Connecticut river at levels as high as the mid to upper 10^7 fibers per liter range (15)(E.M.) In an earlier study on the asbestos content of water supplies in several large metropolitan cities asbestos was found in four of the ten cities sampled. All four cities were located in geographic terrain known to favor occurrance of asbestos. Cities which had a detectable asbestiform fiber concentration in their raw water supply were Boston, Philadelphia, Atlanta, and Seattle. Water supplies of New York, Chicago, Dallas, Kansas City and Denver were relatively free of asbestos (18).

The areas of the U.S. where high concentration of asbestiform phases have been observed in underlying bedrock correspond to the geographic distribution of igneous and metamorphic rocks shown in Figure 1. Although these rock formations cover 30% of the U.S., data are lacking on the amount of asbestiform containing rock which is quarried and used. This may be used where sedimentary rock is not readily available. Calculations were made to estimate the amount of asbestos which might be emitted from the use of asbestos containing rock for surface applications on unpaved roadways in the United States.

The following assumptions and values are used:

Total unpaved roadway, UR	1.2×10^6 km
Gravel Roadways as % of UR, GR	50%
Asbestos containing rock used as % of GR, AR	1%
Asbestos Content of AR, A	0.5%
Silt content of AR, S	12%
Silt finer than 30 µm aerodynamic diamter, SF	60%
Annual vehicular traffic, VT	4380 hrs/yr.
Vehicular speed, V	64 km/hr.
Vehicular traffic rate, T	10 vehicles/hr.
Annual wet days with rainfall >0.03 cm, W	90 days

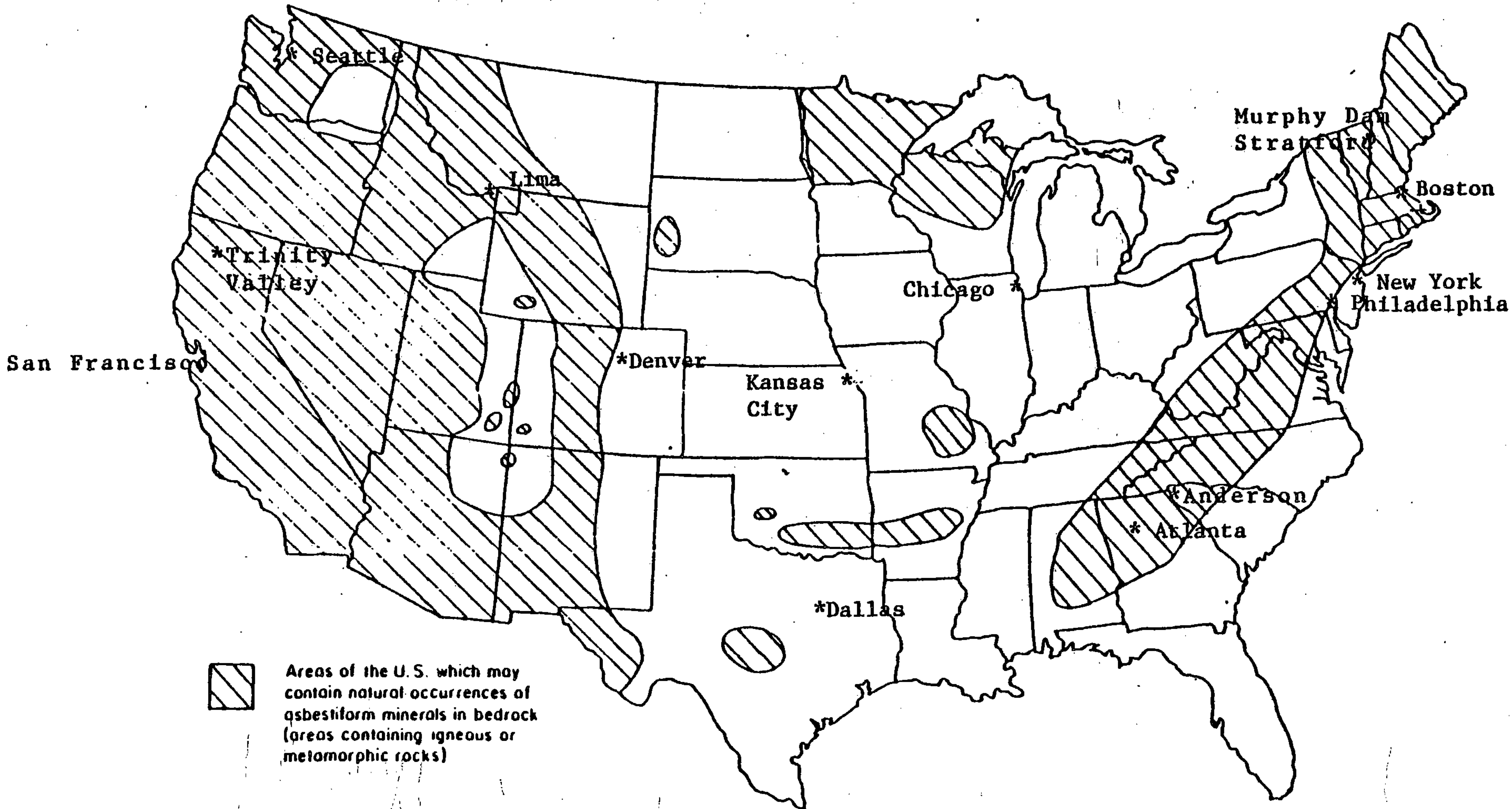

Figure 1. Geographic Distribution of Igneous Rock Terrains (Ref. 11)

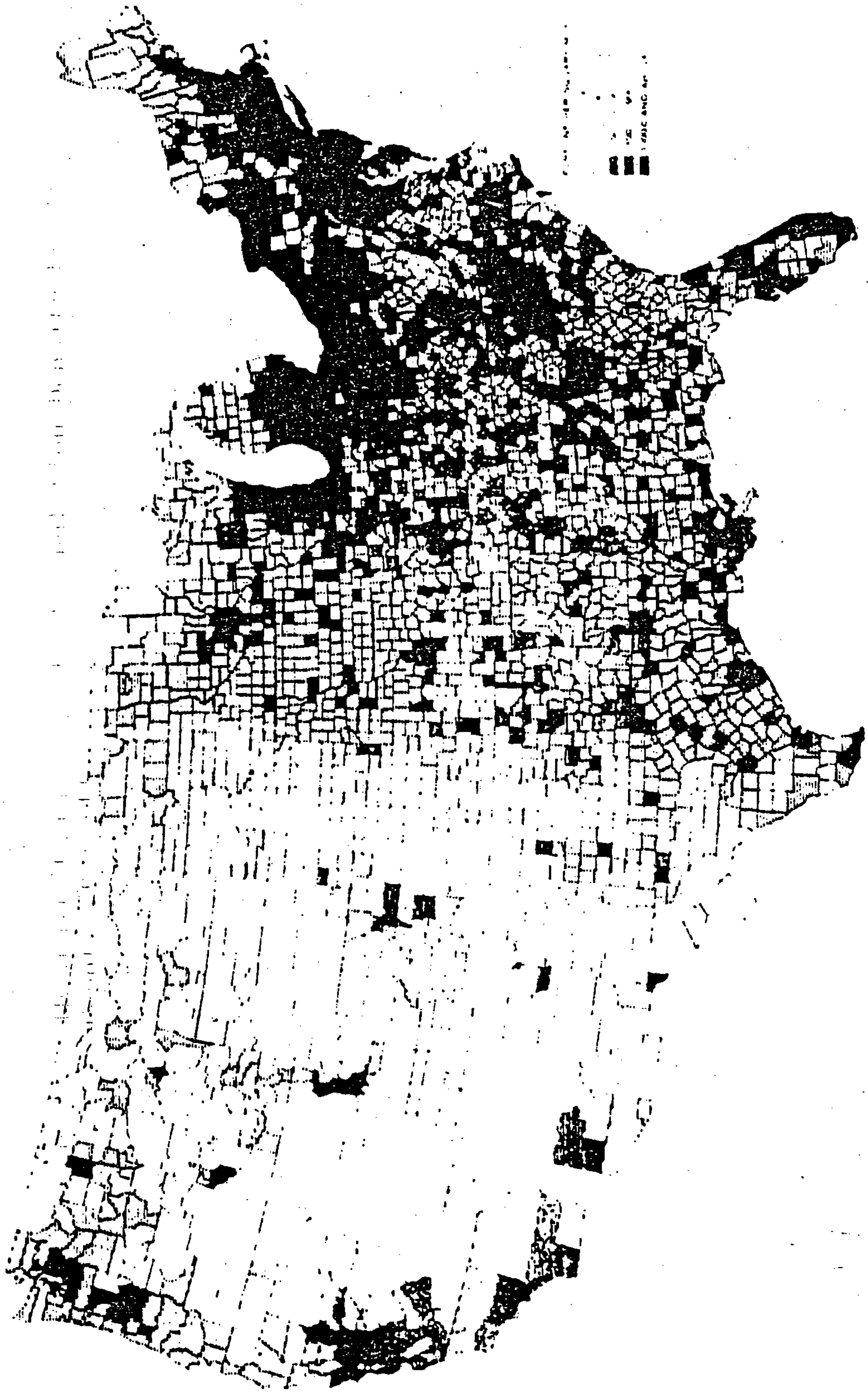

Figure 2. The United States -- 1970 Population Density by County (Ref. 11)

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The vehicular traffic emission factor (28) is calculated as:

$$E = (0.23\ S)\ (\frac{V}{48})\ (\frac{365-W}{365}) \qquad \text{Kg/vehicle-Km}$$

$$E = 2.77 \times 10^{-2}\ \text{Kg/vehicle-Km}$$

Emission Rate = E · SF · A · UR · AR · GR · T · VT

Emission Rate = 2.2 MT/yr.

This value is in the same order of magnitude range as the emissions expected from brake lining wear. However, unpaved roads are usually in areas of low population density and the population exposure may be much less than that for brake lining wear.

It appears that natural occurrance of asbestiform material could lead to population exposure, but the extent and degree to which this might occur is difficult to determine with the data available. This is true for both the rock used on unpaved roadways and for the potable water. One difficulty in dealing with the data on city water supply is that adequate information regarding the presence of other man-made sources up stream of the sampling points is not reported. Without this information it is difficult to judge the real source of the asbestos found in these cities' water supply.

7. TECHNICAL CONTROLS

The thrust of the EPA effort is to control the population exposure to asbestos. This control requires coordinated effort in several areas. These include improvements in asbestos exposure measurement methods, collection of more complete and accurate data on existing sources, control of exposure to emissions from the most significant sources including industrial activities related to asbestos product and commercial product manufacture, and administrative actions.

7.1 Controls to Limit Exposure

Many engineering alternatives are available to control asbestos emissions during processing and disposal of asbestos (1). Some are economic and others are not. The control methods include enclosures, exhaust ventilation, isolation, treatment of fibers, burial and substitution of alternative materials.

For process emissions, the baghouse filter system is the most effective. Other types of particulate control methods are less efficient, often by orders of magnitude.

For those facilities with adequate process emission control, waste disposal can still be a serious source of emissions. Daily burial with six inches of soil cover is recommended. Bagging, pelletizing, lagooning, or covering the loose fines with a chemical stabilizing agent could be equally effective without the expense of daily landfilling.

The current asbestos process and disposal practices and the extent of their usage in the primary, secondary, and commercial products industries are not known at this time. Such information would be useful for determining the extent to which further EPA effort is needed.

Population exposure risk to sprayed-on asbestos in schools and other actively used buildings will be greatly reduced as those buildings with the most highly friable asbestos are identified and remedial steps are taken to reduce their emissions by chemical sealants or by complete removal of those coatings whose state is judged to be beyond repair.

•••••Custodial activity due to its regular frequency is an important source of high dust emissions and has been identified as a source of high asbestos concentrations in buildings with sprayed asbestos ceilings. The contribution of outdoor ambient air to the settled asbestos which is reintrained during custodial activities is not clear at this time. At any rate, cleaning methods other than dry dusting and sweeping could greatly reduce reintrainment emissions.

•••••Serpentinite and other asbestos bearing rock may be the sources of local asbestos exposure. The prevalence of their use should be examined in surface applications, such as unpaved roads, playgrounds, and parking areas, where they are likely to be emitted into the ambient air or pass into surface waters. Stabilizers to control emissions from such surface applications is the subject of a current program.

•••••Fugitive emissions in the dust from the mining, milling and processing of other minerals in which asbestos may occur as an impurity should be monitored and examined to determine the possible extent of asbestos exposure from such sources.

•••••Municipal incineration of commercial and consumer products containing asbestos, such as floor tiles, plastics, and roofing material, may be a significant source of asbestos in the urban air. This should also be examined to determine its importance.

7.2 Administrative Action

Administrative action can be a highly effective method for reducing exposure to asbestos fibers in many situations. It is particularly attractive due to its low cost and speed of implementation. Administrative action can be applied in two areas, the occupational area and the consumer application of asbestos products.

•••••Among the most effective administrative measures are those which alert the individual of his hazard and offer a relatively simple remedy.

Warnings regarding a potential health hazard, when coupled with simple instructions to reduce the hazard (such as "wet before cutting", "mix in a closed bag") have been found helpful in many situations. Difficult or inconvenient remedies are apt to get a poor response from the public.

Similar work rules in the secondary asbestos product industry can be used. Clear, concise instructions for both the rationale and the importance of the rules is critical for acceptance. Industries such as the brake relining industry could easily be targeted for rules to encourage stringent house-keeping, isolation of drilling and polishing operations, personal sanitation, and medical standards. Some of the rules, particularly those affecting only employees, are perhaps more in the purview of OSHA, however the rules may insure the proper disposal of asbestos waste and reduce the secondary emissions caused by inadequate containment of dust and scraps.

•••••Since a number of companies are doing so anyway, it might not be inappropriate to suggest to asbestos industries to limit future hirings of asbestos workers to non-smokers only.

•••••Ways to discourage commercial and consumer use of friable forms of asbestos might be examined.

•••••Ways to encourage development of brake formulations to give low asbestos emissions could also be considered.

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