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ASBESTOS: a review of selected literature through 1973 relating to environmental exposure and health effects

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OFFICE OF TOXIC SUBSTANCES
ENVIRONMENTAL PROTECTION AGENCY
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ASBESTOS: A REVIEW OF SELECTED LITERATURE THROUGH 1973 RELATING TO ENVIRONMENTAL EXPOSURE AND HEALTH EFFECTS

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NOTICE

This report has been reviewed by the Office of Toxic Substances, EPA, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

PREFACE

Asbestos in air has been demonstrated to be a significant threat to health in occupational and certain specific environmental exposures. It has also been suggested to pose a threat to health from more widespread environmental exposure due to presence in air, water, soil, drugs, foods and beverages.

This report is an attempt to summarize and consolidate much of the available information on asbestos throught 1973, preliminary to an environmental hazard assessment and to provide evaluative comments where appropriate. Several more recent documents have also been examined. This report was prepared in the early stages of the development of the Office of Toxic Substances' activities on asbestos. It should be considered primarily a background document which is already somewhat out of date due to the rapid advance of knowledge relating to asbestos over the past two years. This report was written by Frank D. Kover, Office of Toxic Substances.

The writer wishes to acknowledge the guidance provided by Dr. Farley Fisher, Chief of the Early Warning Branch of the Office of Toxic Substances. Appreciation is expressed for the information, comments, suggestions, and technical reviews provided by: Benigna Carroll, National Institute of Occupational Safety and Health; Peter Bertozzi, Environmental Protection Agency - Water Supply Research Laboratory; Robert Carton, EPA - Office of Toxic Substances; Dr. I. E. Wallen, EPA - Office of Toxic Substances; Philip M. Cook, EPA - National Water Quality Laboratory, Duluth; John Cofrancesco, EPA - Water Supply Division; Lawrence Plumlee, EPA - Medical Science Advisor; William Upholt, EPA - Senior Science Advisor, Office of Water and Hazardous Materials Control; William Switky, formerly with EPA - Office of Toxic Substances; George W. Walsh, EPA - Emission Standards and Engineering Division; Lawrence C. Gray, EPA - Office of Air, Land and Water Use; and A.C. Trakowski, EPA - Office of Monitoring and Technical Support.

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INTRODUCTION AND SUMMARY

Sources, Uses, Exposure

Asbestos is everywhere -- including homes, farms, factories, automobiles, ships, trains, and airplanes. It has been estimated to have over 3,000 uses, many of which cannot be satisfied by a substitute. Well over 90% of all asbestos used is the mineral form called chrysotile. Other varieties which include amosite, anthophyllite, crocidolite and tremolite are used in specialized applications. The majority of end-product uses have been said to effectively immobilize the fibers (estimates range from 85 - 92 percent), thus reducing potential exposures to the general population. Specific individual exposure to asbestos is possible from products which contain asbestos as a contaminant, such as talc, food, beverages, and drug preparations. The mining, milling, fabrication, and manufacture of asbestos create many point sources for emissions and for potential water contamination. Many non-point sources of environmental contamination are associated with ultimate use and disposal of the variety of asbestos containing products.

Human Data

Asbestosis, a fibrotic lung disease caused by inhalation of asbestos particles, is largely confined to occupational exposure although there is considerable individual variation in response. Clinical manifestations can result from short, heavy exposures but are usually associated with low to moderate exposures for 20 years or more. All commercially used forms have been shown to produce asbestosis. Indications are that good control practices in industry can significantly reduce the risk and incidence of asbestosis.

An excess risk of lung cancer is associated with workers in the asbestos industry. However, the available evidence suggests that the risk of lung carcinoma and mesothelioma is small among workers in chrysotile mines and mills. Some evidence exists to show that amosite similarly involves a low risk for mine and mill

workers. Crocidolite mining and mill workers are considered to run a higher risk of contracting mesothelioma than amosite or chrysotile workers. In some instances, communities in the neighborhood of mines or other asbestos air pollution sources, have suffered appreciable exposure to asbestos dust, and mesotheliomas have been observed in these populations as well as those exposed to dusty clothing at home (IARC, 1973).

These studies which indicate differences in pathogenicity among types of asbestos should not be considered conclusive since they often lack quantitative data on cumulative exposures, fiber characteristics, the presence of other substances during exposure, and other cofactors which may have been or are operative. The complex exposure factors involved make it unwise to assign a relative risk by type-of-asbestos to either asbestosis or neoplasia.

Industrial exposures can involve mixed types of asbestos. The excess risk of lung cancer in industrial workers has usually resulted from their past record of heavy exposures. Mesothelioma has been observed more frequently in industrial asbestos workers working with crocidolite than with amosite or chrysotile. Onset of symptoms is usually 20 years or more after the first exposure and can occur in the absence of other asbestos-related diseases.

Differences in risk among different segments of the asbestos industry cannot be attributed to a single factor. The type of fiber, past exposure levels, the form of dust produced by the process, and the length of exposure, as well as other factors, may be relevant. There is some indication that the risk of lung carcinoma is related to asbestosis (IARC, 1973).

Cigarette smoking has been shown to enhance the risk of lung carcinoma in asbestos workers to a much greater degree than in the rest of the population (ESL, 1973).

Some direct and some indirect evidence shows that persons other than those working directly with asbestos have been exposed

to the material. Asbestos-like fibers have been observed in the lungs of persons not occupationally exposed. Populations in a few geographic areas have been found with pleural plaques or pleural calcification, considered by some as an indication of reaction to asbestos exposure. Other investigators do not regard pleural calcification as a reliable indication of exposure. Asbestos fibers have been shown to be present in ambient air, and indications are that most human lungs contain thousands or millions of fibers. In the majority of cases, in persons not occupationally exposed, the numbers of fibers are relatively small. Chrysotile fibers have been positively identified in human lung tissue. However, other possible sources of airborne fibers such as man-made fibers and plant fibers derived from the combustion of paper, wood, and coal must be considered. Talc is another source of asbestos fibers often used generously in contact with human skin as a dusting powder. Talc has been shown to contain significant amounts of tremolite as well as chrysotile and anthophyllite.

The discovery of "ferruginous bodies" similar to those found in the lungs of asbestos workers, in a large portion of randomly selected lung specimens from the general population has been taken by some investigators as presumptive evidence that persons with no occupational contact may have inhaled and retained asbestos. Some inferences have been made by extrapolation of a few occupational and para-occupational studies concerning the presence of these bodies and the risk of mesothelioma. However, some occupational populations for which exposure to asbestos greatly exceeds that of the general public have shown <u>no</u> increased risk of mesothelioma. This variation in the relationship between asbestos and mesothelioma in the occupational setting makes extrapolation to the environmental situation difficult.

The excess risk of gastrointestinal cancers and peritoneal mesothelioma observed among asbestos workers has given rise to suggestions that pulmonary clearance and subsequent swallowing of

a large percentage of the inhaled asbestos fibers is the probable mechanism involved.

There is presently little evidence to indicate that past exposure of the general population to asbestos dust in the ambient air or in beverages, drinking water, food, or pharmaceutical preparations has increased the risk of cancer. However, the asbestos contaminated talc which is used in rice processing has been suspected as a factor in the high rate of gastrointestinal cancers observed in Japanese men. Also, neighborhood exposures have been shown to be associated with an increased occurrence of mesotheliomas.

It has been definitely established that asbestos plays a carcinogenic role (active and/or passive), and it must be assumed that the initiation of malignancy after single, low level exposures is possible, although improbable; and that with frequent or chronic exposure and at low levels, the probability of malignancy is increased. It must also be recognized that malignant transformations associated with asbestos do not lead immediately to cancer but may remain latent for a number of years (NIOSH, 1972).

The significance of the long period of latency between exposure and the onset of asbestos cancer must not be underestimated when interpreting current levels of risk.

Although epidemiological studies have presented the most convincing evidence that asbestos is a hazard to working populations, demonstrating an increased risk to the general population is much more difficult. Even if <u>all</u> factors were known which could influence its evaluation, and a prospective study were designed, any conclusions would be subject to doubt because many variables could not be satisfactorily controlled. Extreme difficulties would be encountered in selecting the proper cohort and assuming the rest of the population to be unexposed, or at least to be exposed to a low, uniform level. The increasing use of

asbestos, the differences in its composition, possible exposure in various localities, and exposure to other carcinogens in the environment would further obfuscate the issue. The possibility of an unequivocal answer from epidemiological data alone would be very remote. (Tabershaw, 1968)

Indications From Animal Data

Injections of asbestos into the pleural cavity of laboratory animals have demonstrated that all commercial forms of asbestos can produce mesotheliomas. The role that oils, waxes, trace metals or other coexisting substances play in the carcinogenic response to asbestos remains unclear. Inhalation experiments on rats and guinea pigs have demonstrated fibrotic lesions in lung pleura similar to those found in man. Mesotheliomas and lung carcinomas have also been produced in a small proportion of the experimental rats after inhalational exposure. There are indications from several animal studies that both fiber size and diameter are significant factors in the toxic effects of asbestos. The view receiving current attention is that fibers < 5 microns in length do not produce a carcinogenic effect. Several experimental studies seem to bear this out.

Environmental Effects (other than occupational)

There is little evidence to indicate significant environmental effects from asbestos exposure other than those to man in para-occupational and neighborhood situations closely associated with commercial operations and heavy exposures. Available data indicate that exposure in the general environment is principally to the small fibers (<5μ). Currently (1973) some investigators feel that the hazard associated with exposure to fibers less than five microns in length is small.

Control Technology

The available control technologies appear capable of reducing asbestos emissions in many situations. However, there remain some aspects of the overall asbestos mining and processing operations

which require new or continued development. These would include, for example, controls for air emissions especially in milling, the reduction of potential for water contamination associated with tailing dumps and prevention of dispersal from waste disposal related to processing. Controlling the asbestos contamination of water has received little or no attention until recently.

Analytical Methods and Environmental Monitoring

Much work is being done in this area, but even presently acceptable techniques constantly require refinement in order to improve precision and accuracy. Many methods are highly sophisticated and tedious which limits their usefulness for routine analysis. The development of analytical approaches and refinements to describe asbestos exposures more completely should be encouraged. Past analyses paralleled to present electron microscopic or other analyses, could possibly lead to a useful, statistical correlation or index that would allow comparison with data acquired in the past. Present procedures used for water sample analysis have not been standardized.

Because the correlation of biological effects of asbestos with its physicochemical characteristics has not been determined with certainty, it appears that a prudent analytical approach would involve providing chemical and physical characterizations of asbestos as complete as present technology permits.

Asbestos emission and effluent data are only beginning to be collected with appropriate regard for fiber characterization and quantitation. The need for such data remains critical to a realistic assessment of environmental exposures and associated health and environmental effects.

Research Recommendations

Given the limited information available to assess the environmental hazard of asbestos, and the economic importance of asbestos, a recommendation totally prohibiting its use and production is not justified.

In light of the carcinogenic or co-carcinogenic character of asbestos, prudence dictates that unnecessary exposure to the material be avoided. From this review it is apparent that the strict control of asbestos in industrial and other occupational settings and adjacent neighborhood environments is necessary. We must not be premature in extrapolating the effects of heavy exposures to minor and low-level exposures encountered in the general environment. However, attention should be focused on products with high potential for release of asbestos fibers.

Analytical methodology relates directly to capabilities needed for monitoring of environmental samples including air, water, and biota for asbestos. Many have pointed out the need for research to improve the analytical methodology for asbestos. A recent review of the Duluth, Minnesota, asbestos problem by the Office of Technical Analysis in the Office of Enforcement and General Counsel, EPA (January 1974), lists those methods used by EPA contractors in analyzing samples collected in the course of investigating the problem. The variety of techniques used illustrates the need for research and standardization of analytical methods for asbestos. Standardization will allow better comparison of environmental data.

Much of the deficiency in asbestos health effects research can be attributed to the long latent period before effects are observed, thus leading to an untimely recognition of the problem. Various international meetings of experts in this area have resulted in guidelines and recommendations for research (see Appendix D).

The almost universal occurrence of asbestos fibers in drinking water has led to a recognition of the need for research on the effects of asbestos which has been orally ingested. In November, 1973, a Conference on Biological Effects of Ingested Asbestos was held. The proceedings are published in Environmental Health Perspectives, Volume 9, December, 1974. The closing paper discusses

research needs attuned to present concerns about asbestos in the environment (see appendix D). In 1965, the Geographical Pathology Committee of the International Union Against Cancer published its recommendation in regard to asbestos research problems in the areas of epidemiological studies, pathology and experimental pathology, and others relating to physics and chemistry (related to air exposure). The committee met again in October, 1972, and published further recommendations in 1973. Additional areas of recommended research included morbid anatomy and histology, clinical research, and experimental studies (see appendix D for recommendations).

The Occupational Health Program of the USPHS in 1966 outlined a recommended research program on the health effects of asbestos (also contained in appendix D).

These documents concerning recommendations for future research reflect the consensus of a large number of scientists engaged in research or studies associated with asbestos problems as well as the opinions of those responsible for protection of the public health in regulatory capacities or affiliations. It is quite clear that past research has not answered many important health effects and environmental effects questions regarding asbestos. Specifically, the etiological relationships between asbestos bodies and lung tumors are presently poorly understood; the presence of asbestos bodies in the lungs of the general population further complicates the issue. Studies examining both inhalation and ingestion routes are needed which more clearly define the importance of the nature, severity, and length of asbestos exposure in the development of cancer. Experimental research with animals to determine the mechanism of action is of fundamental importance. The role that the fibrous character, type, size, and forms of asbestos play in the induction of cancer, as well as the importance of co-factors, will, when definitive answers become available, afford a better understanding of the extent of the environmental

hazard posed by asbestos. Definitive data from monitoring efforts which describe environmental exposure to asbestos will also enhance understanding of the problem. However, in all likelihood the answers to these critical questions will not be known for several years.

I. GENERAL INFORMATION

Structure and Properties (Berger, 1963; Kirk-Othmer, 1967; Gaze, 1965; Hendry, 1965)

The word "asbestos" is a broad term referring to a number of fibrous, mineral silicates that vary widely in their chemical composition. Commercially important asbestos fibers consist of two main groups. The largest of these by consumption (about 95%) is chrysotile, with the amphiboles second. Both are fibrous silicates, but they differ in geological origin, chemical composition, crystalline structure, fiber size, and in many other characteristics. It must be kept in mind that the properties shown by the asbestos varieties themselves (chemical structure, thermal and acid behavior, cleavability, etc.) represent functions of the geologic, geochemical, petrographic, and mineralogic conditions that prevailed during their formation period; whereas other characteristics, such as mechanical properties, are governed by the fine fibrous structure.

The varieties of asbestos are subdivided into two main groups. Their approximate formulae are presented below:

1.	Serpentines	- chrysotile	-	$Mg_3Si_2O_5(OH)_4$
2.	Amphiboles	- amosite	-	$(Mg,Fe)_7Si_8O_{22}(OH)_2$
		crocidolite	-	$Na_2(Mg,Fe)_5Si_8O_{22}(OH)_2$
		anthophyllite	-	$(Mg,Fe)_7Si_8O_{22}(OH)_2$
		tremolite	-	$Ca_2Mg_5Si_8O_{22}(OH)_2$
		actinolite	-	$Ca(Mg,Fe)_5Si_8O_{22}(OH)_2$

These compositions are theoretical and correspond only approximately to the figures actually obtained by chemical analysis.

Similar to all natural silicates, chrysotile and the amphiboles have silicon-oxygen tetrahedra as their basic structural unit; the structural difference between the two classes is related to the arrangement of the tetrahedral units. In chrysotiles, the tetrahedral units form Si_2O_5 double layers, resulting in a laminar structure. The amphiboles differ in that they combine to produce Si_4O_{11} double chains, producing a banded structure. The chrysotile layers are held together by layers of brucite [$Mg(OH)_2$], and the chains of amphiboles are held together by cation linkages. The asbestoses can be considered a ternary system consisting of SiO_2, metal oxides, and water (Berger, 1963; Rubin and Maggiore, 1974).

Chrysotile fibers are not solid but hollow tubes formed from layers that appear rolled-up (see figure 1). The silica layer has a somewhat tighter spacing than is required for a good fit with the brucite layer; as a result, the layers are contorted into scrolls or tubes with the magnesium hydroxide layer on the outside. The finest fibers (fibrils) range from 150 to 400 Angstroms in diameter (Gaze, 1965). Fibrils can be considered to be the fundamental form of chrysotile.

It is not generally possible to differentiate with certainty between the various amphibole fibers by electron microscopy. The chains or strips characteristic of amphiboles are loosely bonded to each other along the edges and faces, so fibrous cleavages readily occur (see figure 2). The smallest fibers of amphibole asbestos (usually between 800 and 1000 Angstroms in diameter) are more solid and coarser than are chrysotile fibrils (Gaze, 1965).

It is difficult to classify chrysotile within a particular crystal system due to its capillary structure. The tubular "fibrils" of the natural product are not precise capillaries. All gradations are found from partial to full capillaries. The crystalline types of amphibole fibers, on the other hand, can be

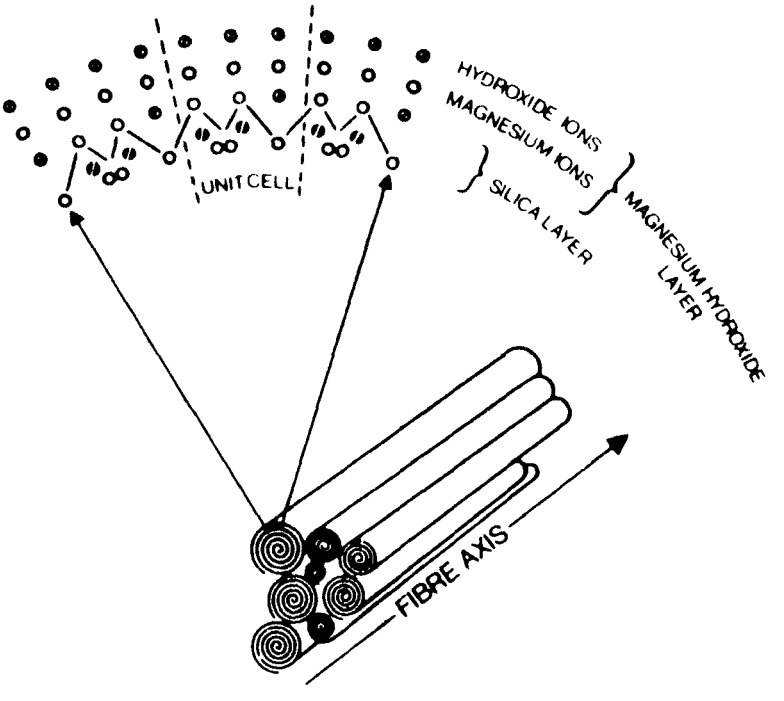

Fig. 1 Schematic diagram of the structure of a chrysotile fibre formed of several scrolls of individual crystallites. Each scroll is formed from a closely connected double layer having magnesium hydroxide units on its external face and silica units on its inner face. The details of a small section of the scroll show the structure of the double layer and of the unit cell based on $Mg_3(Si_2O_5)(OH)_4$.

Figure by permission of Dr. A.A. Hodgson.

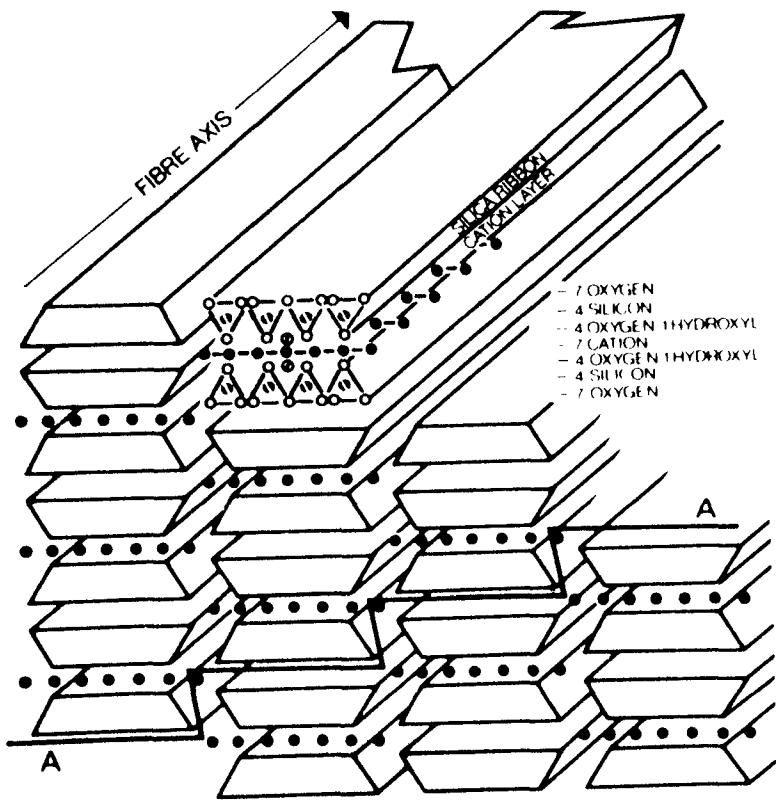

Fig. 2 Schematic diagram of the crystal structure of an amphibole fibre, indicating the unit cell based on $X_7Si_8O_{22}(OH)_2$. The line A-A represent the edge of the preferred cleavage plane along which the fibres will split to form even smaller fibres.

Figure by permission of Dr. A.A. Hodgson

classified since they are solid; amosite crocidolite and tremolite belong to the monoclinic system,while anthophyllite belongs to the orthorhombic system (Berger, 1963).

Commercial asbestos fibers are of various thicknesses and consist of bundles of a great many fibers (up to thousands) lying parallel to one another. The differences in the fineness of commercial asbestos fibers depend on the degree of disintegration (i.e. from processing in the mills). The average diameter for commercial particles of chrysotile is 1 micron, of amphiboles, about 3 microns. Comparison with other known fibers shows asbestos fibers to be the finest known.

Inorganic Fibrous Materials (Berger, 1963)

	Diameter of Fiber (μ)
Chrysotile	0.02 to 0.04
	(commercial 0.75 to 1.5)
Amphibole asbestoses	0.1 to 0.2
	(commercial 1.5 to 4.0)
Glass Silk, glass fiber	1 to 5
Rock fibers	4 to 7
Slag fibers	3 to 5

Organic Fibrous Materials

Bast fibers (flax, hemp, jute, ramie, etc.)	12 to 80
Cotton	10
Wool	20 to 28
Spider web	7
Human hair	40
Copper--artificial silk rayon, nylon	7 to 7.5

Chemical Composition

The percentage composition of asbestos is presented in Table 1. However, it gives only a general guide to typical ranges of composition. Differences in values due to the various localities from which specimens may come reflect the variations in impurities, some of which are part of the crystal structure and others of which are extraneous minerals.

The various "contaminants" which can occur as part of the crystal structure of asbestos may be of great importance in regard to the processing and use of asbestos products, as well as to biological activity. An important undesirable contaminant is magnetite, especially in regard to its uses for electrical purposes. The iron oxides present, FeO and Fe_2O_3, do not exert any electrical disturbing actions. However, magnetite (Fe_3O_4), which can be enveloped in granular form by the fibers, is both electrically conductive and magnetic. Although most of the magnetite is removed from the fibers during the milling operation (with fibers from many sources), there can still be a considerable quantity varying from 2 to 5 percent in the final products. As a result, low-magnetite chrysotiles are acquiring greater importance for electrical applications.

Physical Properties

Some properties of various asbestos minerals are summarized in Tables 2 and 3.

Table 1. Chemical Composition of Common Fibrous Silicate Minerals (Rubin and Maggiore, 1974)

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

Table 2 (Gaze, 1965)
Typical Physical Properties of Chrysotile, Crocidolite and Amosite

		Chrysotile white asbestos	Crocidolite blue asbestos	Amosite
Approximate dimeter of smallest fibers	micron	0.01	0.08	0.1
Specific gravity		2.55	3.37	3.45
Average tensile strength	lb./inch^2	350,000	500,000	175.000
Modulus of elasticity	lb./inch^2	23.5×10^6	27.0×10^6	23.5×10^6

(EPA, 1973)

Table 3. PHYSICAL, CHEMICAL, AND MINERALOGICAL PROPERTIES OF VARIETIES OF ASBESTOS

Property	Chrysotile	Crocidolite	Amosite	Anthophyllite	Tremolite	Actinolite
Chemical formula	$Mg_3Si_2O_5(OH)_4$	$Na_2Fe_5Si_8O_{22}(OH)_2$	$(FeMg)_7Si_8O_{22}(OH)_2$	$(FeMg)_7Si_8O_{22}(OH)_2$	$Ca_2Mg_5Si_8O_{22}(OH)_2$	$(CaMgFe)_5Si_8O_{22}(OH)_2$
Essential composition	Hydrous silicate of magnesia	Silicate of sodium and iron with some water	Silicate of iron and magnesium higher iron than anthophyllite	Magnesium silicate with iron	Calcium and magnesium silicate with some water	Calcium-magnesium-iron silicate; water up to 5%
Percentage chemical composition						
SiO_2	37. to 44.	49. to 53.	49. to 53.	56. to 58.	51. to 62.	--
MgO	39. to 44.	0. to 3.	1. to 7.	28. to 34.	0. to 30.	--
FeO	0.0 to 6.0	13. to 20.	34. to 44	3. to 12.	1.5 to 5.0	--
Fe_2O_3	0.1 to 5.0	17. to 20.	--	--	--	--
Al_2O_3	0.2 to 1.5	--	2. to 9.	0.5 to 1.5	1.0 to 4.0	--
H_2O	12.0 to 15.0	2.5 to 4.5	2. to 5.	1.0 to 6.0	0. to 5.0	--
CaO	trace to 5.0	--	--	--	0 to 18	--
Na_2O	--	4.0 to 8.5	--	--	0. to 9	--
CaO and Na_2O	--	--	0.5 to 2.5	--	--	--
pH	9.2 to 9.8	--	--	Neutral	--	--
Resistance to acids	Poor	Good	--	--	Good	Good
Veining	Cross and slip fibers	Cross fiber	Cross fiber	Slip, mass fiber unoriented and interlacing	Slip or mass fiber	Slip or mass fiber
Color	Green, gray, amber to white	Blue	Gray, yellow to dark brown	Yellowish brown, grayish white	Gray-white, greenish, yellowish, bluish	Greenish
Texture	Soft to harsh, also silky	Soft to harsh	Coarse but somewhat pliable	Harsh	Generally harsh, sometimes soft	Harsh
Luster	Silky	Silky to dull	Vitreous, somewhat pearly	Vitreous to pearly	Silky	Silky
Hardness[a]	2.5 to 4.0	4	5.5 to 6.0	5.5 to 6.0	5.5	6±
Flexibility	High	Good	Good	Poor	Poor	Poor
Spinnability	Very good	Fair	Fair	Poor	Poor	Poor
Tensile strength, lb/in²	824,000 max	876,000 max.	16,000 to 90,000	4,000 and less	1,000 to 8,000	1,000 and less
Fusion point, °F	2,770	2,180	2,550	2,675	2,400	2,540
Specific heat, Btu/lb-°F	0.266	0.201	0.193	0.210	0.212	0.217

Table 3. (continued) PHYSICAL, CHEMICAL, AND MINERALOGICAL PROPERTIES OF VARIETIES OF ASBESTOS

Property	Chrysotile	Crocidolite	Amosite	Anthophyllite	Tremolite	Actinolite
Electric charge	Positive	Negative	Negative	Negative	Negative	Negative
Filtration properties	Slow	Fast	Fast	Medium	Medium	Medium
Specific gravity	2.4 to 2.6	3.2 to 3.3	3.1 to 3.25	2.85 to 3.1	2.9 to 3.2	3.0 to 3.2
Cleavage	010 perfect	110 perfect	110 perfect	110 perfect	110 perfect	110 perfect
Optical properties	Biaxial positive, extinction parallel	Biaxial ±, extinction inclined	Biaxial positive, extinction parallel	Biaxial positive, extinction parallel	Biaxial negative, extinction inclined	Biaxial negative, extinction inclined
Refractive index	1.50 to 1.55	1.7 pleochroic	1.64±	1.61±	1.61±	1.63± weakly pleochroic
Resistance to destruction by heat	Good, brittle at high temperatures	Poor, fuses	Good, brittle at high temperatures	Very good	Fair to good	—
Temperature at ignition loss, °F	1,800	1,200	1,600 to 1,800	1,500	1,800	—
Magnetite content, %	0.0 to 5.0	3.0 to 5.9	0	0	0	—
Crystal structure	Fibrous and asbestiform	Fibrous	Prismatic, lamellar to fibrous	Prismatic, lamellar to fibrous	Long and thin columnar to fibrous	Long and thin columnar to fibrous
Crystal system	Monoclinic and orthorhombic	Monoclinic	Monoclinic	Orthorhombic	Monoclinic	Monoclinic
Mineralogical structure	In veins of serpentine, etc.	Fibrous in iron stones	Lamellar, coarse to fine fibrous and asbestiform	Lamellar, fibrous asbestiform	Long, prismatic and fibrous aggregates	Reticulated long prismatic crystals and fibers
Mineral association	In altered peridotite adjacent to serpentine and limestone near contact with basic igneous rocks	Iron rich silicious argillite in quartzose schists	In crystalline schists, etc.	In crystalline schists and gneisses	In Mg limestones as alteration product of magnesian rocks, metamorphic and igneous rocks	In limestones and in crystalline schists

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

Occurrence (Hendry, 1956)

Asbestos probably occurs in nearly every country in the world. However, it is important to distinguish between occurrences and commercial deposits.

Canada is the world's largest producer of chrysotile. Approximately 93% of the world's total asbestos production can be considered to be chrysotile (See Appendix A).

The United States has significant commercial chrysotile deposits in Vermont, Arizona and California. Anthophyllite is mined in North Carolina.

Contaminants of Asbestos

Trace Metals

The presence of nickel, chromium, manganese, and iron has been determined in asbestos fibers (chrysotile, crocidolite, amosite) by atomic absorption (AA) spectrometry. Chromium and nickel have been found to be common impurities in natural and processed fibers (Dixon *et al.*, 1970; Cralley *et al.*, 1967; Roy-Chowdhury *et al.*, 1973).

Lockwood (1974) analyzed chrysotile asbestos fibers (natural chemical state) by AA and found the following metals at microgram levels in one gram samples: beryllium (6-8 μg), cadmium (3-5 μg), chromium (202-771 μg), cobalt (40-78 μg), copper (9-13 μg), manganese (325-651 μg), nickel (437-1187 μg) and thallium (40-71 μg).

Trace Organic Compounds

Some samples of asbestos have been shown to contain appreciable amounts of primary (natural) oils which may contain polycyclic hydrocarbons such as benzo(a)pyrene (Harrington and Roe, 1965). Secondary oils may be present as a result of contamination during processing and transport. Antioxidants, oils from polyolefin bags, and oils from jute bags have been found in commercial

asbestos samples. Commins and Gibbs (1969) found 4,4'-bis-(2,6-ditertiary butyl phenol) and 3,3',5,5'-tetratertiary butyl dipheno-quinone in chrysotile and crocidolite which were stored in poly-ethylene bags. The quinone is apparently an oxidation product of the phenol.

In a Japanese study of asbestos (amosite, chrysotile, crocid-olite) for the presence of polynuclear aromatic hydrocarbons using thin layer chromatography and fluorescence spectroscopy, all samples were reported to contain pyrene, fluoranthenes, chrysenes, benzo(a)pyrene, benzo(b) fluoranthene, benzo(k)fluoranthene, perylenes, anthanthrene, and benzo- perylene. Amosite from Africa also contained benzo(a)anthracene and coronene (Matsushita and Arashiya, 1972). Details on experimental variables such as the sample size and sample history (milled, natural, storage conditions) were limited in the available account of this study so that the significance of these results is difficult to evaluate.

Hilborne, et al., (1974) studied the organic content of the U.I.C.C. reference samples of asbestos and found that they consist largely of n-alkanes. "Evidence for the presence of potentially carcinogenic polycyclic hydrocarbons was inconclusive due to the fact that these compounds, if present, are found as traces in the organic extract. In addition, the complexity of the chromatograms from the oils made identification of polycyclics based solely on retention times uncertain. However, it can be calculated that if only 1% of the organic material is polycyclic aromatic hydrocar-bons, then each gram of asbestos contains a maximum of 2-3 micro-gram of polycyclic aromatic hydrocarbons."

Asbestos as a Contaminant

Asbestiform minerals are an ubiquitous impurity in many deposits of commercially valuable, non-metallic minerals such as talc and mica (Speil and Leineweber, 1969).

Anthophyllite and tremolite have been found to constitute minor or major fractions of commercial talc (Schulz and Williams, 1942; Merliss, 1971; Blejer and Arlon, 1973; Kleinfeld et al., 1973).

Chrysotile has also been found in talc, although amphiboles are much more common. Of 22 cosmetic talcum products analyzed, fiber contents ranged from 8 to 30 percent and included anthophyllite, tremolite, and chrysotile (Cralley et al., 1968).

Rohl and Langer (1974) have discussed the geological coexistence of talc and many hydrated magnesium silicate mineral species, many of which are asbestos. Table 4 summarizes the chemical, physical property information on talc and associated asbestos minerals.

Asbestos minerals are also associated with metallic mineral deposits such as taconite (iron ore).

Table 4. Talc and its Associated Asbestos Minerals. (Rohl and Langer, 1974)

	Talc	Tremolite	Anthophyllite	Chrysotile
Empirical formula	$Mg_6Si_8O_{20}(OH)_4$	$Ca_2Mg_5Si_8O_{22}(OH)_2$	$(Mg,Fe)Si_8O_{22}(OH)_2$	$Mg_6Si_4O_{10}(OH)_8$
Common chemical substitutions	Fe for Mg Al for Si	Fe for Mg Mn for Mg Na for Ca	Fe for Mg Al for Si	Fe for Mg Ni for Mg
Structure and habit	Sheet silicate, plates common; fibers common; forms massive foliated aggregates; intergrowths on submicron scale; many talc fibers observed in platy talcs on submicron scale	Chain silicate; fibers common; often as massive aggregates; forms intergrowths in some talcs on submicron scale; fibers tend to short and stubby; size ranges from visible by eye to sublight microscopic	Chain silicate; fibers common; columnar or fibrous aggregates; forms intergrowths in some talcs; fibers tend to be long and thin; size ranges from visible by eye to sublight microscopic.	Sheet silicate; curved sheets form fibers; often as compacted fibers in pseudo-plates (foliated masses), especially in serpentine rock; forms interplanar (interlaminar) contaminant in talc plates; fibers in talc tend to be sublight microscopic in size
Crystal system	Monoclinic; triclinic	Monoclinic	Orthorhombic	Monoclinic orthorhombic
Cleavage	Parallel to plate; (001) perfect; prism terminations	Parallel and across fiber axis; (110) perfect	Parallel and across fiber axis; (110) perfect	Parallel to fiber axis; (001) for clino variety
Optical properties				
n_x	1.539–1.550	1.581–1.615	1.596–1.654	1.532–1.549
n_z	1.589–1.600 Indices higher for fibers	1.601–1.641	1.625–1.666	1.545–1.556 Indices lower for low-iron chrysotiles
Mass absorption coefficients (CuKα = 1.542)[a]	~1032	~1335	~1072	~717
Occurrence	Generally present as the major mineral in commercial talc	Common contaminant in many talcs (in carbonate rocks)	Often a contaminant in talcs (in carbonate and serpentine rocks)	Occasional contaminant in talcs (especially in serpentine rocks)
Other minerals commonly in talc:	Carbonates (e.g., calcite); micas (e.g., phlogopite), clays (e.g., montmorillonite); chlorite; feldspars (e.g., andesine); quartz, serpentine (e.g., antigorite); spinels (e.g., magnetite)			

[a] All coefficients calculated on the basis of the empirical formula for each.

II. CHEMISTRY

Reactions Involved in Uses

Treating chrysotile with soap forms a surface layer of magnesium stearate (or oleate, etc.) to make the fiber water repellent (U.S. Patent, 1937).

Other Reactions

A 0.5% suspension of chrysotile in water that is free of carbon dioxide acts somewhat like magnesium hydroxide, giving a pH of 10.33 (Pundsack, 1955). Acids readily attack chrysotile and dissolve the magnesium, leaving mostly a silica structure (Badollet, 1948). Magnesium leaches from chrysotile fibers in aqueous solutions with a pH reading under 10.8 (Nagy and Bates, 1952).

Chrysotile is the most susceptible of the asbestoses to acid attack. It is almost completely destroyed when placed in 1N HCl for one hour at 95°C. Strong acids decompose chrysotile rapidly removing all the MgO and 60% of the total weight. The remaining residue consists of amorphous silica which retains a very fragile, fibrous morphology (Speil and Leineweber, 1969).

In contrast, amphibole fibers are more resistant to acids. Crocidolite, for example, in 4N hydrochloric acid at 100°C after eight hours decomposes only by about nine percent (Speil and Leineweber, 1969).

Chrysotile is decomposed by water. Soxhlet extraction (three to four hours) results in a high concentration of magnesium in the extract. The precipitation of amorphous magnesium silicate accompanies the loss of magnesium. Magnesium and silica are both removed in amounts proportional to their representation in chrysotile after an initially rapid reaction. Whether removal of silica is by solution or by formation of colloidal silica remains to be determined. It is clear that chrysotile is slowly "soluble" in water under conditions of continuous extraction (Speil and Leineweber, 1969).

With crocidolite, four percent of the silica and six percent of the sodium are removed by Soxhlet extraction with water (Speil and Leineweber, 1969).

Decomposition

In air at 600°C chrysotile partially degrades to olivine (forsterite). At 650°C - 700°C chrysotile completely decomposes to forsterite. At 750°C the formation of enstatite begins (Hargreaves and Taylor, 1946). The probable reaction is: $Mg_3Si_2(OH)_4 \xrightarrow{heat} Mg_3SiO_4 + SiO_4 + 4H_2O$, with SiO_2 present as amorphous silica (Deere *et al.*, 1966).

At the temperatures reached on brake linings (about 900°F), thermal metamorphosis of asbestos to different minerals, forsterite and enstatite, occurs. Less than one percent free fiber has been found in the decomposition product, as compared to about 50% in the lining (Lynch, 1968; Hickish and Knight, 1970).

III. PRODUCTION, IMPORTS, EXPORTS, CONSUMPTION

The total apparent consumption of asbestos in the United States for 1974 is reported to be 817,100 tons (CEH, 1975). Total apparent consumption is arrived at by summing quantities produced, adding imports, and subtracting exports. The average apparent consumption for the last ten years is 791,100 tons. A more detailed breakdown including market values is shown in the tables presented in Appendix A.

Asbestos mines, processing plants, and sites are listed by state in Appendix B.

Asbestos is mined domestically in four states, and approximately 90% of the asbestos consumed in the United States is imported.

Production Methods and Processes

Mines, U.S. (May and Lewis, 1970) -- In Vermont, the fiber-bearing rock is removed by open-pit methods. Similar methods are employed in the Copperopolis district of California; but in the Coalinga district, the highly sheared ore is simply "plowed" and allowed to air dry; the coarse fraction is then screened out from the mill feed.

In Arizona, a heading is driven into barren limestone beneath the fiber zone, then blasted down and hand-cobbed.

In North Carolina, open pit methods are used.

Milling - Air Separation (Paddock *et al.*, 1972) -- All but one of the U.S. plants use a mechanical means to free the fibers and air aspiration for removal from the ore. The incoming coarse ore is typically crushed by a "jaw crusher" to a given size that depends upon the particular mill. Oversized rock is separated by rotating cylindrical trammel screens and crushed in a secondary crusher, usually a cone type. The ore streams in most plants are then conveyed to a dryer (rotary kiln in larger plants) where moisture

in the ore (up to 30% by weight) is removed. The dried ore is then stored. Large amounts are often held to allow for variations in fiber demand and mine production over short periods of time.

The dried ore is conveyed to an additional crushing step and then through a series of milling, shaking, and aspirating steps. Milling is carried out by hammer mills or crushers which separate the fibers from the rock and each other. Shaking is carried out on progressively finer screens so that the smaller rocks and fiber bundles fall through and larger rocks are retained for conveying to tailing dumps or for further crushing. The freed fibers are removed by air-flow through powerful suction hoods.

The separated fibers are caught in dry cyclones and conveyed to grading screens. After grading (fiber length segregation), the fibers are stored in bins by grade. Final operations consist of removing the fibers from the storage bins, blending in a mixer to produce the desired final grade, and bagging for shipment.

The dry cyclone control device depends upon centrifugal force. The asbestos-laden air enters tangentially into a vertical cylinder which has an inverted cone attached to its base. The air or gas spirals downward toward the apex of the cone. Centrifugal force moves the particles to the wall, and they fall into the cone and through to a collecting hopper. The clean air escapes through a centrally set tube which extends into the cylinder. Large volumes of air, 30 to 25,000 cubic feet/minute, can be cleaned by this device. Loadings must be high (10g/ft) for good efficiencies. Particle size should be in the range of 5 to 200 microns. Banks of cyclones operated in parallel are often used.

Wet Method -- The details of this process are proprietary. Only one plant in the United States mills with a wet method. Its known points are that ore from the mill's source is naturally loose with little crushing required, and the product is available as loose fiber or as compressed pellets of 1/4" to 1/2" diameter.

Manufacture of Asbestos-Containing Products (Paddock et al., 1972)

Processes common to the manufacture of all asbestos containing products are receiving, handling, and storage of the (bagged) asbestos fiber (removal from the bags, fluffing of fibers, discarding of bags, etc. are also included). In the manufacture of asbestos cement products the asbestos fiber is mixed with the cement either wet or dry and comprises about 15%--20% of the total material. The resulting mixture (if mixed with ore) is generally metered in a flat layer onto an open surface where the necessary water is applied by an overhead spray. The resulting layer is then wound onto mandrels (for pipe) in a spiral mat until the requisite thickness is achieved; or it is layed flat into wall board, shingle, and other forms. A similar winding or layering process may be used for wet-mixed products, or the mixture may be cast.

Finishing processes of the dried products may include grinding, drilling, sawing, and cutting.

Asbestos Vinyl and Asphalt Floor Tile (Paddock et al., 1972) -- Asbestos, as used in these products, comprises 10 to 30% of the total product weight. It is used because it improves strength and stability without reducing flexibility or compressibility. The fiber is added to hot vinyl or asphalt. Finishing processes involve cutting the tiles to size and shredding wastes and trimmings for reuse. If the asbestos is in polyolefin bags, they can be shredded and used as part of the material input.

Asbestos Friction Products (Paddock et al., 1972) -- Friction products and gaskets using asbestos contain from 30% to 80% asbestos in an organic binder. These products are made either by mixing loose fiber with the binder or by impregnating matted or woven textile asbestos with the binder. The latter is probably more suitable for gaskets. Subsequent processes include molding and curing. Finishing processes include shaping, cutting, and sawing cured material.

Asbestos Paper Products (Paddock et al., 1972) -- Asbestos papers are made by the same techniques as are standard wood-pulp papers, but the fiber is 80% to 90% asbestos; usually china clay and starch or sodium silicate are present as binders. (The slitting process may be an emission source.)

Asbestos Textile Products (Paddock et al., 1972) -- Chrysotile can be incorporated into the full range of textile products (other asbestos types cannot be woven). Long fibers are necessary for spinning. To protect fiber length, the fiber is often obtained in "crude" form as unopened, hand-cobbed, rock-free, fiber blocks or bundles.

If the fibers are received in the crude form, they are opened by knife-edge into small, fiber-like bundles. These are then milled into extremely fine fibers for flexibility. The resultant fibers are both more delicate and breakable and they are also more floatable.

When the fibers have been adequately opened and fluffed, they may be blended with up to 20% of a cellulosic fiber such as cotton, the specific material depending upon the application of the final product. Subsequent processes such as carding, lapping, roving, spinning, weaving, and braiding are all performed on equipment essentially the same as standard textile machinery. A recent development in asbestos textile technology uses a thin coating of a polymer on the asbestos yarn which increases efficiency of the process and reduces fiber emissions.

IV. USES

Asbestos has been referred to as "the mineral of a thousand uses." This expression is entirely appropriate since asbestos is a major constituent in a very wide variety of products. To a large extent the different characteristics among the types of fibers dictate their uses and applications (Hendry, 1965).

Major use categories based on amount of asbestos used include:

(1) asbestos cement products

(2) floor tile

(3) asbestos paper

(4) friction materials and gaskets

(5) paints, roof coatings, caulks, etc.

(6) asbestos textiles

(7) plastics

Significant minor uses include:

(1) sprayed insulation for fire proofing

(2) molded thermal insulation

(3) filter media

Although most of the asbestos used is chrysotile, it is meaningful to look at the major uses for each type of asbestos.

(1) Tremolite and actinolite are utilized in the chemical industry as filter mediums and as inexpensive fillers in manufactured products. Tremolite is processed and repurified (by acid treatment) for special uses in the filtration field.

(2) Anthophyllite, because of its low strength fibers, finds limited usage in products which need reinforcement, such as asbestos cement, floor tile, etc. However, it is finding greater usage as filler material or as a partial replacement

for higher strength chrysotile fibers. Anthophyllite is used in the chemical industry as a filler in rubber and plastics and in various adhesives and cements.

(3) Amosite has a more unique use in the insulation field in the form of pipe and boiler coverings, bulkhead linings in ships, and 85% magnesia insulation.

(4) Crocidolite is chiefly used in the manufacture of asbestos cement products. In addition, this mineral is used in the manufacture of acid-resistant filters, packings, insulations, and certain types of lagging.

(5) Chrysotile

(a) The asbestos textile industry consumes long fibers for the manufacture of safety clothing, curtains, lagging cloth, woven brake linings, clutch facings, and many other articles. These products serve both the electrical insulation industry and the construction industry. The chrysotile asbestos content of these products can vary from 80 to 100 percent. (b) The

(b) The asbestos cement industry is the principal consumer of chrysotile in terms of both tonnage and dollars. Most countries of the world have one or more asbestos cement operations contributing to the manufacture of pipes, flat and corrugated sheets, shingles, etc. The asbestos cement manufacturing process combines medium- long to medium-short fibers with cement, silica, and water, thoroughly mixed to produce the maximum open state of the fibers. The chrysotile fibers function as tiny reinforcing rods in the finished product. Depending on the product, the proportion by weight of asbestos to cement may vary from 15 to 90%.

(c) A wide variety of chrysotile grades is employed in the manufacture of friction materials and packings. Chrysotile is used for its heat stability. At the same time, it also serves as a reinforcing agent, a filler, an inhibitor of resin flow in the molding process, and as a dispersing agent for the metal chips and other particles formed. It is also used because it is less abrasive than other heat stable fillers in the same low price range.

Five major types of friction materials contain chrysotile. They are woven, dry mix, sheeter, profile calender, and extruded. The composition of friction materials includes binder, metal chips, friction particles, chrysotile asbestos, filler, and solvent. The asbestos content may vary from 30 to 80% of the total. On the average 40-50% chrysotile is used. Disc brake pads require less asbestos fiber than do conventional drum brake linings.

Packings and gaskets used to reduce friction between surfaces may contain 40 to 75% chrysotile. This level of asbestos content is essential for the strength, toughness, resiliency, durability, and heat resistance required in the final product.

(d) Paper products made from chrysotile include mill board, roofing felts, pipe covering, fine quality electrical papers, insulating papers, asbestos-latex flooring felt, and many others. Asbestos papers are necessary for the inorganic properties reflected in the final product, such as heat resistence, chemical inertness, and electrial and insulating properties. Asbestos paper products may contain 30 to 90% asbestos.

(e) Only very short chrysotile fibers are used in the manufacture of floor tile. The fibers serve as filler and reinforcement media. The typical floor tile formulation contains from 10 to 30% chrysotile with either vinyl resin or asphalt in combination with various other fillers.

(f) The use of short chrysotile fibers in paint, roof coatings, caulks, sealants, and joint fillers have developed to a high degree in the U.S. and Canada. Chrysotile in these uses serves the purpose of an inexpensive filler, as well as a reinforcer.

(g) Very short grades of chrysotile are used in a wide range of plastic products including cold-molded, thermoplastic, and thermosetting plastics. The chrysotile imparts toughness, increases hardness, retards the burning rate, and reduces molding costs by allowing more control of the material under pressure.

(h) Miscellaneous uses include sprayed insulation, asphalt paving, welding rod coatings, filter mediums, chlorine cell diaphragms, acetylene cylinder packings, and many others.

Discontinued Uses

Food, beverage, and drug processing filters are being replaced with cellulose membrane filters.

Spraying-asbestos insulation and fireproofing are uses that have been curtailed due to restrictions and outright banning by some states and municipalities.

Possible Alternatives to Uses

Glass fibers have frequently been substituted for asbestos fibers with some success where insulation properties are sought.

For many products and uses, a suitable substitute doesn't exist; for others, economics makes them impractical.

Possible alternatives for friction materials have been mentioned. A list of possible replacements, with significant remarks, was presented by Hatch, 1970:

Glass Fiber	- Low strength, relatively low melting point, (520°C) severe frictional instability
Steel Wool	- Low availability, high cost, low strength, damage to drums
Mineral Wool	- very low strength, brittle to the extent of limiting mixing processes.
Carbon Fibers	- very expensive.
Sintered Metals	- probably the best possibility eventually, but cost will always be relatively high.

Manufactured inorganic fibers of alumina and zirconia to replace asbestos for some uses are currently under development by Imperial Chemical Industries (trade mark - Saffil). These fibers are being evaluated by ICI in a variety of potential applications including high temperature furnace insulation; air, hot gas, potable liquid and chemical filtration; and reinforcement for friction materials such as brake linings. (Bate, 1973)

It is important that the potential hazard of proposed substitutes be evaluated before large scale production and use begins.

Appendix C contains tables which list the variety of uses and products associated with asbestos.

V. CURRENT PRACTICES

Special Handling in Use-Bags (Paddock et al., 1972) -- Several types of bags for containing asbestos currently in use are jute, Kraft paper, and polyolefin. Emissions can occur as a result of the tearing or breaking of weak bags, or leakage can occur through seams or permeation. In addition, spillover from the bagging process and fibers adhering to the bag surface can contribute to emissions.

Methods for Transport and Storage (Paddock et al., 1972) -- The milling industry has been advocating bulk transportation in sealed railroad cars with appropriate loading and unloading techniques to minimize losses and, consequently, emissions. Such handling, if properly done, could eliminate losses from bagging, unbagging, and bag disposal. Until this method of handling is generally adopted, bagging appears to be the best solution.

Disposal Method (Paddock et al., 1972) -- Tailing dumps are used for wastes from mining of asbestos and both metallic and non-metallic mining operations associated with asbestos deposits. For example, the taconite beneficiation process leads to direct discharge of asbestos waste which coexists with the taconite one.

Air-method and wet-method fibrous milling wastes are recovered and usually sold for lower grade uses. Associated ore wastes may go back to tailing dumps or to non-specific landfills or dumps. Wet-method wastes may have a reduced emission potential, but they possess greater potential for contamination of waterways.

Asbestos cement product waste from finishing processes collected by a baghouse filter may be recovered for reuse.

Asbestos vinyl and asphalt floor tile wastage is reuseable in the product.

More information is necessary on the disposal methods for wastes associated with the processing of asbestos to produce

friction, paper, and textile products. Effluent discharges associated with asbesto containing product manufacture are subject to Effluent Guidelines established by EPA (see Appendix E).

VI. ENVIRONMENTAL DISPERSION POTENTIAL

General

Asbestos fibers are easily dispersed in air as a result of mining, milling, processing, and related activities. Contamination of waterways may similarly occur from such operations and other related mining or milling processes. It has been estimated that about 85% of the asbestos currently consumed is used in applications where the fibers are "locked in" or tightly bound and are therefore not able to become airborne to a significant degree (Tabershaw, 1968).

The open-pit mining and milling of various other minerals which may contain associated asbestos-bearing rock could result in asbestos fiber emissions. An example is the taconite beneficiation process on western Lake Superior where amphibole fibers coexist with taconite ore. Similar emissions can occur when secondary blasting is done to reduce boulders to a size acceptable for mill operations or to dislodge large rock disposits in open-cast mining (EPA, 1973).

Harwood and Blaszak (1974) in a recent review for EPA characterized the asbestos emissions from open sources including asbestos mines, mills, and manufacturing waste piles. In their recommendation they suggest that the fate of sub-micron aerosol particles (like asbestos) has not been sufficiently studied and that the possibility is very real that they remain suspended for very long time periods and that they are continually increasing in concentration. They also conclude that waste dumps associated with manufacturing are a more important source of exposure since they are usually located in populated areas. On the other hand, asbestos mining operations which emit more fibers are regarded as a less serious source of airborne exposure since in the U.S. they are found in remote unpopulated areas.

All of the processes associated with asbestos mining are potential sources of air emissions while some permit dispersion to water. Local meteorological conditions can significantly influence the degree of emission. For example, rain, sleet, and snow are favorable conditions because they wet or cover exposed ore deposits in addition to scavenging the atmosphere. Conversely, strong winds that are capable of widely distributing existing emissions, in addition to entraining loosely bound fibers from exposed material, are an adverse condition. Also, the natural phenomena of earth movement, temperature cycling, wind erosion, and water erosion present opportunities for the dispersion of asbestos in air and water media from virgin surface-ore deposits (EPA, 1973).

Asbestos emission factors for all source categories based on 1968 data were developed for EPA by Davis et al., 1970. See appendix A (p. A-7).

Environmental Dispersion from Asbestos Mining Operations

Open-cast mining involves removing ore from shallow deposits by earth-moving equipment. A shallow overburden containing low concentrations of asbestos fibers must usually be removed initially. Heavy emissions can occur from drilling, blasting, and overburden and ore removal. In addition, surface ore transfer and the hand-cobbing of ore can lead to significant emissions (Paddock et al., 1972).

Open-pit mining is similar to open-cast operations except that the work goes much deeper in order to follow fiber veins. Blasting and ore removal occur primarily on the sides of the pit along terraces which spiral down toward the bottom. Sources of emission are essentially the same as for open-cast mining (Paddock et al., 1972).

Underground mining involves following the veins of ore with shafts, galleries, and drifts using blasting and earth moving. Overburden removal is not necessary. The ore veins are not

exposed to weathering, and many dusty operations take place underground. Emissions from this type of mining are lower than from surface techniques.

Open-pit mining, by the block-caving technique, significantly reduces the required blasting and eliminates the need for removing the overburden, thus reducing potential emissions. The volume of rock to be mined is undercut, leaving solid support pillars to hold up the main block. As the block caves in down the "chimney", ore is removed from below; mill and mine tailings are replaced on top to maintain the downward pressure on the block. This use of tailings also reduces tailing-dump emissions and space requirements. This block-caving technique is said to reduce direct mining emissions to a level comparable to "normal" underground mining operations (Rezovsky, 1957).

Other aspects of mining operations may give rise to environmental dispersion, such as the run-off entering waterways. Similarly, naturally occuring, surface-exposed deposits can give rise to dispersion from weathering or surface or ground water contact. Wet methods used in mining operations to reduce emissions is a mixed blessing, as the dispersion potential to waterways is increased.

Environmental Dispersion From Asbestos Milling Processes

The milling of asbestos ore by a dry process requires an extensive amount of handling and subdividing of the material in both the damp and dry states. There are many potential sources of asbestos emission at a milling facility. A primary source is the effluent from ore dryers, where mechanical agitation and contact with large volumes of air contribute to the potential for emissions. Feed and discharge points on primary and secondary crushers may give rise to emissions. Other sources at a milling facility include the transfer of waste rock from the mill site, the packaging and shipping operations, the grading processes, conveyor transfer within the facility, and the dumping of mine ore onto a stockpile or into receiving hoppers (EPA, 1973).

Air aspiration systems used to accomplish fiber removal require 7 to 10 tons of process-air for every ton of fiber produced. Such large volumes of air lead to significant potential emissions. Davis, et al., (1970) estimated 64 pounds per ton as the overall emission factor for asbestos milling based on a baghouse efficiency of 99.5% and cyclone efficiency at 80%.

The greatest potential emissions arise from the cyclone collector's exhaust. The series of process cyclones normally used are of a relatively large diameter design in order to limit damage to the fiber. As a consequence, the overall efficiency of capture is in the range of 90% and the fibers which escape are predominantly the smaller, respirable, and wind transportable ones (Paddock et al., 1972).

Wet-method milling is a proprietary method, and details of the processes are not known. However, because of the nature of the ore where this method is used, the emission potential from transport and unloading could be substantial because much more of the asbestos is free fiber at this stage. Drying of the fiber should also have great emission potential because the fiber is more free than with other ores. Wastes discarded to tailing dumps may have low emission potential, but their water contamination potential is high (Paddock et al., 1972).

Environmental Dispersion Potential From Manufacture of Products Containing Asbestos (Paddock et al., 1972)

Most of the well over 1,000 different asbestos products fall into one of two categories: essentially free fiber throughout the fabrication process and in the final product; or wetted or bound into a matrix at an early stage of processing. These two categories effectively describe asbestos emission potential for the manufacturing industry, and, to a certain extent, water pollution potential. The asbestos product categories with largest volume are the following:

General Nearly all manufacturing and processing operations involve the handling of dry, readily dispersible asbestos fibers prior to their mixing and introduction into various product formulations. These operations have in common a high potential for abestos emissions.

Asbestos cement products Willowing (fluffing) of the fibers in the dry state carries a high potential for emission. Dry-mixing methods have a higher emission potential than have wet methods. Finishing processes on dried cement products have some emission potential. Wet methods, of course, present the possibility of water contamination with discharges from indiscriminate disposal.

Asbestos vinyl and asphalt floor tile (18 to 25% asbestos) In this case emission potential is virtually nil once the fibers are mixed with the hot vinyl or asphalt. The potential for emission may be significant during those operations which introduce the dry asbestos fibers into the formulation and during the mixing process which follows. Emission from the finishing processes should be negligible, since the cutting process does not disperse fibers. Wastage and trimmings are readily reused by introducing into the hot vinyl or asphalt.

Asbestos friction products The potential for emission arises here principally from finishing processes and operations preceding inclusion of the asbestos in a wet-processing mixture. Finishing operations which generate dust include the use of band saws, abrasive wheels, drills, cylindrical grinders, disc grinders, and circular saws. For example, the drilling and grinding of brake linings can result in the release of as much as 30% of the lining materials as waste (Davis, et al., 1970).

Asbestos paper products Significant emission potential is associated with the slitting process as well as the pre-wet-mix handling operations.

Asbestos Textile Products Milling associated with obtaining the long fibers necessary for spinning has a high potential for emission of the smaller, respirable fibers. The resultant fibers (opened and fluffed) are delicate and highly transportable by wind.

Standard textile-type equipment and processes are used. Large surface areas per unit volume of asbestos exist during the entire processing procedure, creating a high emission potential. The weaving operation potentially generates more dust than any other textile operation. The separate large pieces of equipment used are necessary for frequent access and are difficult to hood for emission control (Paddock, et al., 1972).

Environmental Dispersion From Transport and Storage

Transporting the ore from the mine to the mill can result in emissions. Typically, open trucks of 20 to 75 ton capacities are used, although some 200 ton units are in use. Private mine-mill roads are frequently paved with tailings which liberate fibers to the environment when trucks pass by. In this context, the use of 200 ton trucks is of mixed significance for emission levels during transport. Larger truck capacities should reduce emissions from the transporting of the ore with their larger volume-to-surface ratio. Their size reduces the number of trips per unit of ore. However, the road itself suffers more damage from each truck's passing. The relative significance here is undetermined. Any stored ores exposed to weathering can generate emissions and pose a potential for water contamination (Paddock et al., 1972).

Asbestos mills store dried ore in large amounts and hold it to allow for variations in fiber demand and mine production over the short term, thus giving rise to potential emissions from the requisite handling operations. Residual rock, which contains small amounts of unremoved fiber and dust, is usually transported to a tailing dump. With wet-method milling, it is suspected that

there is a low emission potential from transport and storage, since the material is wet (Paddock et al., 1972).

Environmental Dispersion Potential From Disposal (Paddock, et al., 1972)

In mining operations, large quantities of asbestos ore are sometimes rejected at the mine site because either the concentration or the form the ore is dispensed in renders recovery of the asbestos uneconomical. In most surface mining operations it is necessary to remove the overburden that contains small concentrations of asbestos in order to expose asbestos ore deposits. The taconite beneficiation process again illustrates the water contamination possible with waste from other types of mining and milling operations

Related to manufacturing is the disposal of bags which have asbestos fibers clinging to them. Wastes from the finishing processes of asbestos cement products, asbestos friction products, and asbestos textile products are reuseable in some situations. The manufacture of asbestos cement and asbestos paper produces a mixture of asbestos fibers and water; this mixture poses a potential contamination for natural ground and surface waters or, if contained and allowed to dry, may give rise to emissions. A lot of asbestos wastes come from baghouse collections. The ultimate disposal of asbestos wastes in open dumps can significantly raise emission potential as well as contribute to water contamination.

Environmental Dispersion Potential From Use

Emissions of asbestos from sprayed asbestos fireproofing and insulation arise from handling the dry mixture, the escape of unwetted fiber and mixture, overspray and backsplash, and the cleanup and disposal of wastes (Paddock et al., 1972; Reitze et al., 1972). Regulations related to this problem are discussed in a later section.

The construction industry, which utilizes many materials containing asbestos, (wall board, insulation, etc.) can create

many sources of asbestos emissions, if not controlled. A similar situation for emission potential develops when buildings are demolished. Wastes from demolition are frequently sources of asbestos containing materials including materials such as pipe and boiler thermal insulations, and bound materials such as asphalt-asbestos floor tile, vinyl-asbestos flooring products, asbestos-cement roofing and siding shingles, and acoustical ceiling tile (EPA, 1973).

Return-air plenums and the interior surfaces of buildings with asbestos fireproofing or insulation create a potential exposure for occupants. This problem relates to the issue of indoor air pollution (Castleman and Fritsch, 1973).

Asbestos friction products, such as brake linings and clutch facings, emit fibers during vehicle operation. On the average less than 1% of the 30-50% asbestos contained in brake linings escapes into the atmosphere as free asbestos fiber. The remainder is thermally decomposed to some other non-fibrous mineral form (Lynch, 1968). A recent emissions test study by Jacko et al. (1973) showed an average of 0.23% asbestos content (by weight) in brake emissions indicating the remainder is converted to other products. Brakes containing brass chips emitted 1/3 less asbestos than those without. The calculated annual national emissions of asbestos from brake and clutch use is 5,060 pounds. A summary of estimated emissions is presented in Table 5 from Jacko et al. (1973).

Davis et al. (1970) estimated that 190 tons of asbestos was emitted to the atmosphere in 1968 as a result of grinding and fitting during installation of new brake linings.

Asbestos cement pipe has been suggested as a source of contamination in drinking water where it is used to carry water supplies. But, the contribution asbestos-cement pipes make to the asbestos fiber content of tap water is uncertain (Kuschner

Table 5. Summary of All Brake and Clutch Emissions (lb. per year) (Jacko, et al., 1973)

	Number of Vehicles	Total Asbestos Emissions	Distribution		
			Dropout	Airborne	Brake Retention
Passenger Cars	96,400,000	60,400	49,470	2,230	8,700
Light Trucks	17,100,000	32,300	28,420	940	2,940
Medium Trucks and Buses	2,600,000	16,300	14,330	470	1,500
Heavy Trucks	1,200 000	32,900	28,920	950	3,030
Miscellaneous[1]	6,615 000	16,300[1]	14,330	470	1,500
Totals		158,200	135,470	5 060	17,670
% of Total			(85 6)	(3 2)	(11 2)

[1]Estimated equal to medium trucks as weights of friction material used for both categories are almost equal. Includes motorcycles, trailers, and the like

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et al., 1974). Use of the product in sewage pipes has also been suggested as contributing to asbestos contamination of waterways.

Asbestos-asphalt paving compounds which contain two to three percent by weight asbestos may give rise to some asbestos fiber emission as a result of abrasions to the pavement. This type of paving has been used extensively in California. Rainfall could wash abraded fibers into nearby ground and surface waters (EPA, 1973).

EM examination of the wastewater effluent from chlor-alkali plants which use an asbestos diaphragm cell process showed 1.5 x 10^8 asbestos fibers/liter. The steam condensate from caustic evaporation was also found to contain 2.0 x 10^8 fibers/liter (Beaman et al., 1975).

Many consumer products contain asbestos, among them ironing board covers, drapes, filtering and insulating materials.

Talc and talc products contain varying amounts of asbestos as an impurity and have uses which may give rise to asbestos exposure.

Many food and drug products have been filtered through asbestos pads; however, this practice is said to be declining sharply.

Environmental Exposure Factors

Presence of asbestos or asbestiform fibers in the air and waters of North America is widespread and appropriately considered ubiquitous.

Air

Asbestiform fibers can be released to the atmosphere directly from fibrous silicate mineral outcroppings and indirectly from soils or as a result of weathering processes. Asbestiform fibers can also enter the atmosphere from mining and milling of asbestos, talc, and other mining operations (e.g., taconite) as well as

manufacture and use of asbestos containing products, building demolition and solid waste disposal of many types (NAS, 1971).

Selikoff et al. (1972) measured mass concentrations of chrysotile in ambient air at various sites in New York City ranging from 10 to 60 x 10^{-9} g/cubic meter. Other urban areas also showed chrysotile asbestos fibers in ambient air samples: Philadelphia, Allegany, Pa. and Ridgewood, N.J.

Alcocer et al. (1970) detected asbestos fibers in urban air samples from New York, San Francisco, San Diego and Newark.

Water

Contamination of water supplies can result from improper waste disposal of asbestos during mining, milling, manufacture of asbestos containing products, or primary and secondary use. Other mining and milling processes with coincident asbestos deposits may also contribute. This contamination can be supplemented by atmospheric asbestos dust settling or washing out by precipitation as well as erosion of natural deposits. It is noteworthy that the amphibole minerals are more plentiful and more widely distributed than serpentine although chrysotile is the most extensively used and has received the most attention to date (Nicholson, 1974).

Cunningham and Pontefract (1973) reported that Ottawa tap water contains approximately 2 x 10^6 fibers/liter while Ottawa river water concentrations ranged from 8.1 to 9.5 x 10^6 fibers/-liter and melted snow contained 33.5 x 10^6 fibers/liter. Some inferences about atmospheric asbestos contamination and dispersal can be made from the snow figures and may indicate that asbestos fibers serve as condensation nuclei.

A survey of municipal surface water supplies of 22 Ontario (Canada) cities showed upon EM analysis that all contained asbestos fibers ranging in concentration from 446,000 fibers/liter to 3,876,000 fibers/liter (Kay, 1974).

Cooke, et al. (1974) reported the detection of asbestiform amphibole fibers in municipal water supplies taken from western Lake Superior. (The asbestos contamination in this part of the lake is the result of industrial effluent discharge of taconite tailings.) Estimates from EM examination of 1973 Duluth water supply samples ranged from 1 to 30 x 10^6 amphibole fibers/liter. Amphibole fibers were also detected in water samples taken from the Minnesota towns of Silver Bay, Beaver Bay, Two Harbors and Cloquet.

Nicholson (1974) also analyzed samples from the Duluth water supply system. He found amphibole fibers ranging from 20 x 10^6 to 75 x 10^6 fibers/liter. Nicholson also identified the fibers which required the use of electron diffraction and electron microprobe analytical techniques as well as transmission electron microscopy. Approximately 50-60% of the fibers were in the cummingtonite-grunerite series, 20% were in the actinolite-tremolite series and about 5% were chemically identical to amosite.

A recent report by the Great Lakes Research Advisory Board (1975) indicates that the background level of asbestos fiber concentration in the water of the Great Lakes varies widely, but averages from less than 1 to 10 million asbestos fibers per liter.

EM examination of water samples from various water sources and municipal supplies in the U.S revealed the presence of asbestiform fibers. Concentrations reported ranged 0.0048 to 6.42 μg/gallon (Kuschner et al., 1974).

Food

FDA found asbestos fibers in salt recovered as a by-product from chlorine production (chlor-alkali process employing asbestos diaphragms) and intended for table salt use. Such use was approved in 1974 by FDA but is expected to be revoked. The FDA analysis by light microscopy revealed 225 asbestos fibers in 25 grams of the by-product salt as compared to none in supermarket purchased salt.

Further analysis by electron microscopy showed 16 million asbestos fibers per gram of by-product salt and none in supermarket purchased salt. The expected official regulation will have little impact since the by-product salt never reached the marketplace (Burros, 1975).

Transport Across Media

Dispersed asbestos fibers can be washed from the atmosphere by precipitation and/or settle to the earth's surface and become suspended in runoff water and contribute to the contamination of ground and surface waters. Similarly, asbestos fibers may be entrained in waterways as they traverse natural or man-made deposits.

VII. CONTROL TECHNOLOGY

General

Dry cyclone devices, as previously mentioned, are commonly used to control asbestos emissions from mining, milling, and many other processing operations. Their collection efficiency is low because many of the asbestos fibers are small (less than 1 micron diameter) and have low specific gravities (approximately 2-3).

Twin cyclone collectors four feet in diameter have been found to be the most efficient type for use in the Quebec area mines. However, even their best performance is not satisfactory due to their low efficiency on fine particles and fibers (Li, 1973). Dry cyclones should be considered as precleaners to reduce fabric filter loadings.

"Wet" collecting equipment such as wet cyclones or venturi scrubbers are rarely used because resultant asbestos slurries tend to clog pumps, drains, etc., and reuseable fibers are more difficult to reclaim. In connection with the use of a fabric filter, clogging and blocking problems arise in the baghouse due to the humidity created in wet collecting (Paddock et al., 1972).

Electrostatic precipitators have been tried and proven to be inefficient collectors due to the resistivity characteristics of most types of asbestos (Ibid).

Fabric filters have been found to be the most efficient type of collector for controlling asbestos emissions and are currently in wide use. These types of filters are often enclosed in moderate-sized structures and referred to as a "baghouse".

Typically, tubular bags 5 to 18 inches in diameter and 2 to 30 feet long are suspended with open ends attached to an inlet manifold at either the top or bottom of the housing, or both. The lower manifold serves as a collector for dust. Entering air

strikes a baffle plate which causes the larger particles to fall into a hopper. The air then passes through the bags, leaving the dust on the interior surface of the cloth. Cleaning is generally done by shutting down and shaking the bags from the top. The material used for filters depends upon the corrosiveness of the gases, temperature, and humidity. The efficiency of a cloth filter is largely dependent upon the accumulated layer of dust, i.e., efficiency increases with high dust loadings.

Advantages of Fabric Filter Baghouses

One advantage of this control method is that further processing of captured asbestos fibers for reuse is not required. Collected materials may be returned directly to the process or used in some other application such as friction material. Water treatment and water handling are not required. Systems can be sectionalized so that maintenance may be done on one section while the others continue to operate. Baghouses are less costly to buy, maintain, and operate than any other system with a comparable collection efficiency. Baghouses can also control other dry particulate emissions if necessary (Paddock et al., 1972).

Disadvantages of Fabric Filter Baghouses

A large area per unit of gas flow is needed for installation. Minor damage to a bag can cause significant loss in its cleaning efficiency. The cleaning efficiency is variable, being lowest just after bags are cleaned or when new bags are installed. Bag changing is expensive--both in labor and materials. The baghouse temperature must be kept above the dewpoint but below the limit of bag tolerance which is sometimes a delicate procedure (Ibid).

The following sections briefly describe typical control approaches. Particulate control efficiency estimates for various segments of the asbestos industry are contained in Appendix A (p. A-8).

Mining Controls

Overall emissions from asbestos mining facilities are not stringently controlled at the present time. The lack of a higher

degree of control is due to the fact that most operations are completely exposed to the atmosphere, with the result that emissions are diluted with ambient air over relatively large surface areas, such as mining pits and roads (EPA, 1973). The block-caving technique of open-pit mining can significantly reduce asbestos emissions. The baghouse-collection technique has only limited application in mining processes. Portable baghouse systems can be used to good effect during drilling operations which occur prior to blasting. However, a wet drilling method could be just as effective and cost less.

Blast emissions are impossible to collect but can be controlled by employing a good blast technique and by calculating how to produce minimum breakage of the rocks.

An effective technique has been developed for coal mining in France which uses plastic capsules filled with water or water-containing wetting agents to suppress dust from the blast; 20 to 80 percent reductions in emissions have been achieved. It may have potential for application to asbestos mining but may present a problem if present milling methods cannot remove the plastic contamination from the ore (Grossmueck, 1968).

Dusts generated during ore transport are usually controlled by covering the truck bodies with canvas.

Road surfaces covered with tailings can be wetted with water, road oil, a 10 to 25% water solution of liquid sulfonate, or emulsified asphalt. However, chemical dust suppressants on mine roads over the ore body may cause unacceptable ore contamination.

In Canadian mines, wet drilling is not practical because of the severe winter climate. One solution has been to use envelope-type bag filters on percussion primary drills mounted on the frame of the rig. The bags used are made of silicate-treated nylon

acetate, which sheds dust easily and dries quickly if water is accidentally drawn into the filter (see figure 3).

With larger rotary drills, the platform serves as the top of the dust hood. The sides of the hood are formed by rubber aprons, the end apron being hinged to prevent cuttings from being dragged back into the hole (see figure 4).

The ultimate disposal of mill tailings and overburden in the Canadian mine operations is complicated by the close proximity of towns to the mines. The disposal of tailings is further complicated because they leave the mill in a very dry state. Recent experiments involving the application of wetting agents at the point where tailings are discharged have had an undetermined degree of success, and further work is needed. Revegetating areas of tailings is also being investigated by the Quebec Asbestos Mining Association's research laboratory. One of the major difficulties with this technique is the high alkalinity (pH 9) of serpentine tailings. Grass has been grown on selected areas after mixing with acidic tailings from a copper mine at a depth of 2 inches (Li, 1973).

The stabilization and revegetation of overburden waste areas have not presented many difficulties, as the waste area's alluvial sands and clays are usually neutral. Grasses and trees have been successfully established on overburden waste (Li, 1973).

Asbestos Milling Process Controls

Ore stockpile emissions can be controlled by spraying with water. However, the discharge of asbestos-containing water from the facility also requires control (EPA, 1973).

In-plant transfer by conveyor should be fully enclosed to prevent asbestos emissions from the material in transit and from

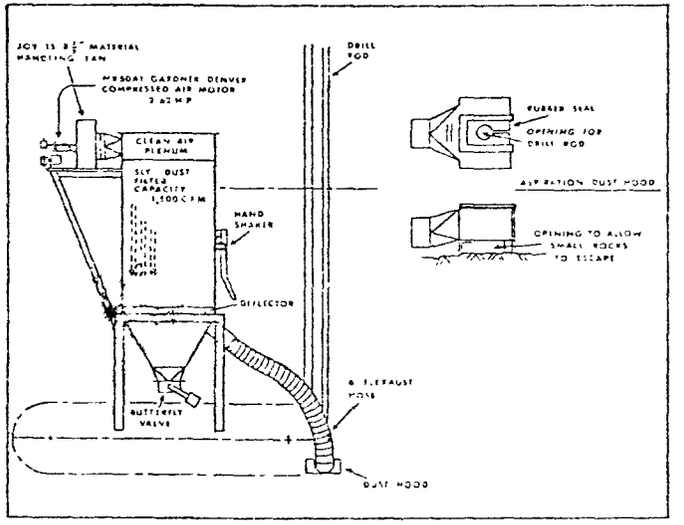

Fig. 3 - Dust control for percussion drill (Li, 1973)

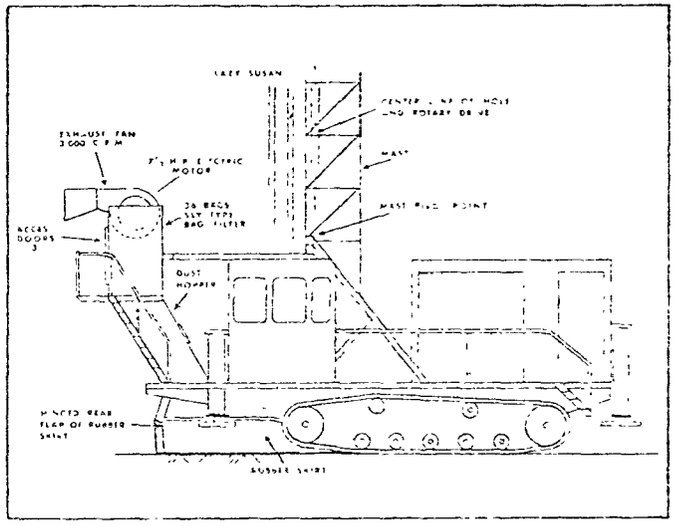

Fig. 4 - Rotary drill with dust control system (Li, 1973)

the emptied return side of the conveyor. Such control is currently applied only to a limited extent (Ibid).

Feed and discharge points for crushers can be fitted with hoods ventilated to a gas cleaning device. A cyclone collector is usually used. Cyclone exhaust may then be directed into a fabric filter baghouse.

The cyclone collector has been the most widely applied type of gas-cleaning device to control asbestos emissions from ore dryers.

A baghouse filter which collects ore-dryer emissions requires heat resistant materials, such as orlon or dacron, due to the high temperatures (250°F) and humidity of the exhaust stream. Other heat resistant materials used for the bags are fiberglass, teflon, and Nomex. Also, insulation of the baghouse is necessary to avoid condensation and resultant blockage (EPA, 1973).

Asbestos emissions from the beds of vibrating grading screens are amenable to control by capture-hoods, exhausted to cyclone collectors, and finally sent to a bag filter. Asbestos emissions from bagging operations can be similarly controlled (EPA, 1973).

The control of emissions at mill tailings piles can be controlled somewhat by maintaining a relatively flat disposal pile. This is achieved by use of a mobile dumper at the end of the conveyor belt that transports the wastes. As the disposal proceeds, the location of the dumper is periodically changed in order to maintain the tailings pile as nearly level as possible and thereby minimize emissions caused by moving the tailings with earth-moving equipment. An inverted funnel mounted to the dumper discharges the wastes close to the surface in order to lower emissions at the point of deposition. However, a water or chemical spray may be needed to eliminate visible emissions at the point of discharge. Similarly, mixing the tailings with water

prior to deposition is an effective technique for controlling asbestos air emissions. However, the possibility of shifting the problem from air to water media again presents itself (EPA, 1973).

The wet method of milling reduces emission potential; however, the drying process may have a greater emission potential than conventional ore drying (Paddock et al., 1972).

Manufacturing Emissions Control

Current control of mill-to-manufacturer handling and storage emissions is effected by bagging the fiber in jute, kraft paper, or polyolefin. Prior to introduction in the final product, the asbestos fibers must be removed from their bags and fluffed to loosen them from their packed condition. Enclosure of the total process and baghouse filter collection is the usual control. A dry cyclone for precleaning may be necessary if air fluffing is used.

Other

The collection of emisssions from finishing processes associated with asbestos cement products is best controlled by the baghouse method.

In the asbestos vinyl and asphalt floor tile industry, controls are applied at stages before the fibers are mixed with the hot vinyl or asphalt. Baghouse filtering is applied to the fluffing or blending processes. If polyolefin bags are reused in the process, their emission potential is reduced.

It has been found that a thin coating of a polymer on the asbestos yarn improves the processing efficiency and results in about an 80% reduction in fiber emissions from successive processes (Paddock et al., 1972).

Sprayed Asbestos Fireproofing and Insulation

This use has been totally banned in some areas under regulations of the Clean Air Act, which restricts spraying to materials containing less than one percent asbestos. Alternative materials have been found which are suitable and of negligible economic impact. They include mineral wool, ceramic fibers, calcium silicate, and vermiculite alumina.

VIII. ANALYTICAL METHODS

Analysis for asbestos in environmental samples (air, water, tissue, food, etc.) presents many problems. The development of solutions to these problems will take a good deal of time. The research community in this field is in its infancy and just beginning to grow (Everett, 1974). Recognizing the probability that new developments in this field will arise rather rapidly, the discussion in this section is likely to quickly be outdated and is therefore limited.

Langer (1974) has discussed the various approaches to asbestos fiber identification and quantification and associated constraints. The range of media in which asbestos contamination is sought can present sample preparation problems. Electron beam instruments (electron microscopes) are superior for identification purposes but, the area searched is generally small and may not be representative of the total sample. Another difficulty is the presence of other fibrous particles in the sample, especially in water. In practice this means that in scanning one would have to stop and perform electron area diffraction on each fiber for identification. In addition, with amphibole fibers microchemical analysis is always necessary. Electron beam instrument analysis also requires a great deal of time which limits the number of particles as well as the number of samples which may by analyzed. A summary of limitations associated with various instruments used for asbestos analysis is contained in Table 6.

Langer and Pooley (1973) have reviewed and summarized by asbestos type the capabilities of electron beam instruments in identifying asbestos fibers in tissues.

Chrysotile

Individual unit fibrils can be resolved with a transmission electron microscope (TEM). Fibril morphology of chrysotile

Table 6. Possible Instrumentation for Fiber Analysis and Constraints (Langer, 1974)

Instruments	Starting material and information obtained	Constraints
Single particle, large Light microscopy Bright field illumination Phase contrast Polarized light	Paraffin sections,[a] stained or unstained; ashed or unashed; bulk extracts in immersion oils Dust distribution in tissues; very limited morphology and size-distribution; crystallinity, limited indices of refraction and optical properties; identification of some phases	Size and resolution limited, small, particles not detectable; light visible particles seen only, overlapping properties of phases; change of "standard" optical properties with reduced size
Single particle, small Electron beam instruments Transmission electron microscope Selected-area electron diffraction Electron microprobe analyzer Scanning electron microscope with energy dispersive x-ray detector	Paraffin sections[a] followed by carbon extraction; bulk extracts mounted on appropriate substrates Single particle analysis; diffraction data of groups of particles; number, morphology, size distribution, relative crystallinity of dusts, structure and chemical composition of particles; unique identification of phases.	Area scanned is small and may not be representative; large number of particles required for statistical evaluation; sample preparation and scanning is time-consuming; instrumentation and interpretation expertise required
Many particles X-ray diffraction Diffractometer Film technique	Paraffin sections[a] may be used if sufficient dust present; bulk extracts more useful Bulk analyses are obtained (mixed phases and x-ray patterns); crystallinity of phases; average size distribution of phases; identification of crystalline phases	Mixed dusts yield x-ray patterns difficult to interpret; small particles yield diffuse patterns; body salts confound analyses; line-broadened spectra common; extraction technique may alter phases or produce an artifact dust population
Other techniques Infrared spectroscopy (IR) Differential thermal analysis (DTA) Emission spectroscopy (ES) X-ray fluorescence Atomic absorption spectroscopy (AAS) Wet chemical analysis (WCA)	Bulk materials required in all cases, usually "pure" samples, free of organic contaminants; samples required range in size from micrograms to grams. Entire particle populations are analyzed simultaneously, structural and molecular makeup for identification of phases; thermal reactions for characterization; bulk and trace chemical analyses of dusts	IR and DTA data are ambiguous, difficult to interpret uniquely; bulk chemistry by ES, AAS, WCA is destructive; chemical data difficult to assign to individual phases; nature of trace metal phases unknown.

[a] For fibers in tissues.

is so unique that the mineral species may be identified on this basis alone. This unique morphology results in a characteristic electron diffraction pattern which identifies the fiber as chrysotile.

Use of an electron microprobe analyzer for chemical identification has had limited success, since chrysotile tends to degrade both chemically and physically in vivo; the fibers tend to break down into units of a size not easily resolved by the probe, and chrysotile readily loses magnesium.

Amphiboles (amosite, anthophyllite, crocidolite, and tremolite)

The optical properties of these fibers may be ambiguous, as they may have become altered in vivo or may be obscured by "asbestos body" coatings. Generally, upon electron microscopic examination, these fibers appear straight and electron dense. Single fibers tend to be similar and cannot easily be differentiated. When many amphibole fibers are present, knowledge pertaining to exposure may be the only key to identification. Each of the fiber-types appears to possess a unique diameter distribution. Anthophyllite fibers are significantly thicker than amosite fibers, which in turn are significantly thicker than those of crocidolite; tremolite fibers tend to be short and stubby. However, most asbestos exposures are mixed, so the value of morphological analysis for fiber identification is limited. Electron diffraction patterns of amphiboles are also non-distinctive; the pattern is unique for the group but not for the individual mineral species.

Microchemical analysis probably provides the best means of differentiating between amphibole fibers. The electron microprobe analyzer is presently the most reliable instrument for the identification of amphibole fibers. The size limitation in using this instrument (0.2 microns) allows only the largest fibers to be analyzed without difficulty and with high confidence.

Langer and Pooley (1973) recommended the following analytical procedure for identifying single asbestos fibers in tissue:

> "Tissue preparation: Use of the carbon extraction method is recommended since it can be used on normal histologic preparations and the carbon substrate is stable under the electron beam; the grids should be mounted on locator-type, copper substrates to insure ease of particle location.
>
> Light microscopy: This phase of examination should be used only to check on the extraction preparation and the general condition of the grids; areas which contain visible fibers and amounts of relict tissue should be selected; areas which appear to be void of fibers should be scanned as well.
>
> Electron microscopy and selected area diffraction: Photographs of fibers should be taken as a basis for their morphological identification; selected area diffraction patterns are necessary on all electron-dense fibers to determine if they are amphibole types; the locations of these fibers should be noted for further microchemical analysis with the probe.
>
> Electron microprobe: Fibers on which diffraction and morphological studies have been completed can be located by means of the locator grids and Microchemical analyses obtained."

Asbestos in Air -- (Langer *et al.*, 1973; Lynch and Ayer, 1968; Cralley, 1971) Light microscopy samples are collected on cellulose membrane filters. Particles smaller than a nominal pore size are retained. The samples are then mounted on standard microscope slides, and a viscous solution of diethyl oxalate and dimethyl phthalate is placed on the filter to make it transparent. This preparation is stable for 28-30 days. After that, migration of fibers and particles occurs, causing a loss in areal concentration.

The fibers on the filter surface are counted under phase-contrast conditions at a magnification of 450X. The counting field is delineated by a Porton reticle. Only fibers greater than 5 microns are counted. Any particle with an aspect ratio of three or greater is considered a fiber (Edwards and Lynch, 1968).

This method is used to determine the level of asbestos in occupational environments so that compliance with the TLV and OSHA standards can be checked.

The major deficiences of this method are that it doesn't identify asbestos fibers and it is not capable of resolving particles smaller than one micron. It is said to be only a useful index of fiber concentration, since only a fraction of the fibers seen with an electron microscope is observed.

Samples collected on membrane filters may be transferred directly to coated grids for analysis under an electron microscope (Keenan and Lynch, 1970).

X-ray diffraction is suitable for quantitatively determining the amount of chrysotile, amosite, and crocidolite in bulk or settled dust samples (Ibid). X-ray diffraction will identify the presence of certain minerals except where there are strong interferences from associated materials. This method cannot distinguish between a fibrous mineral and the parent, non-fibrous mineral with the same crystal structure, e.g. non-fibrous serpentine and chrysotile. This method also appears to be somewhat dependent on particle size and has a sensitivity which is not generally low enough for airborne exposure samples.

Atomic absorption spectrometry has been used for the analysis of certain metallic elements present in samples of airborne asbestos fibers and also in bulk asbestos minerals. Magnesium in airborne samples may be measured and used to indicate exposure if only one compound carrying the element to be analyzed is in the sample (Keenan and Lynch, 1970).

Neutron-activation analysis has been used to irradiate samples for analyses using tracer techniques (Ibid).

The electron microprobe under ideal conditions is capable of analyzing for all elements of atomic number 5 and greater and can

be used to identify metallic impurities located on the surface of, or incorporated within, the lattice of asbestos fibers (Keenan and Lynch, 1970). However its usefulness for routine analysis is limited.

Emission spectroscopy is applicable only to bulk samples for a determination of elemental composition. Table 7 summarizes some of the analytical methods used for asbestos (Keenan and Lynch, 1970).

Table 7. Summary of Methods and Their Application

Method	Application	Characteristic Determined	Type Sample	Comments
Light Microscope				
Light Field (100×)	Detection and Enumeration	Total dust	Impinger	Traditional standard method for evaluating asbestos exposure
Phase Contrast (400×)	Detection and Enumeration	Fibers by shape	Membrane filter and lung residue	New method for tentative asbestos TLV. Do not see fibers smaller than about 0.1 μ diameter
Dispersion Staining	Identification	Refractive Index	Bulk or airborne dust	Distinguish asbestos from non-asbestos fibers
Electron Microscope	Detection and Identification	Fiber by shape Fine structure	Bulk, airborne dust and lung	May identify fibers with unique fine structure.
X-ray Diffraction	Identification and Analysis	Crystal structure	Bulk airborne dust (≥ 1.0 mg)	Cannot distinguish fibrous from non-fibrous minerals of same crystal structure
Atomic Absorption	Analysis	Elemental composition	Bulk and airborne dust	Sensitive enough for trace elements in mg samples and gross composition of count samples
Emission Spectroscopy	Analysis	Elemental composition	Bulk	Gross and trace constituents
Electron Microprobe	Detection Identification and Analysis	Elemental composition	Bulk airborne dust and lung	May determine gross composition of selected fibers and grains

Asbestos in Water -- For the most part, the methods mentioned above have been adapted for the analysis of asbestos fibers in water. Success has been very limited. In addition to the problems inherent in these methods, attempts to quantify and identify asbestos fibers in water have been plagued by sampling difficulties because fibers may settle out or adhere to the walls of the sample container. Another problem is that these fibers may change their physical or chemical characteristics over time while immersed in water. In fact, it has been shown that if chrysotile fibers are allowed to remain in water, much of their magnesium leaches out and the central canal begins to fade (Cunningham and Pontefract, 1973).

The method principally used for water analysis is light microscopy for enumeration and detection at 450X. (Recently 1000X has been used by EPA.) Electron beam instruments are also used for identification and enumeration. Reproducibility of results with both methods has frequently proven inadequate.

General Note

The development of a rapid method for the sampling and analysis of asbestos in air, water, tissue, food, etc. has been largely unsuccessful. All of the above methods which can identify asbestos require sophisticated equipment and much time; from one day to one week (depending on sample loading), to make a determination on one sample. The light microscopic technique, although it lacks identification capabilities, is a faster method for the enumeration of fibers greater than one micron and may give a statistically useful index of asbestos fiber concentration.

In summary, the inadequacy of present analytical techniques requires that activities to develop techniques which can identify and enumerate asbestos fibers in environmental samples be given a high priority.

IX. ENVIRONMENTAL EFFECTS

Chemical Stability In the Environment

Asbestos is considered to be indestructible, but changes in physical and chemical properties have been produced by high heat, chemicals, and body fluids (Tabershaw, 1968).

The brucite [$Mg(OH)_2$] layer of chrysotile results in a reactivity characteristic of magnesium hydroxide. Chrysotile is slowly "soluble" in water, losing magnesium ions from its crystal structure (Speil and Leineweber, 1969).

Biological Degradation

The *in vivo* alteration of chrysotile (by leaching of magnesium) to amorphous and crystalline silica has been observed (Suzuki and Churg, 1969; Langer *et al.*, 1973 cites six references).

Persistence

Mechanical degradation can lead to the release of fibers where asbestos is subjected to weathering and physical forces and where there are materials containing asbestiform minerals that are not "locked in". There are no indications in the literature that significant degradation of asbestos occurs in the environment. Thus, it must be considered persistent. Asbestos is best thought of as a fibrous particulate. If immobilized, the fibers present less potential for dispersion throughout the environment.

Environmental Transport

The fineness of asbestiform mineral fibers makes them readily transportable as particulates through air and water media. The key factor again is whether the fibers are immobilized throughout the operations related to mining, milling, use, disposal, etc.

Bioaccumulation

Apparently, only partial clearance of asbestos from the lungs occurs, so inhalational exposures are therefore cumulative. The presence of asbestos in human lungs would seem to indicate this (Selikoff et al., 1972). Animal experimentation indicates that the oral exposure route probably does not lead to absorption. No study was found to indicate that asbestiform minerals can be conveyed in a food chain.

Environmental Epidemiologic Studies - Asbestos and Mesothelioma in Man

Wagner et al. (1960) reported 33 cases of mesothelioma in the North Western Cape Province of South Africa. Several of these cases had no known exposure to asbestos except that they lived in the vicinity of the asbestos mines. The authors pointed out that mesothelioma is rarely observed elsewhere in South Africa.

Newhouse and Thompson (1965) surveyed a series of 83 mesothelioma patients from the London Hospital to determine possible exposure to asbestos. They observed that occupational and domestic exposures (living in the same house as an asbestos worker) gave rise to an increased risk of mesothalioma. In addition their survey indicated that neighborhood exposures may be important. Eleven of their mesothelioma patients with no occupational or domestic exposures lived within 1/2 mile of an asbestos factory.

Lieben and Pistawka (1967) studied 42 cases of mesothelioma and observed that eight (8) had only been exposed to asbestos by either living in the immediate neighborhood of asbestos plants (within 1/2 to 1 1/2 mile radius) or being employed next to an asbestos plant.

Others have also observed mesothelioma associated with neighborhood exposure to asbestos (Borow et al., 1967; Bohlig et al., 1970; Ashcroft and Heppleston, 1967; Anspach, 1969; and Solomon, 1969). Hain et al. (1974) reviewed the literature from

1964-1972 on mesothelioma associated with asbestos exposure and found that 95 cases of neighborhood (environmental) exposure have been reported.

A retrospective study of 150 cases in Hamburg (Hain et al., 1974) showed 20 cases associated with neighborhood (environmental) exposure (within 1 km. around an asbestos plant) and 8 cases in outlying areas. In a previous survey of Hamburg by this group (Bohlig et al., 1970), they pointed out that working conditions of the asbestos factories in Hamburg were uncontrolled until the mid-30's when indoor dust control was started but without any control on exhausted air. Not until after World War II was the exhausted air controlled for economic reasons (recovery for reuse). Of the 119 cases studied 43 were not associated with occupational or domestic exposure to asbestos but were neighborhood exposures. In their later study (Hain et al., 1974) which does overlap with the previous one, they advise that neighborhood (environmental) exposure requires precise definition and should not be referred to as general urban exposure. Also, it is appropriate to note that the latent period before onset of mesothelioma is long and exposures likely occurred when asbestos plants practiced little or no internal or external environmental control.

X. HUMAN EFFECTS

General

The background document on asbestos for the hazardous pollutants list in Section 112 of the Clean Air Act cites about 30 occupational studies. Nearly all the positive evidence linking asbestos with human effects has come from such occupational studies. Except for a few specific (neighborhood) environmental exposures, these occupational studies concern workers engaged in the mining and milling of asbestos, the manufacture of asbestos-containing products, and the application and removal of asbestos-containing insulation material.

The major deficiences in these studies is the lack of detailed exposure histories in regard to (1) what other materials may have been inhaled besides asbestos, (2) time-dose information, (3) size distribution of fibers and (4) quantitative exposure estimates.

Asbestosis

Pulmonary asbestosis is a slowly progressive, diffuse, interstitial fibrosis which may not be detectable by chest x-ray in the early stages. Fibrosis and calcification of the pleura may also have varying degrees of association. The main symptom is dyspnea. Finger clubbing, cyanosis, and fine basal rales tend to develop a long time after the onset of exposure. Severe fibrosis can ultimately lead to death from cardiac failure (reviewed in Castleman and Fritsch, 1973).

Asbestosis usually develops after long exposure to high concentrations of asbestos dust. Thus, it is largely confined to occupational exposures. The degree of risk varies directly with the length of exposure and the concentration. Following continued exposure to high concentrations, asbestosis may develop to clinical stages in seven to nine years and may cause death as early as

thirteen years from the onset of exposure. However, the usual exposure period in workers before recognition of asbestosis is 20 to 40 years, with death following two to ten years later. Once established, asbestosis progresses even after exposure has ceased. Short, heavy exposures have lead to asbestosis. Dose vs. time relationships for the onset of the disease have been difficult to establish; however, the data available has been used to arrive at a "threshold limit value" for occupational exposure which appears to reduce the risk of asbestosis (ACGIH, 1971).

All varieties of asbestos can produce asbestosis. It is not known whether one type is more fibrogenic than another (ESL, 1973).

Association With Neoplastic Disorders of the Hematopoietic System

Five cases of asbestosis associated with tumors of the hematopoietic system (in a series of 35 cases confirmed by autopsy) have been reported. The disorders observed included two cases with multiple myeloma, two with myeloproliferative disorders, and one Waldenstrom's macroglobulinemia. The incidence of this association is significantly higher than the overall incidence of such disorders in the corresponding age group of patients without asbestosis (Gerber, 1970).

Other Clinical Features

Physiological changes are observed consistent with a restrictive lung disorder manifested by decreased forced vital capacity, diminished diffusion capacity, and decreased pulmonary compliance (Kleinfeld, 1973).

The prevalance of pulmonary fibrosis in one study was 40% in smokers and 24% in non-smokers. Age, sex, and the duration of exposure did not account for this difference (Weiss, 1971).

Lung Cancer

Lung cancer is not an unusual complication of asbestosis. It may appear unaccompanied by asbestosis but after asbestos exposure (Athanassiadis and Sullivan, 1969).

Kannerstein and Churg (1972), after a review of the literature and their own studies, were not able to accept fibrogenesis as an intermediate, essential, causal phase in inducing lung cancer since a quantitative relationship between the severity of asbestosis and lung cancer was not evident. Increased incidence of pulmonary carcinoma has not been observed in other fibrosing pneumoconioses.

A relationship has been established between past occupational exposure to asbestos and a higher than expected incidence (5X-7X) of lung cancer (Kleinfeld, 1973; Wagner et al., 1971).

Some studies demonstrate differences in the degree of risk between different occupationally exposed groups; these are probably related to type and concentration of asbestos fiber; nature of the work performed and other factors, such as smoking cigarettes (Selikoff et al., 1968).

Selikoff et al., (1968) in a study comparing insulation workers who smoked cigarettes to men who neither smoked nor worked in the insulation industry, reported a mortality rate from lung cancer 92 times greater in the former as compared to the latter.

Features peculiar to asbestos-related lung cancers are: (ESL, 1973)

a) all cell types that are histological indicators of malignancy are observed;

b) 2/3 of the lung cancers are lower lobe types;

c) the cancers tend to be peripheral;

d) the pleura are often involved early;

e) bronchus tumors are infrequent.

In a study of textile workers by, Knox et al. (1968), there are indications that the incidence of lung cancer decreases with progressively smaller total exposures to asbestos fibers. However,

a true dose-response relationship was not established nor can one be inferred.

One study of a population of asbestos textile workers has shown that the occurrence of pulmonary cancer differs markedly with total exposure. No increase in the incidence of bronchogenic cancer in a group that had low to moderate exposure was observed, whereas a heavily exposed group showed an eight-fold increase in incidence of lung cancer (Newhouse, 1969).

Similarly, a recent study of mortality in chrysotile mines and mills in Quebec showed only a small excess from lung cancer. However, the "heavily exposed" workers had a rate of lung cancer five times that of the "lightly exposed" workers (McDonald et al., 1971).

Whether the carcinogenic role of asbestos is related to the specific kind of fiber has not yet been determined. Only one study exists that involves exposure to only one kind of fiber. This study showed that exposure occurring during the mining of anthophyllite in Finland was associated with a three-fold increase in lung cancer deaths (Kiviluoto and Meurman, 1970). It should be pointed out that this was a small study (eight cases) and observed only short exposure times.

The data from one occupational study suggests a cocarcinogenic role for asbestos. In the study of insulation workers by Selikoff et al. (1968), not a single bronchogenic cancer was found in an insulation worker who was a noncigarette smoker, even though asbestos exposures were the same as for those who smoked and developed lung cancer. The role of cofactors other than cigarette smoking remains to be determined.

Mesothelial Tumors

Primary malignant tumors of the pleura, peritoneum, and pericardium have been a matter for dispute until very recent times. Investigators in many parts of the world have examined the

distribution and the frequency of mesothelioma in populations occupationally exposed to asbestos. These studies indicate that there is a relationship between exposure to asbestos fiber and the incidence of mesothelioma (Wright, 1969).

However, there still remains some controversy among pathologists regarding diagnostic criteria. Histological aspects, as well as the determination by autopsy, of whether the tumor is primary or secondary, are the major points of difference (NAS, 1971). Many of the cases reported in the literature as being related to asbestos are diagnosed on the basis of a biopsy alone, so that under- or over-diagnosis of mesothelioma is possible (Wright, 1969).

Approximately seven percent of deaths among asbestos workers are caused by pleural and peritoneal mesothelioma (2/3 peritoneal and 1/3 pleural). After diagnosis, the duration of life is only infrequently longer than a year (ESL, 1973).

It has been suggested that inhaled asbestos fibers cleared from the lung and swallowed migrate through the gastrointestinal (GI) wall to the peritoneum. This may account for the association of peritoneal mesotheliomas with inhalational exposure to asbestos. It is estimated that only about 1% to 2% of the dust inhaled during a lifetime is retained in the lungs. The remainder is transported via the pulmonary clearance mechanism to the pharynx, thus it is probable that the GI tract receives much of the inhaled and subsequently ingested dust including fibers (Gross, et al., 1974).

The first cases reported in the literature were not taken seriously until 1960, when Wagner reported 33 cases of pleural mesothelioma discovered in the Northwest Cape of South Africa. Seventeen of the cases were from occupational exposure; all but two of the remaining had lived near the mines or had household contacts (Wagner et al., 1960).

No studies have been possible to determine if a specific kind of fiber is involved in the relationship between asbestos and mesothelioma. However, the Kiviluoto and Meurman (1970) study has been cited in this regard because not a single mesothelioma was observed in a population of mine and mill workers exposed only to anthophyllite. Caution has been urged, however, as the period between exposure to asbestos and the appearance of mesothelioma is often longer than 30 years (Wagner, 1965; Selikoff and Hammond, 1963).

All of the studies which indicate differences in pathogenicity among various types of fibers conspicuously lack quantitative data on cumulative exposures, fiber characteristics, and the presence of other substances and cofactors.

There has been some speculation where mesothelioma cannot be related to occupational, para-occupational, or specific environmental exposure to asbestos. Selikoff has pointed out that asbestos is not the only substance shown to be associated with mesothelioma; the disease has also been associated with silica and polyurethane (in laboratory animals) (Selikoff and Hammond, 1968).

Gastrointestinal Cancers

A two to three-fold increase in the incidence of gastrointestinal-tract cancer (stomach, colon, esophagus, rectum) has been observed among asbestos workers (ESL, 1973).

Since 1955 asbestos-like fibers have entered the water supply of Duluth, Minnesota. Masson et al. (1974) conducted a study of the correlations to cancer mortality for Duluth from 1955-1969. They found no carcinogenic effect apparent in the patterns of cancer mortality among persons of all ages in Duluth for the 14 year period. An excess of cancers of the colon for 1965-1969 was observed, but, the authors feel it was a chance observation since the latest statistics on asbestos workers show cancer of the esophagus and stomach in far greater excess than cancer of the

colon. Masson, et al. point out that their study cannot be considered conclusive since the period of observation is short relative to the observed latent periods for occupationally induced carcinogenesis from asbestos. A much longer follow-up is necessary in the future to assess the cancer hazard related to asbestos fibers in drinking water supplies.

Other Cancers

Asbestos has also been suggested as an etiologic factor in ovarian cancer. Asbestos-related mesotheliomas have been observed to resemble ovarian cancer in appearance (Graham and Graham, 1967). Keal (1960) was impressed by a higher incidence of ovarian cancers in women suffering from pulmonary asbestosis as compared to other women.

Generally, studies on other cancers and their association with asbestos are inconclusive, due in part to insufficient data concerning other substances and other factors associated with exposure (NAS, 1971).

Pleural Calcification

Calcified pleural plaques have been observed frequently in workers exposed to asbestos (NAS, 1971). Pleural plaques are also used by some investigators in diagnosing an asbestos-related disease (ESL, 1973).

Pleural calcification has been reported to occur in varying frequencies in different occupationally exposed groups. These differences have not been explained (NAS, 1971; Kleinfeld, 1973).

In asbestos workers, calcified plaques rarely appear until 20 years after their first exposure and are not necessarily correlated with fibrosis (NAS, 1971).

Pleural plaques are often absent in persons with well-developed, diffuse, pulmonary fibrosis resulting from asbestos exposure, and they can be very extensive in persons with little or no diffuse fibrosis (Wright, 1969).

The finding of pleural calcification or pleural plaques in large segments of populations that are not directly exposed occupationally but live in or near regions where asbestos fibers are produced and used has been reported as being common (Wright, 1969; Kleinfeld, 1973; Kiviluoto, 1960).

No evidence exists to indicate that there is any relationship between pleural plaques and the development of mesothelioma (Wright, 1969; Kleinfeld, 1973).

The use of pleural plaques or pleural calcification as an indicator of exposure to asbestos appears to have limited value since factors other than asbestos can result in pleural calcification and the asbsence of plaques in no way connotes a lack of exposure.

"Asbestos Bodies" - Ferruginous bodies

The coated fibers characteristically observed in lung tissue in cases of asbestosis were originally called "asbestosis bodies." The designation was shortened when it was discovered that persons without asbestosis had these bodies in their lungs. It was later determined that the presence of these bodies is not always related to asbestos exposure but may be due to other fibrous materials which can produce bodies identical in appearance (Gross *et al.*, 1969). Gross and associates (1968(a)) suggested the term "ferruginous bodies" (rust color--iron containing) for these structures and felt that they should be called "asbestos bodies" *only* when it is known with certainty, or could be presumed on the basis of known exposure, that the central fiber of the body is in fact asbestos.

The frequency of "bodies" occurring in the lungs of the general public apparently depends upon the volume of lung tissue examined and on the intensity of the search. Findings have ranged from 25 to almost 100 percent frequency in the population studies

which involve direct examination of long tissues or of the juices pressed from such tissue (Thomson, 1965; Utidjian et al., 1968).

Attempts at identifying the core fibers have often been unsuccessful because of inconclusive results (NAS, 1971).

The total amount of fibrous matter in the lung has recently become the focus of attention; that is, coated and uncoated fibers are enumerated and identification attempts made. A study of 3,000 consecutive autopsies in New York City showed that approximately half (1449) had coated fibers in the lungs and that two-thirds of these also had uncoated fibers present. One-quarter of the total sample had no coated fibers in the lungs. Twenty-eight samples from this same series were examined by electron microscopy and were found to contain sublight microscopic chrysotile fibers (Langer et al., 1971).

It appears to be relatively well established that asbestos fibers are present in many human lungs. However, it is noteworthy that sources of airborne fibers exist other than asbestos. Some vegetable fibers are probably derived from the burning of leaves and from burning plant products such as paper, wood, and coal. Man-made fibers (principally vitreous) have also been identified in the sediment isolated from human lungs. Talc, mentioned several times earlier in this report, may contain significant amounts of asbestos fibers (NAS, 1971).

Information is limited concerning the increasing use of asbestos and its correlation with increased numbers of lungs containing fibers and ferruginous bodies. Reports in the literature include those of Selikoff and Hammond (1969) who compared lung tissues obtained in 1934 with 1967 samples and found no significant increase in the number of lungs containing ferruginous bodies. However, Um (1971) reported an increase in asbestos bodies each succeeding decade in samples of lungs taken from persons who died in London in 1936, 1946, 1956, and 1966.

Davis and Gross (1973) have observed that many of the fibers found in the lungs of adults are less than five microns long and about 10% can be identified as chrysotile. After study of ferruginous bodies in lungs not industrially exposed to asbestos fibers, they concluded that ferruginous bodies do not qualify as an index of asbestos air pollution for the following reasons:

"(1) Ferruginous bodies are not specific for asbestos.

(2) There is no quantitative relation between the number of ferruginous bodies and the number of asbestos fibers in a lung.

(3) The mobility of people in industrialized communities precludes the likelihood that ferruginous bodies found in a lung are nucleated by fibers inhaled in only one community."

It is clear that further study of ferruginous bodies is necessary in both qualitive and quantitative terms before any meaningful interpretation of their significance can be made as to health risk for persons other than those occupationally and para-occupationally exposed.

XI. TOXICITY - ANIMAL STUDIES

Presently, there are no satisfactory experimental models which can duplicate the prolonged inhalation of asbestos by man. Studies of routes other than inhalation are very limited. Most studies involve inhalation or the intrapleural administration of asbestos associated with asbestosis and/or neoplasia.

Experimental Asbestosis

Asbestosis (pulmonary fibrosis) has been produced in various species including rats, guinea pigs, hamsters, rabbits, and monkeys (Wagner, 1963). The fibrosis produced resembles early asbestotic development in man. However, in order to produce diffuse fibrosis, very high concentrations of asbestos dust and long periods of exposure or observation were necessary. Studies to determine correlations between asbestosis and fiber length have been inconclusive (NAS, 1971).

Experimental Neoplasia

The following possible mechanisms for carcinogenesis have been or are under consideration: (Harington *et al.*, 1967).

(1) That it is due entirely, or in part, to organic materials associated with the fiber, either naturally or as a result of contamination or treatment of the asbestos during processing.

(2) That it is due to the presence of certain carcinogenic metals or metal-complexes in asbestos from ores or from mining, milling, processing, and shipping operations.

(3) That it is an "Oppenheimer effect," i.e., that cancer arises as a result of prolonged residence in the tissues of a chemically inert material which cannot be removed or can only be slowly removed by phagocytosis.

(4) Related to (3) above is the size distribution of fibers (length and diameter).

(5) The type of asbestos may be relevant.

(6) The promoting or potentiation of other organic and inorganic substances in the respiratory tract may be enhanced.

Lung cancer has been produced in rats (sixteen out of seventy-two) from inhalation exposure to chrysotile dust (86 mg/M_3) (Gross et al., 1967 (b)).

Other investigators (Stanton et al., 1969) did not find a carcinogenic response in the lung or pleura of rats exposed to implanted wax pellets containing asbestos; nor was there a response from artificially produced infarcts which allow accumulation of asbestos fibers. However, sarcomas of the pleura and pericardium developed in 74% of those rats in whom the pleura was covered with an asbestos-impregnated, fibrous, glass coat.

Continuation of Stanton's work (Stanton and Wrench, 1972) with amosite, chrysotile, and four different specimens of crocidolite applied via a fibrous glass vehicle to the pleura of rats yielded high incidences of pleural mesotheliomas (ranging from 58 to 75%) two years later. (The sample size of the experimental rat groups was 30.)

Mesothelioma has been reported in rats and hamsters that received intrapleural injections of amosite, chrysotile, and crocidolite (Smith et al., 1965; Wagner, 1962; Wagner and Berry, 1969). However, the amounts introduced were very large, and extrapolation of these results to human inhalation cannot be used for drawing firm conclusions.

Malignant mesotheliomas were induced in the peritoneum of rats by a single injection of chrysotile or crocidolite asbestos fibers. Immediate toxicity manifested as acute peritonitis producing approximately 40% mortality was noted in both groups eight days after injection. In the first two or three days after intraperitoneal injection, liver sections from the crocidolite

group revealed clearly visible asbestos fibers surrounded by white blood cells. Between ten and fourteen months after exposure, nine of 45 rats developed peritoneal mesothelioma. In the chrysotile group, eight of 33 rats developed peritoneal mesothelioma. Shin and Firminger (1973) feel that the large numbers of asbestos fibers in their experiments played an important role in producing cytotoxic inflammatory reactions with subsequent fibrosis, which may not be directly related to the development of mesothelioma. They suggest that the initiation of mesothelioma may be associated with a much smaller number of asbestos fibers without significant inflammatory reaction at the site.

It has been suggested that natural oils, waxes, and contaminant oils from milling could contribute to the induction of cancer (Harington and Roe, 1965). However, asbestos samples prepared from the five UICC standards (amosite, Rhodesian and Canadian chrysotile, crocidolite, and anthophyllite) from which the oils were extracted gave very similar results to unextracted fibers. In total, 58 out of 160 rats in the oil-extracted group and 56 out of 160 in the unextracted group developed mesotheliomas after intrapleural administration (Wagner, 1972).

Studies to ascertain the importance of fiber diameter, length, and shape have been conducted. Timbrell and Rendrall (1972) ground UICC Canadian chrysotile to a fine powder; it produced higher incidences of mesothelioma by intrapleural administration in rats than did the standard. However, Stanton and Wrench (1972) found fewer mesotheliomas with pulverized UICC crocidolite than with the standard. It should be pointed out that these studies are not strictly comparable because techniques of grinding may differ; the asbestos type may be different; and other test parameters may have varied.

Chrysotile asbestos powder (50% suspension in normal saline) was intraperitoneally injected into mice. A proliferative, granulomatous, and invasive fibrosis was observed to be histologically

similar to mesothelioma, although specific morphologic evidence of an actual malignancy was not obtained (Jagatic et al., 1967).

Evidence that variation in fibrogenic and carcinogenic response is correlated to asbestos fiber length has been inferred by observations in hamsters. Intrapleural injections of 25 mg samples of chrysotile suspended in saline were administered to test groups of 50 hamsters maintained up to 700 days. Groups injected with long fibers (5.3 to 38.9 microns) showed intra-thoracic tumors with characteristics of pleural mesotheliomas in approximately one-fifth of the test group (ten animals). The shorter fiber groups (0.37 to 0.86 microns) induced relatively thin pleural adhesions with no characteristics of mesothelioma (Smith et al., 1972).

Stanton (1974) and Gross (1974) have focussed attention on fiber size as the the possible carcinogenic mechanism in asbestos cancers as a result of the observed lack of effects in experimental studies associated with "small" asbestos fibers i.e. fibers <5μ in length (Gross) and >3μ diameter of various lengths or <3μ diameter and <20μ length (Stanton). If these observations are correct, the majority of asbestos fibers to which people in the general environment are exposed would be "too small" or "too large" to be considered potent carcinogens (Stanton, 1974). The asbestos fibers present in drinking water and certain beverages nearly all fall into the "toc small" catagory. Stanton (1974) also raises the possibility that if fiber size is the important carcinogenic factor then other fibers generally >5μ length may present a carcinogenic hazard.

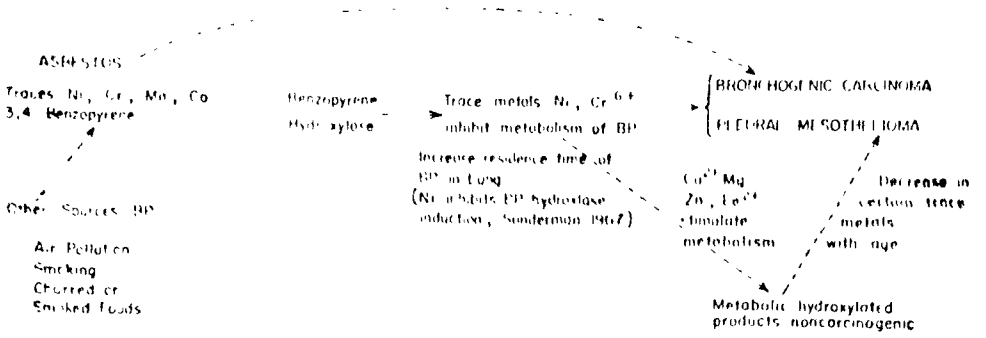

Figure 5. Working Hypothesis of Trace Metals in Chemical Carcinogenesis in Asbestos Cancers

A mechanism was hypothesized by Dixon et al., (1970) which involved the role of trace metals in chemical carcinogenesis associated with asbestos cancers (see figure 5). The experimental work relating to this hypothesis involved an in vitro procedure where microsomal fractions of homogenates (from rat lungs) were used to which were added increasing concentrations of metals (associated with asbestos).

Results were that metals could stimulate or inhibit the activity of BP hydroxylase depending on the relative concentration of the metal added to the microsomal fraction.

All the metals do not show the same activity. Copper (Cu+2), Magnesium (Mg+2), iron (Fe+2), zinc (Zn+2), nickel (Ni+2), and cobalt (Co+2) stimulated BP hydroxylase enzyme activity significantly at low concentrations as well as inhibited the enzyme at higher concentration. Beryllium (Be+2), iron (Fe+3), and chromium (Cr+6) significantly inhibited the enzyme. No effect was demonstrated with arsenic (As+3), selenium (Se+4), and chromium (Cr+3).

Trace metals extracted from chrysotile asbestos, when added to the enzyme reaction mixture, inhibited enzyme activity approximately 73%. The investigators feel that inhibition of BP hydroxylase by the trace metals contained in chrysotile suggests that chrysotile has the potential for interfering with the detoxication of benzopyrene and could thereby contribute to carcinogenesis (Dixon et al., 1970).

Studies conducted by Roe et al. (1967) in mice showed the development of pleural and peritoneal mesothelioma after subcutaneous injections of crocidolite, amosite, and chrysotile, indicating that asbestos fibers can migrate in tissue. These studies are of otherwise limited significance in drawing conclusions regarding the pathogenicity of these fibers to man, in whom subcutaneous exposure would be uncommon.

Studies Related to the Ingestion of Asbestos

In female rats that were fed chrysotile asbestos (six percent in a synthetic diet), electron microscopy revealed asbestos particles on many sites in the colonic epithelium and lamina propria. These particles appeared to have migrated through the mucus of the goblet cells into the cell itself and then to the lamina propria. It was suggested by the researchers that this observation may have significance in relation to carcinogenesis of the gastrointestinal tract (Westlake et al., 1965).

Chrysotile fibers injected into the stomachs of rats were isolated two to four days later from the blood, spleen, liver, kidney, omentum, muscle, lung, and brain. The highest levels were found in the omentum. The investigators concluded that this was evidence that the fibers crossed the GI wall. Tissues were solubilized and samples prepared for observation with the electron microscope. Unexpected high levels of asbestos, the source of which could not be determined, were also found in the tissues of the control rats (Cunningham and Pontefract, 1973). Table 8 summarizes these results.

Tritated chrysotile fibers intravenously injected into rats are rapidly removed from the blood; most of them are deposited in the tissues within six minutes, with the highest levels being found in the lungs, liver, and spleen. But during the next 24 hours the levels in the lung tend to fall and the levels in the liver, spleen, and muscle increase slightly (Ibid).

Table 8. Asbestos Fibers Found After Intragastric Injection (Millions/g)

Tissue	Controls	Killed at 2 days (9.4 billion administered)	Killed at 4 days (94 billion administered)
Blood	0.00	4.65**	1.19
Spleen	2.33	4.11	3.45
Omentum	2.46	2.74	18.25
Heart	2.09	—	2.28
Brain	0.05	0.31	0.29*
Lungs	1.06	1.80	1.74

* = $P \leq 0.05$; ** = $P \leq 0.01$.

Neutron-activated asbestos intravenously injected into rats on the fifteenth day of pregnancy resulted in considerable activity in the whole fetus and in fetal liver. The authors feel this is another indication of the ability of asbestos fibers to cross membranes (Ibid).

Pinocytosis (incorporation into a cell by invagination and pinching off of a region of membrane) and physical piercing have been suggested as mechanisms by which asbestos fibers could cross the gastrointestinal wall (Cunningham and Pontefract, 1973).

As an adjunct to their studies, Cunningham and Pontefract (1973) analyzed for asbestos content tissues from three humans who died of natural causes. Levels of 0.378 million fibers per gram were found in the brain, 0 - 0.253 in the spleen, and 0.773 - 0.915 in the peritoneum.

Gross et al. (1974) reported on three independent investigations of the ability of ingested asbestos fibers to penetrate gastrointestinal (GI) tissue in rats. All three concluded that there was no evidence of tissue penetration or storage of ingested asbestos mineral fibers. Separate studies were conducted with

amosite, chrysotile, crocidolite and taconite tailings. The animals in one of these studies were fed asbestos (chrysotile and crocidolite groups 0.2 to 0.4% in butter) over much of their lifetime and allowed to live to the age of reproduction. No evidence of "carcinogenic" effect was observed. The very few fibers (1-3) observed in tissue digest with the electron microscope were attributed to contamination. The authors also presented the rationale that if transmigration of fibers through the GI wall was a fact, one would expect more than one to three fibers out of billions to accomplish the feat and this phenomenon to be demonstrable in more than five out of 37 rats.

The results obtained in these studies contrast those of Cunningham and Pontefract (1973) discussed above. It has been suggested that experimental error and the technique (intragrastric injection) used account for the contrasting observations.

The issue of GI transmigration of asbestos fibers is still felt to be unresolved by some. Gross et al (1974) have pointed out the differences from a histological standpoint between alveolar membrane and GI mucosa to attain a proper perspective. The alveolar membrane is largely composed of thin squamous cells, whereas the intestinal mucosa is composed not only of mucin-covered tall columnar epithelium but also by a substantial tunica propria mucosae. The GI mucosa is thus a much more formidable barrier against the intrusion of foreign particles than the alveolar membrane. In addition, the presence of enlarged, discolored satellite lymph nodes in coal and hard rock miners demonstrates penetration of the alveolar membrane. However, no such involvement of mesenteric lymph nodes has been described even though these miners ingest (via pulmonary clearance) during their lifetime many times the amount of dust retained and stored in their lungs and satellite nodes.

Webster (1974) reported on crocidolite ingestion studies with baboons. The baboons had eaten food and drunk water contaminated

with asbestos for up to five years. No evidence was found of peritoneal or gastrointestinal tumors. Only occasional asbestos fibers were found in ashed tissue of the stomach ranging in size from 0.5 to 1 micron which Webster feels probably came from iron containing macrophages.

Pooley (1974) points out that in his attempts to find asbestos fiber in GI tissue one of the first things found was that angulations in the GI tract can hold material up for an appreciable period of time with an attendant high risk of sample contamination. In addition, the mucus on the gut wall can hold material that might later be regarded as being within the specimen. Pooley found no fibers in GI tissue specimens with the light microscope and only 6 or 7 in a few animals by electron microscopy.

Davis et al. (1974) studied the penetration of cells by asbestos fibers in rats fed asbestos in butter ad libitum. Examination of the gut lining by electron microscopy showed no evidence of penetration by asbestos fibers either through or between epithelial cells.

In rats two to three days after intraperitoneal injections of crocidolite, liver sections revealed clearly visible asbestos fibers (Shin and Firminger, 1973).

Zaidi (1974) has commented on the choice of test animal for asbestos ingestion studies. He indicates that the rat is not one of the animals which should be used. Since its stomach is lined with squamous epithelium and therefore does not simulate the human stomach. Dogs and guinea pigs are suggested as the animals of choice since they seem to be most similar to man as indicated by experimental ulceration studies.

Radioactive tracer methods were used to study the distribution of crocidolite between the upper and lower respiratory tracts in rats after single, short inhalation exposures. With the UICC (International Union Against Cancer) standard reference

sample of crocidolite, it was found that 50 ± 5% of the deposited asbestos was in the lower respiratory tract after a single short exposure. Rats held for 30 days showed ^{59}Fe activity in the feces indicating about 73% excretion of the total deposition (Evans et al., 1973).

In an incompletely described study (Smith et al., 1965) using 45 hamsters maintained on a diet of one percent chrysotile or amosite throughout life, no gastrointestinal tumors or gastric carcinomas were observed. However, an anaplastic neoplasm in the mesentery near the colon was observed, as well as occasional gastric ulcers, one lymphoma that invaded the pancreas, and one cholangiocarcinoma of the liver. The researchers did not comment on the significance of these observations except to mention that gastric ulcers, lymphomas, and cholangiocarcinomas have been described as spontaneous lesions in hamsters by Fortner et al. (1961).

Other studies where animals have ingested asbestos are said to have been conducted; however, their negative results have inhibited publication. A Federal interagency effort to conduct appropriate feeding studies was begun in 1974 under FDA leadership.

Other In Vivo Studies

A study by Jagatic et al., (1967), involved intraperitoneal injections of mice with chrysotile asbestos fibers in a 50% solution of normal saline; the fibers had previously been treated at very high temperatures (1000°C) for three hours. Within 24 hours, nine had died and all 50 mice injected showed severe signs of toxicity. Within 36 hours, 26 mice were dead; at 48 hours, 30 mice were dead. The remaining 20 mice in the group showed a toxic reaction for approximately four days and subsequently recovered. A study by Hayashi (1974) using chrysotile heated to 650° to 800°C and injected intraperitoneally in mice gave similar results with death occuring in 48 hours.

Analysis of heat-treated material similar to that used by Jagatic et al. (1967) was analyzed by x-ray diffraction and showed the major constituent to be forsterite, Mg_2SiO_4. The minor constituent was identified as a member of the pyroxene group, enstatite [$Mg(SiO_3)$]. (Free crystalline silica was not detected.) Chrysotile and serpentine are converted to olivine by heating. This conversion occurs at around 750°C. The probable reaction is: $Mg_3Si_2(OH)_4 \xrightarrow{heat} 3\ Mg_2SiO_4 + SiO_2 + 4H_2O$, with SiO_2 being present as amorphous silica (Deere et al., 1966).

In Vitro Studies

In vitro effects of chrysotile, crocidolite, and amosite asbestos on hamster peritoneal macrophages have been monitored by estimating the release of acid phosphatase into the culture medium, and by changes in the phospholipid composition on the cells in addition to cell number and morphological examination. Chrysotile was observed to be toxic to the cultures, while crocidolite and amosite were relatively inert (Miller and Harington, 1972).

Chrysotile fibers have been observed to exert marked hemolytic activity on suspensions of washed sheep erythrocytes, whereas the amphiboles show only negligible hemolytic properties. Chrysotile hemolytic properties (ability to cause destruction of red blood cells) are dependent on the openess of the fibers (i.e. the degree that fiber ends are split into many fibrils); hammer-milled and air-jet-milled samples showed hemolytic activity while none of the hand-cut, crude samples was active (Schnitzer and Pundsack, 1970).

The hemolytic activity of chrysotile has been confirmed by others (Harington et al., 1971). Other forms of asbestos were observed to have varying hemolytic activities related to the magnesium to silicon ratio of each form. Notably, amosite and crocidolite were observed to be relatively inactive in this

regard. Although hemolysis as such appears to have little or nothing to do with pathogenesis, such an *in vitro* technique for hemolysis is a simple and rapid way of studying the effects of mineral dusts and fibers on a biological membrane.

CURRENT ENVIRONMENTAL REGULATIONS AND STANDARDS

Emission Standards

Illinois -- The Illinois Pollution Control Board emission standard initiated June 30, 1972, provides that "... a factory, plant, or enterprise which engages in the processing or manufacturing of any asbestos-containing product shall discharge no visible emission of particulate matter from such manufacturing or processing into the ambient air and shall emit no concentrations of asbestos fiber in excess of two fibers per cubic centimeter of air."

The method of counting specified is the phase-contrast optical technique routinely used for industrial hygiene measurements.

National -- The national emission standard under Section 112 of the Clean Air Act was published in the Federal Register, Volume 38, Number 66, pages 8821 - 8823 on April 6, 1973. This standard relies on limitations on visible emissions with an option in some cases to use designated control equipment, requirements that specific procedures be followed and prohibitions on the use of certain materials or of certain operations. EPA concluded that satisfactory means of measuring asbestos emissions are unavailable and the regulation indicates it is not practicable at this time to establish allowable numerical concentration or mass emission limits for asbestos. The standard applies to asbestos mills, selected manufacturing operations, the use of spray-on asbestos materials, demolition operations and the surfacing of roadways with asbestos tailings. Amendments to the national emission standard were published in the Federal Register, Volume 40, Number 199, pages 48292-48311 on October 14, 1975. They extend the scope of the asbestos regulations to include shot-gun shell manufacturing and asphalt plants. Among other changes disposal regulations were ammended to include properly operated sanitary landfills as acceptable disposal sites for asbestos-containing wastes.

Asbestos Spray in Building Construction

The national emission standard prohibits visible emissions from sprays containing more than one percent asbestos which are used to insulate or fireproof equipment and machinery.

On April 13, 1970, New York City took the lead in the United States and promulgated strong regulations controlling the application and use of all sprayed fireproofing materials -- both asbestos and non-asbestos-containing material (Ahmed et al., 1972). Chicago, Boston, and Philadelphia have also established regulations regarding spraying of asbestos-containing material (Ahmed et al., 1972).

On July 18, 1971, the Philadelphia Board of Health regulation prohibiting the use of asbestos spray in building construction and limiting the allowable quantity of asbestos fiber exposure became effective. Included in the regulations are the following paragraphs (Gorson and Lieberman, 1973):

"1. (a) No spray material containing asbestos as a component part shall be applied in building construction, reconstruction, or alteration within the City of Philadelphia."

"2. (b) No worker shall be exposed to the inhalation of airborne asbestos fibers exceeding the following Threshold Limit Value - asbestos (all types): five fibers (greater than five microns in length) per milliliter of air."

"4. No building shall be occupied by the general public whenever the concentration of airborne asbestos fibers exceeds the maximum permissible concentration of 2.5 fibers (greater than five microns in length) per milliliter of air averaged over any eight-hour period."

The regulations also require air monitoring for asbestos fibers in places of employment and buildings occupied by the general public whenever the concentration of airborne asbestos fibers is likely to exceed certain stated limits (Gorson and Lieberman, 1973).

Chicago's ordinance prohibits the spraying of asbestos-containing substances in or upon any building, structure, column, frame, floor, ceiling, or other portion, part, or member thereof

during its construction, reconstruction, alteration, or repair (Ahmed et al., 1972).

The Boston buildings' commissioner recently issued a directive stating that the spraying of asbestos is not an "acceptable practice" and that building permits would not be granted unless some other mode of applying asbestos is specified (Ibid).

State of Illinois regulations prohibited the spraying of asbestos-containing material on March 31, 1972. Additional regulations that became effective on April 14, 1972, provide proper housekeeping procedures for the spraying of non-asbestos products in all work performed in an area open to the atmosphere. They further provide that the cutting, fitting, trimming, and stripping of asbestos materials be conducted in properly enclosed areas (Ibid).

Effluent Standards

National -- The national effluent guidelines and standards for the asbestos manufacturing point source category under Section 304(b) of the Federal Water Pollution Control Act were promulgated in two phases. Phase I applies to the following subcategories: asbestos-cement pipe, asbestos cement sheet, asbestos paper (starch binder), asbestos paper (elastomeric binder), asbestos millboard, asbestos roofing and asbestos floor tile (published in the Federal Register, Volume 39, Number 39, pages 7526-7533 on February 26, 1974). Phase II applies to the following subcategories: coating or finishing of asbestos textiles, vapor absorption (removal of volatilized organic matter from atmospheric emissions by means of wet scrubbers) and wet dust collection (published in the Federal Register, Volume 40, Number 6, pages 1874-1878, on January 9, 1975).

Other Regulations

The U.S. Occupational Safety and Health Administration (OSHA) and the Bureau of Mines (BOM) enforce regulations which protect workers who are exposed to asbestos in their place of

employment (OSHA - 29 CFR 1910.93a; BOM - 30 CFR 55.5). On October 9, 1975, OSHA published proposed revisions to the regulations on occupational exposure to asbestos (Federal Register, volume 40, number 197, pages 47652-47665.) In general the proposed changes are more stringent than existing regulations and would require better environmental control (workroom) as well as revise and update other required industrial hygiene controls and practices. The regulations of these two Federal agencies when complied with reduce the capacity of asbestos mines, mills and associated industrial operations to become major sources of asbestos emissions. The EPA National Emission Standard takes into account the reduced pollution potential as a result of the above cited regulations.

The Food and Drug Administration (FDA) enforces regulations which limit the amount of asbestos that food, drug and cosmetics products may contain. In some cases this relates to the use of asbestos filters for preparation of these products (see Federal Register, Volume 38, Number 188, Friday, September 28, 1973).

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Appendix A

Table 1.—Salient asbestos statistics (Clifton, 1973)

		1967	1968	1969	1970	1971
United States:						
Production (sales)	short tons	123,189	120,690	125,936	125,314	130,882
Value	thousand	$11,102	$10,406	$10,648	$10,696	$12,174
Exports and reexports (unmanufactured)	short tons	47,718	41,236	36,173	46,585	53,678
Value	thousands	$6,025	$4,679	$4,979	$6,996	$7,863
Exports and reexports of asbestos products (value)	thousands	$23,767	$24,527	$28,183	$25,391	$31,419
Imports for consumption (unmanufactured)	short tons	645,112	737,909	694,558	649,402	681,367
Value	thousands	$65,743	$72,930	$76,422	$75,146	$80,090
Consumption, apparent [1]	short tons	720,583	817,363	784,321	728,131	758,571
World: Production	do	3,207,259	3,315,301	3,599,123	3,846,475	3,917,996

[1] Measured by quantity produced, plus imports, minus exports.

Table 4.—U.S. imports for consumption of asbestos (unmanufactured), by classes and countries (Clifton, 1973)

Year and country	Crude (including blue fiber)		Textile fiber		All other		Total	
	Short tons	Value (thousands)	Short tons	Value (thousands)	Short tons	Value (thousands)	Short tons	Value (thousands)
1970								
Canada	80	$4	15,398	$5,657	597,832	$64,104	613,310	$69,765
Finland	-	-	-	-	4,141	276	4,141	276
Germany, West	-	-	--	-	65	11	65	11
India	-	-	-	--	5	(1)	5	(1)
Italy	-	-	2	3	2	1	4	4
Mexico	--	--	--	--	100	20	100	20
Mozambique	--	--	-	--	70	8	70	8
Norway	--	--	--	--	132	10	132	10
Portugal	--	--	-	--	231	16	231	16
Rhodesia, Southern	--	--	--	--	200	101	200	101
South Africa, Republic of	23,788	4,158	85	18	2,855	568	26,728	4,744
Southern Africa, n.e.c.	110	22	--	--	--	--	110	22
United Kingdom	90	19	211	36	5	1	306	56
Yugoslavia	--	-	1,488	43	2,512	70	4,000	113
Total	24,068	4,203	17,184	5,757	608,150	65,186	649,402	75,146
1971								
Canada	240	96	11,620	5,306	636,782	69,577	648,642	74,979
Finland	--	--	--	--	4,182	342	4,182	342
Italy	2	4	--	--	--	--	2	4
Mexico	--	--	18	8	40	3	58	11
Mozambique	203	43	--	--	157	31	360	74
South Africa, Republic of	23,188	4,104	1	(1)	1,822	399	25,011	4,503
Swaziland [2]	160	46	--	--	230	59	390	105
United Kingdom	-	--	--	--	109	3	109	3
Yugoslavia	--	--	--	--	2,613	69	2,613	69
Total	23,793	4,293	11,639	5,314	645,935	70,483	681,367	80,090

[1] Less than ½ unit.
[2] Effective Jan. 1, 1971, formerly Southern Africa, n.e.c.

Table 5.—U.S. imports for consumption of asbestos from specified countries, by grades (Clifton, 1973)

(Short tons)

Grade	1970			1971	
	Canada	Southern Rhodesia	Republic of South Africa	Canada	Republic of South Africa
Chrysotile:					
Crudes	80	--	591	188	1,655
Spinning fibers	15,398	-	85	11,620	1
All other	597,832	200	2,855	636,782	1,822
Crocidolite (blue)	--	--	8,936	52	6,953
Amosite	--	--	14,261	--	14,580
Total	613,310	200	26,728	648,642	25,011

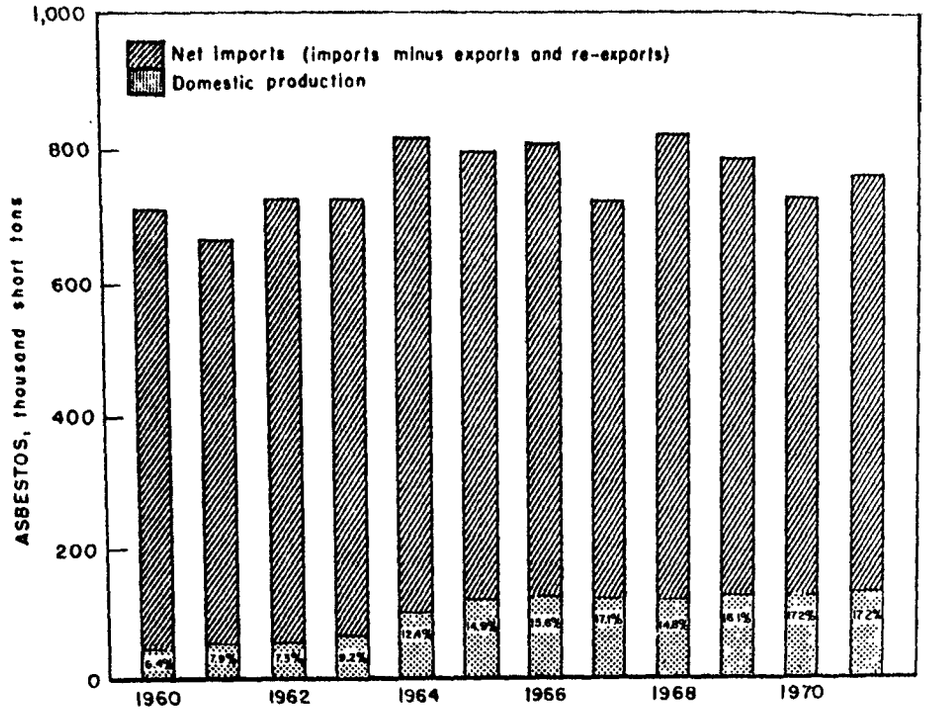

Figure 1.—Domestic consumption of asbestos. (Clifton, 1973)

Table 6.—Asbestos: World production, by country [1]

(Short tons)

(Clifton, 1973)

Country	1969	1970	1971 [p]
North America:			
Canada (sales)	[r] 1,576,876	1,661,644	1,634,662
United States (sold or used by producers)	125,936	125,314	130,882
South America:			
Argentina	359	39	[e] 40
Brazil [e]	[r] 14,000	18,000	22,000
Europe:			
Bulgaria	3,100	3,307	[e] 3,300
Finland [2]	[r] 15,487	15,019	[e] 15,000
France [e]	550	550	550
Italy	124,039	130,614	131,692
Portugal	224	223	[e] 220
U.S.S.R. [e]	[r] 1,060,000	1,175,000	1,270,000
Yugoslavia	12,634	13,342	17,011
Africa:			
Mozambique	868	251	[e] 250
Rhodesia, Southern [e]	88,000	88,000	88,000
South Africa, Republic of	284,588	316,822	351,963
Swaziland	[r] 43,077	36,439	39,114
United Arab Republic	--	[3] 495	[e] 500
Asia:			
China, People's Republic of [e]	[r] 175,000	190,000	175,000
Cyprus	23,927	28,247	[e] 24,925
India	10,734	10,840	12,122
Japan	[r] 23,141	23,451	[e] 24,000
Korea, Republic of	6,515	1,513	--
Philippines	[r] 50	1,337	[e] 1,300
Taiwan	3,396	3,133	2,565
Turkey	5,698	1,857	[e] 1,900
Oceania: Australia	[r] 924	1,008	[e] 1,000
Total	[r] 3,599,123	3,846,475	3,947,996

[e] Estimate. [p] Preliminary. [r] Revised.

[1] In addition to the countries listed, Czechoslovakia, North Korea, and Romania also produce asbestos, but available information is inadequate to make reliable estimates of output levels.

[2] Includes asbestos flour.

[3] Includes vermiculite.

[4] Exports.

PRICES*

(Clifton, 1973)

Quoted prices for Quebec asbestos were increased 4 to 6 percent effective July 1, 1971. The increases were not abnormal in an inflationary economy, but the price of British Columbia and Arizona asbestos remained unchanged.

Prices for Arizona chrysotile asbestos have remained unchanged since August 1, 1968. Quotations, f.o.b. Globe, were as follows:

Grade	Description	Per short ton
Group No. 1	Crude	$1,410-1,650
Group No. 2	do	700- 950
AAA		800
Group No. 3	Nonferrous filtering and spinning.	425- 700
Group No. 4	Nonferrous plastic and filtering.	400- 500
Group No. 5	Plastic and filtering	385- 425
Group No. 6	Refuse or shorts	250
Group No. 7	do	65- 90

As of July 1, 1971, Vermont chrysotile asbestos, f.o.b. Morrisville, was priced as follows:

Grade	Description	Per short ton
Group No. 4	Shingle fiber	$220.00
Group No. 5	Paper fiber	159.50-187.50
Group No. 6	Waste, stucco or plaster fiber.	116.00
Group No. 7	Shorts and floats	43.50- 97.00

Quotations for Canadian (Quebec) chrysotile, f.o.b. mine, were as follows, as of July 1, 1971:

Grade	Description	Per short ton
Group No. 1	Crude	Can $1,615
Group No 2	do	875
Group No. 3	Spinning fiber	412- 675
Group No. 4	Shingle fiber	227- 383
Group No. 5	Paper fiber	164- 195
Group No. 6	Waste, stucco or plaster.	120
Group No. 7	Refuse or shorts	52- 100

Prices for British Columbia, Canada, chrysotile asbestos have remained unchanged since January 1, 1971. Quotations, f.o.b. Vancouver, were as follows.

Grade	Description	Per short ton
AAA	Nonferrous spinning fiber.	Can$877
AA	do	697
A	do	529
AC	Asbestos cement fiber.	380
AK	Shingle fiber	263
CP	do	248
AS	do	228
CT	do	223
AX	do	208
CY	do	147
AY	do	147

Private negotiated sales are the African asbestos producers' modus operandi. As this rules out market quotations, the following are averages, regardless of grade, of the values of South African imports calculated from U.S. Department of Commerce Data:

Type	Per short ton		
	1969	1970	1971 [1]
Amosite	$153	$160	$164
Crocidolite	189	196	212
Chrysotile	192	198	120

[1] First 6-month data on exports, Department of Mines, Johannesburg.

Figure 2, drawn from calculations on pertinent data,[4] depicts dramatically that the increased demand and greater price increases have gone to the asbestos used in cement products (groups 5, 7).

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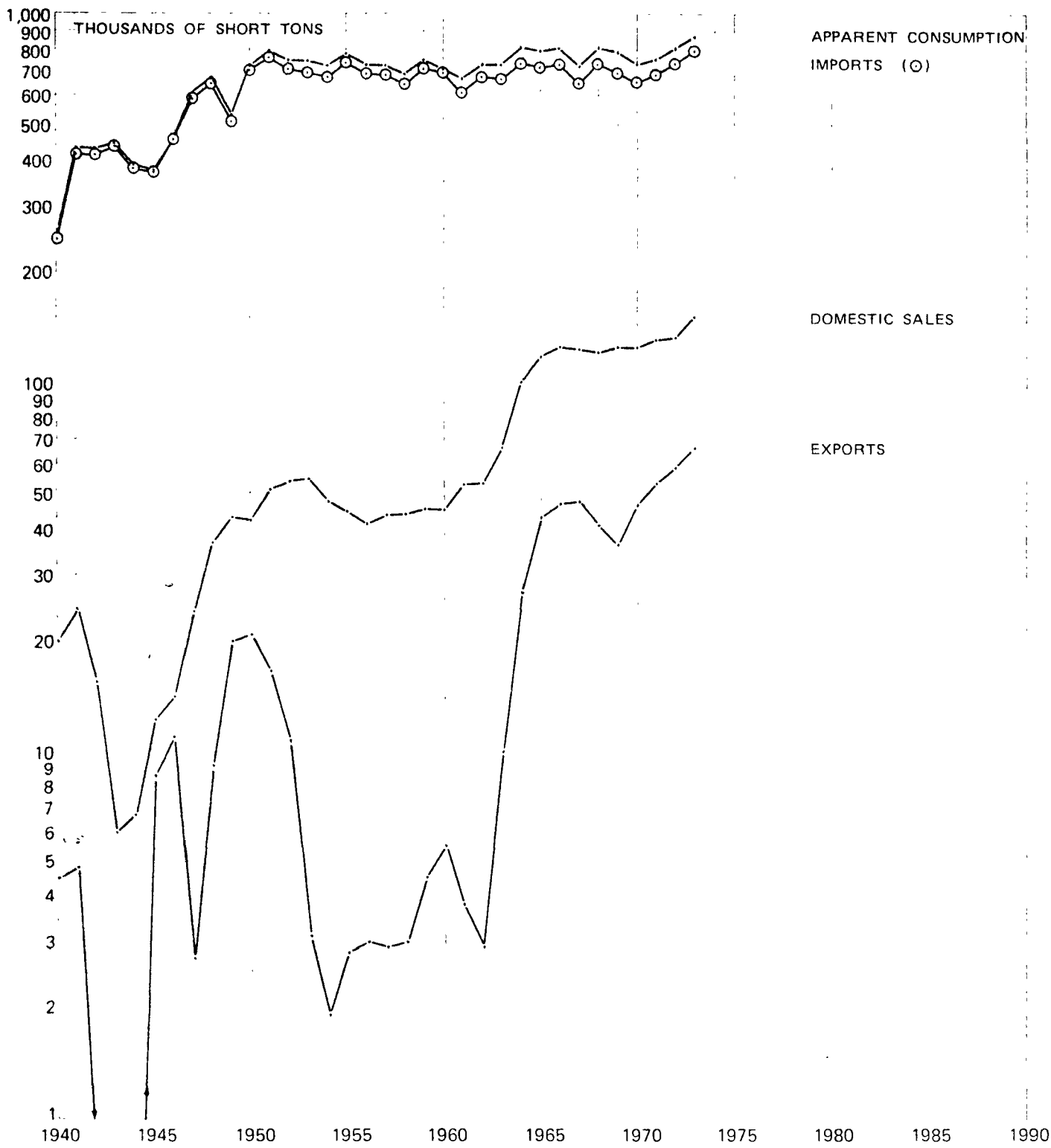
*Asbestos. V. 53, No. 4, October 1971, p 44.

[4] Industrial Minerals (London). No. 28, January 1970, pp. 9-29.

ASBESTOS – SALIENT STATISTICS



(1) ADDITIONAL CATEGORY: PRODUCTION is included in the table. Data have not been available since 1957.

(2) Data for 1973 are preliminary.

(3) ASBESTOS are naturally occurring fibrous mineral silicates that are classified as serpentine or amphibole. Serpentine (chrysotile) fibers are tubular with a large cross-section. Amphibole fibers (further subdivided by chemical structure as anthophyllite, amosite, crocidolite, tremolite, and actinolite) are solid and appear as narrow sheets of smaller cross-section.

20 B

ASBESTOS — SALIENT STATISTICS

(Thousands of Short Tons)

	DOMESTIC PRODUCTION	DOMESTIC SALES	IMPORTS	EXPORTS	APPARENT CONSUMPTION
1940	19.2	20.1	246.6	4.5	262.2
1941	22.4	24.4	419.2	4.8	438.7
1942	15.3	15.5	419.2	0.8	433.9
1943	3.9	6.0	440.3	0.4	445.9
1944	7.6	6.7	383.0	0.5	389.2
1945	13.6	12.2	374.4	8.6	378.0
1946	14.4	14.1	455.7	11.0	458.7
1947	25.1	24.0	594.8	2.7	616.2
1948	37.2	37.1	647 9	9.2	675.7
1949	42.9	43.4	509.4	20.0	532.7
1950	41 4	42.4	705.5	20.9	727.0
1951	51.7	51.6	761.9	16.5	797 0
1952	53.9	53.9	709.5	10.7	752.6
1953	58.0	54.5	692.2	3.1	743.6
1954	45.8	47.6	678.4	1.9	724.1
1955	44.8	44.6	740.4	2.8	782.2
1956	41.6	41.3	689.9	3.0	728.3
1957	43.0	43.7	682.7	2.9	723 5
1958	--	44.0	644.3	3.0	685.3
1959		45.5	713.0	4.5	754.0
1960		45.2	669.5	5.5	709 2
1961		52.8	616.5	3.8	665.5
1962		53.2	676.0	2.9	726 2
1963		66.4	667.9	10.0	724.2
1964		101 1	739.4	27.1	813 3
1965		118.3	719.6	43.1	794 7
1966		125.9	726.5	47.0	805.4
1967		123.2	645.1	47.7	720.6
1968		120 7	737.9	41.2	817.4
1969		125 9	694.6	36.2	784.3
1970		125 3	649.4	46.6	728.1
1971		130 9	681.4	53.7	758 6
1972		131 7	735.5	58 6	808.6
1973p	--	150.1	792 5	66 4	[illegible]
1974		114.0	766.[illegible]	[illegible]	[illegible] p

See MANUAL OF CURRENT INDICATORS for additional data.

4) PRODUCTION and SALES. Domestic production consists of chrysotile from mines in Arizona, California, and Vermont and anthophyllite from mines in North Carolina. Production value was $10.7 million in 1970, $12.2 million in 1971, $13.4 million in 1972, and $16.4 million in 1973. In 1972, California accounted for 69% of the total domestic production (from 4 mines), followed in order of production by Vermont (1 mine), Arizona (1 mine), and North Carolina (2 mines). Since 1940, the number of mines operating domestically has varied from a low of 8 in 1946 and 1972 to a high of 21 in 1954, with a mean number of 12 mines. Data for 1947, the last year in which a production breakdown was given, were 24 5 thousand short tons of chrysotile and 0 7 thousand short tons of amphibole.

5) IMPORTS Data represent shipments of unmanufactured asbestos. Principal imports are chrysotile from Canadian mines (711.3 thousand short tons in 1972), amosite, crocidolite, and chrysotile from South Africa (7.1, 5.4, and 2.4 thousand short tons, respectively, in 1972), and unmanufactured crudes, chiefly from Canada, Finland, and the Republic of South Africa Imports of chrysotile that had been under the Rhodesian Sanctions were resumed in 1972

6) EXPORTS Data represent shipments of unmanufactured asbestos Data for 1940-1946 include material of domestic origin or foreign material that has been milled, blended, or otherwise processed in the United States. Beginning in 1947, data also include material that has been imported and subsequently exported without processing. India, Japan, and South Korea have been major recipients of exports since 1965, of the total exports in 1972, these three countries accounted for 44% (25 7 thousand short tons). Imports to South Vietnam have increased from 1.7 thousand short tons in 1970 to 6.4 thousand short tons in 1972 (11% of the total).

ASBESTOS – SALIENT STATISTICS

(7) APPARENT CONSUMPTION. Reported by the Bureau of Mines and based on asbestos sold or used by producers, plus IMPORTS, minus EXPORTS. Chrysotile accounted for over 97% of the total apparent consumption in 1972 The construction industry (e.g., asbestos cement for pipes and other building materials) is the chief domestic market for asbestos, accounting for 42% of total consumption in 1972. Other end uses, and relative 1972 consumption, are: floor tile-11%, friction products-10%, paper-9%, asphalt felts-6%, packing and gaskets-4%, insulation-2%, and textiles-1% (The data for this consumption pattern are based on a revised form and from an expanded list of consumers, and therefore are not comparable to previously issued data.) Since 1964, imports have accounted for 89-91% of total domestic consumption (down from an earlier average of approximately 95%).

(8) Government stocks as of October 31, 1972, contained 58.6 thousand short tons of amosite, 12.2 thousand short tons of specification grade chrysotile, and 25 4 thousand short tons of crocidolite.

(9) Because of its reported carcinogenic effect and its deleterious respiratory effects, environmental regulations have been established for asbestos mining, milling, and manufacture by the following U.S. Government agencies: Bureau of Mines, Environmental Protection Agency, Food and Drug Administration, and the Occupational Safety and Health Administration. These regulations limit the incidence of fibers in ambient air (restrictions to be tightened further in 1976, if not earlier) and in water effluent; in addition, these regulations restrict the use of asbestos products in certain areas and applications (e.g., fibers for general use, and filters in food and drug production). Although it is not yet evident in the above statistics, these regulations will soon have an adverse effect on production and markets.

SOURCES: (A) MINERALS YEARBOOK, U.S Department of the Interior, Bureau of Mines (PRODUCTION, SALES, and APPARENT CONSUMPTION data for 1940-1972, and IMPORTS and EXPORTS data for 1940-1971)

(B) MINERAL INDUSTRY SURVEYS, ASBESTOS, 1973 Annual, Preliminary, U.S. Department of the Interior, Bureau of Mines (SALES datum for 1973).

(C) U.S. IMPORTS–GENERAL AND CONSUMPTION, FT 135, U.S. Department of Commerce, Bureau of the Census (IMPORTS data for 1972 and 1973).

(D) U.S. EXPORTS, FT 410, U.S. Department of Commerce, Bureau of the Census (EXPORTS data for 1972 and 1973).

(E) Kirk-Othmer, Editors, ENCYCLOPEDIA OF CHEMICAL TECHNOLOGY, Second Edition, Volume 2, Interscience Publishers, New York, 1963, pp. 734-742 (information in footnote 3).

ASBESTOS EMISSIONS
(Davis *et al.*, 1970)

1 9 6 8

SOURCE CATEGORY	SOURCE GROUP	SHORT TONS	
MINING AND OTHER BASIC PROCESSING	Mining and Milling		5,610
REPROCESSING			678
	Friction Materials	312	
	Asbestos Cement Products	205	
	Textiles	18	
	Paper	15	
	Floor Tile	100	
	Miscellaneous	28	
CONSUMPTIVE USES			291
	Construction	61	
	Brake Linings	190	
	Steel Fireproofing	15	
	Insulating Cement	25	
INCINERATION OR OTHER DISPOSAL			NA
	TOTAL		6,579

NA - Data not available

EMISSIONS BY REGION

	PLANTS	SHORT TONS
Region No. 1	7	3570
Region No. 2	-	-
Region No. 3	1	20
Region No. 4	1	2020

Regional distribution includes the source groups - Mining and Milling (representing 85 percent of total emissions)

Undistributed 15 percent 969

ASBESTOS EMISSIONS FACTORS
(Davis *et al.*, 1970)

MINING AND OTHER PROCESSING	C	93 lb/ton of asbestos produced
REPROCESSING		
Friction Materials	C	6 lb/ton of asbestos processed
Asbestos Cement Products	C	1 lb/ton of asbestos processed
Textiles	C	2 lb/ton of asbestos processed
Paper	C	1 lb/ton of asbestos processed
Floor Tile	C	1 lb/ton of asbestos processed
CONSUMPTIVE USES		
Brake Linings	NC	10 lb/ton of asbestos processed
Steel Fireproofing	NC	10 lb/ton asbestos applied
Insulating Cement	C	25 lb/ton asbestos applied

Asbestos emissions factors are based on particulate control indicated as follows:

Mining and Other Processing	-	Eighty percent.
Friction Materials	-	Ninety five percent.
Asbestos Cement Products	-	Seventy five percent.
Textiles	-	Ninety five percent.
Paper	-	Seventy five percent.
Floor Tile	-	Seventy five percent.
Insulating Cement	-	Eighty nine percent.

C - Controlled
NC - Not Controlled

Appendix B

ASBESTOS MINES IN THE UNITED STATES
(Davis, 1970)

ARIZONA	LOCATION	ASBESTOS TYPE
Asbestos Manufacturing Company	Gila County	Chrysotile
Jaquays Mining Corporation	Gila County	Chrysotile
Metate Asbestos Corporation	Gila County	Chrysotile
CALIFORNIA		
Atlas Minerals Corporation	Fresno County	Chrysotile
Coalinga Asbestos Company [1]	Fresno County	Chrysotile
Pacific Asbestos Corporation [2]	Calaveras County	Chrysotile
Union Carbide Corporation	San Benito County	Chrysotile
NORTH CAROLINA		
Powhatan Mining Company	Yancey County	Anthophyllite
Powhatan Mining Company	Jackson County	Anthophyllite
Powhatan Mining Company	Transylvania County	Anthophyllite
VERMONT		
GAF Corporation	Orleans County	Chrysotile

[1] - Owned by Johns-Manville Corporation

[2] - Acquired by H. K. Porter Company, Inc. during 1968.

REPROCESSING PLANTS PRODUCING ASBESTOS FRICTION MATERIALS (Davis, 1970)

CALIFORNIA	LOCATION
H. Krasne Manufacturing Company	Los Angeles
Silver Line Brake Lining Corporation	Los Angeles
Lasco Brake Products Corporation, Ltd.	Oakland
CONNECTICUT	
H. K. Porter Company, Inc.	Middletown
Raybestos-Manhattan, Inc.	Stratford
ILLINOIS	
Gatke Corporation	Chicago
Grizzly Brake Division of Mar Pro Inc.	Chicago
The L. S. Miley Company	Chicago
Johns-Manville Corporation	Waukegan
INDIANA	
Raybestos-Manhattan, Inc.	Crawfordsville
H. K. Porter Company, Inc.	Huntington
World Bestos Company (sub. of Firestone Tire & Rubber Co.)	New Castle
KENTUCKY	
H. K. Porter Company, Inc.	Richmond
MASSACHUSETTS	
Auto Friction	Lawrence
MICHIGAN	
American Brakeblock - Division Ambes Corp.	Birmingham
American Brake Shoe Company	Troy

NEW JERSEY

Johns-Manville Corporation	Manville
Reddaway Manufacturing Company, Inc.	Newark
Raybestos-Manhattan, Inc.	Passaic
H. K. Porter Company, Inc.	Trenton

NEW YORK

Bendix Corporation	Troy

NORTH CAROLINA

Southern Friction Materials Company	Charlotte

OHIO

American Brake Shoe	Cleveland
General Motors Corporation	Dayton
Maremont Corporation	Paulding

PENNSYLVANIA

Raybestos-Manhattan, Inc.	Manheim
H. K. Porter Company, Inc.	Pittsburgh

TEXAS

Standco Brake Lining Company	Houston

TENNESSEE

Bendix Corporation	Cleveland

VIRGINIA

American Brake Shoe	Winchester

(Thomas Register, Dec., 1968 Ed., Fortune-1966 Plant & Product Directory of the 1000 Largest U.S. Industrial Corporations; U.S. Department of Commerce.)

REPROCESSING PLANTS PRODUCING ASBESTOS CEMENT PRODUCTS

ALABAMA	LOCATION
U. S. Cast Iron Pipe Company	Anniston
GAF Corporation	Mobile
Cement Asbestos Products Company	Woodward

CALIFORNIA	
Southern Pipe & Casing Company	Azuza
Johns-Manville Corporation	Long Beach
Johns-Manville Corporation	Pittsburgh
Certain-Teed Products Corporation	Riverside
Certain-Teed Products Corporation	Santa Clara
Johns-Manville Corporation	Stockton

CONNECTICUT	
Tile Roofing Company	Stratford

GEORGIA	
Uniroyal, Inc.	Hogansville
GAF Corporation	Port Wentworth

ILLINOIS	
Acme Asbestos Covering & Flooring Company	Chicago
Asbestos & Magnesia Materials Company	Chicago
Flintkote Company	Chicago
Western Slate Company	Elmhurst
Fel-Pro, Inc.	Skokie
Johns-Manville Corporation	Waukegan

INDIANA	
U. S. Gypsum Company	East Chicago

LOUISIANA

Johns-Manville Corporation	Marraro
National Gypsum Company	New Orleans

MASSACHUSETTS

Johns-Manville Corporation	No. Billerica

MICHIGAN

American Asbestos Products Company	Detroit

MINNESOTA

Mac Arthur Company	St. Paul

MISSOURI

Certain-Teed Products Corporation	St. Louis
GAF Corporation	St. Louis
National Gypsum Company	St. Louis

NEW HAMPSHIRE

Johns-Manville Corporation	Nashua

NEW JERSEY

Johns-Manville Corporation	Manville
National Gypsum Company	Millington
Philip Carey Manufacturing Company	Perth Amboy
GAF Corporation	So. Bound Brook
U. S. Plywood-Champion Papers, Inc.	South River

NEW YORK

Asbeka Fabricators Corporation	Brooklyn
National Gypsum Company, Inc.	Buffalo
Flintkote Company	White Plains

NORTH CAROLINA

H. K. Porter Company, Inc.	Charlotte
Johns-Manville Corporation	Marshville

OHIO

Philip Carey Manufacturing Company	Cincinnati
Seagrave	Columbus
Flintkote Company	Ravenna

PENNSYLVANIA

Certain-Teed Products Corporation	Ambler
Nicolet Industries, Inc.	Ambler
Supradur Manufacturing Company (sub. of Seagrave)	Windgap

TEXAS

Johns-Manville Corporation	Dennison
Certain-Teed Products Corporation	Hillsboro
Philip Carey Manufacturing Company	Houston

WISCONSIN

Wisconsin Gasket & Manufacturing Company	Milwaukee

(Thomas Register, Dec., 1968 Ed.; Fortune-1966 Plant & Product Directory of the 1000 Largest U. S. Industrial Corporations; U.S. Department of Commerce.)

REPROCESSING PLANTS USING ASBESTOS IN FLOOR TILE

CALIFORNIA	LOCATION
GAF Corporation	Long Beach
Armstrong Cork Company	South Gate
Flintkote Company	Vernon
ILLINOIS	
Flintkote Company	Chicago
GAF Corporation	Joliet
Armstrong Cork Company	Kankakee
Johns-Manville Corporation	Waukegan
LOUISIANA	
Johns-Manville Corporation	Marrero
Flintkote Company	New Orleans
MASACHUSETTS	
Flintkote Company	Watertown
MISSISSIPPI	
Armstrong Cork Company	Jackson
NEW JERSEY	
Congoleum-Nairn, Inc.	Kearny
Johns-Manville Corporation	Manville
American Builtrote Rubber Company, Inc.	Trenton
NEW YORK	
GAF Corporation	Vails Gate

OHIO

Johns-Manville Corporation	Chillicothe

PENNSYLVANIA

Armstrong Cork Company	Lancaster

TEXAS

GAF Corporation	Houston

(Thomas Register, Dec., 1968 Ed.; Fortune-1966 Plant & Product Directory of the 1000 Largest U. S. Industrial Corporations; U.S. Department of Commerce.)

OTHER ASBESTOS REPROCESSING PLANTS

ALABAMA	LOCATION	CODE
GAF Corporation	Mobile	B
CALIFORNIA		
Hill Brothers Chemical Company	City of Industry	
Fibreboard Paper Products Corporation	Emeryville	C
Johns-Manville Corporation	Pittsburg	B C
Fibreboard Paper Products Corporation	Redwood City	B
Scott Labs, Inc.	Richmond	C
Sacomo Manufacturing Company	San Francisco	A B C
George Short Company	San Francisco	C
COLORADO		
The Verticel Company	Englewood	
CONNECTICUT		
Brosites Industries, Inc.	Greenwich	
Standard Washer & Material, Inc.	Manchester	C
Auburn Manufacturing Company	Middletown	C
DELAWARE		
Haveg Industries, Inc.	Wilmington	
GEORGIA		
Terri-Cord Mills	Roberta	
ILLINOIS		
Unarco Industries, Inc.	Bloomington	C
Accurate Felt & Gasket Manufacturing Co.	Chicago	C
Acme Asbestos Covering & Flooring Co.	Chicago	B

Asbestos & Magnesia Materials Company	Chicago	A B
Asbestos Textile Company	Chicago	A
Chambers Gasket & Manufacturing Company	Chicago	C
Colonial Kolonite Company	Chicago	
A. Daigger & Company	Chicago	C
Filpaco Industries, Inc.	Chicago	C
Geraghty Gasket & Manufacturing Company	Chicago	C
L. E. Harnisch & Company	Chicago	B C
John Herman Manufacturing Corporation	Chicago	A
Industrial Hermetic Materials, Inc.	Chicago	C
Kopel Filter Paper Company	Chicago	C
Sall Mountain Company	Chicago	C
Singer Safety Products, Inc.	Chicago	A
Grant Wilson, Inc.	Chicago	A B
United Gasket Corporation	Cicero	C
Industrial Gloves Company	Danville	A
GAF Corporation	Joliet	B
F. D. Farnam Company	Lyons	A B C
Luse-Stevenson Company	Melrose Park	C
Blackhawk Gasket Corporation	Rockford	C
Excelsior Leather Washer Mfg. Co.	Rockford	C
Nicolet Industries, Inc.	Union	
Johns-Manville Corporation	Waukegan	B C

LOUISIANA

Johns-Manville Corporation	New Orleans	B

MARYLAND

Congoleum-Nairn, Inc.	Cedarhurst	B

MASSACHUSETTS

Armstrong Cork Company	Braintree	C
Pepperell Braiding Company	East Pepperell	A
Barwood Manufacturing Corporation	Everett	C
Asbestos Textile Company, Inc.	No. Brookfield	A

MICHIGAN

Detroit Gasket & Manufacturing Company	Detroit	B
Great Lakes Filter Media Company	Detroit	C
Walker Manufacturing Company	Jackson	

MISSOURI

GAF Corporation	Kansas City	B
Standard Asbestos Mfg. & Insulating Co.	Kansas City	B C
General Gasket Corporation	St. Louis	C
Tallman-McCluskey Fabrics Company (sub. of H. K. Porter Co. Inc.)	St. Louis	A

NEW HAMPSHIRE

American Asbestos Textile Corporation	Meredith	A
Johns-Manville Corporation	Tilton	B C

NEW JERSEY

Howard Industries, Inc.	Berkley Heights	
Asbesto Corporation	Bloomfield	A
Kavon Filter Products Company	Cranford	C
Janos Asbestos Company	East Rutherford	A B C
GAF Corporation	Gloucester City	B
Columbia Filter Company	Hawthorne	C
Cellulo Company	Hoboken	C
Imperial Products Company	Hoboken	
Ladden Asbestos Corp. of New Jersey	Irvington	A B
Smyth Rubber & Packing Company	Jersey City	C
Smith & Kanzler Corporation	Linden	B C
Johns-Manville Corporation	Manville	B C
Flaherty-Kennedy Filter Fabrics	Maplewood	C
Asbestos Products Mfg. Corp.	Newark	C
Asbestospray Corporation	Newark	C
Johns-Manville Corporation	New Brunswick	C
Electrical Insulation Sales Company	North Bergen	C
Brassbestos Manufacturing Corporation	Patterson	
La Favorite Rubber Manufacturing Co.	Patterson	C
J. T. Baker Chemical Company	Phillipsburg	
Minerals & Insulation Company, Inc.	Rochelle Park	C
Baldwin-Ehret-Hill, Inc.	Trenton	C

NEW YORK

Atlantic Asbestos Corporation	Bronx	B C
Able-Val Canvas & Rope Mfg. Co.	Brooklyn	A
Acme Canvas & Rope Company	Brooklyn	A
Eureka Packing Company	Brooklyn	A
Smith Chemical & Color Company	Brooklyn	

U. S. Indestructible Gasket Company	Brooklyn	A C
Armstrong Cork Company	Fulton	B
National Filter Corporation	Mt. Vernon	C
Asbestos Ltd.	New York City	
Atlantic Asbestos Corporation	New York City	
Scientific Filter & Machinery Company	New York City	
Whittaker, Clark & Daniels, Inc.	New York City	
Pam Narrow Fabrics Corporation	Oceanside	A
Garlock, Inc.	Palmyra	A C
Gaddis Engineering Company	Port Washington	B C

NORTH CAROLINA

Carolina Asbestos Company	Davidson	A
Tar Heel Mica Company	Plumtree	

OHIO

G. P. Hall Company	Akron	
Johns-Manville Corporation	Avery	B
The Blemker Company	Cincinnati	
Cincinnati Gasket Packing & Mfg. Co.	Cincinnati	C
Russel Gasket Company	Cincinnati	C
Zimmerman Packing Company	Cincinnati	C
Asbestos Products Company	Cleveland	
Bodwell-Lemmon Company	Cleveland	
Foseco Inc.	Cleveland	C
Russell Gasket Company	Cleveland	C
Nicolet Industries, Inc.	Hamilton	
The Cellulo Company	Sandusky	C
Asbeka Fabricators Corporation	Willoughby	C

PENNSYLVANIA

Keasbey & Mattison Company	Ambler	A C
Nicolet Industries, Inc.	Ambler	C
GAF Corporation	Erie	A C
Debco Products	Herminie	B
Raybestos-Manhattan, Inc.	Manheim	A C
American Asbestos Textile Corporation	Norristown	A
Nicolet Industries, Inc.	Norristown	
Atlas Asbestos Company	North Wales	A
Greene Tweed & Company	North Wales	C
Aljay Manufacturing Company	Philadelphia	A

Anchor Packing Company	Philadelphia	C
Austen Hill Manufacturing Company	Philadelphia	
Burnswick Asbestos Company	Philadelphia	
Collins Packing Company	Philadelphia	C
Delaware Asbestos & Rubber Company	Philadelphia	
Manufactured Rubber Products Company	Philadelphia	
Mercer Rubber Company, Inc.	Philadelphia	A
Philadelphia Asbestos Corporation	Philadelphia	A C
George A. Rowley & Company, Inc.	Philadelphia	
Charles A. Wagner Company, Inc.	Philadelphia	
Armstrong Cork Company	Pittsburgh	C
Pittsburgh Corning Corporation	Pittsburgh	
Westinghouse Electric Corporation	Pittsburgh	C
Refractory and Insulation Corporation	Port Kennedy	C
Quaker Safety Products & Mfg. Co.	Quakerstown	
Carlisle Corporation	Ridgway	

SOUTH CAROLINA

H. K. Porter Company, Inc.	Bennettsville	A
Raybestos Manhattan, Inc.	North Charleston	A C

TEXAS

GAF Corporation	Dallas	B
Johns-Manville Corporation	Fort Worth	B
Philip Carey Manufacturing Company	Houston	A
Standco Asbestos Textile Company	Houston	A C

VIRGINIA

Capitol Asbestos Fabricators Corporation	Alexandria
Forcee Manufacturing Corporation	Tappahannock

WISCONSIN

Ametek/Plymouth Plastics Division	Sheboygan

CODE - A - Textiles
B - Paper
C - Miscellaneous

(Thomas Register, Dec., 1968 Ed.; Fortune-1966 Plant & Product Directory of the 1000 Largest U.S. Industrial Corporations; U.S. Department of Commerce.)

Appendix C

Table 1 ASBESTOS USES (Sullivan and Athanassiadas, 1969)

Textiles:

Varieties used: Chrysotile, crocidolite, and in part amosite

Yarns and Cords:

Processes: Weaving of yarns and cords
Braiding (interlacing)

Classification of chrysotile fabrics:

Class	Quality Code	Asbestos Content (%)
1	AAAA	75-79.9
2	AAA	80-84.9
3	AA	85-89.9
4	A	90-94.9
5	Underwriters Commercial	95-100

Sealing and Packing Materials:

Packing (woven fabrics)
stuffing for boxes and sleeves
manhole rings, boiler covers

Flat Packing:

Gaskets, flanges (on pipes) and containers

1. Without metal: high pressure gasket sheets (rubber)

2. With metal: material for sealing cylinder heads and exhausts in motors and combustion engines, and for sealing compressors and turbines

Asbestos Boards and Papers:

Boards
Filtering and clarifying
Coverings, coatings, casings, and jacketings for all kinds of surfaces
Manufacturing of welders' and melters' shields
Slideways in the glass industry
Handles and fire-doors
Auto Parts
Safes
Protective walls
Curtains, etc.

(continued)

ASBESTOS USES

Sheets

Inner/outer linings of furnaces and heating vessels, drying ovens, incubators, heaters, climate-controlled spaces, etc.

Plates

Insulating buildings against vibrations (aluminum-asbestos)
Solar-heat reflecting surfaces (70% of solar heat)

Special Asbestos Papers

Filters

Asbestos Cement (10 to 25% asbestos):

Slabs
Corrugated sheets
Pipes
Corrugated tiles for roofs in industry, agriculture, and dwellings
Planks for platforms in buildings under construction
Balcony canopies
Rain gutters
Interior walls
Ventilating shafts
Air conditioning assemblies
Pressure piping (for underground drinking water distribution systems, fuel gas, and sewage)
Cooling towers (electricity-generating stations)

Thermal Insulants and Fire-Proofing:

Sprayed asbestos (insulant in both heating and refrigeration), sound absorbent (eliminates booming and improves acoustical properties of walls and ceilings)
Magnesia asbestos (85% magnesia, 15% asbestos) as thermal insulant for covering pipes

Friction Material:

Woven:	Brake lining
Nonwoven:	Clutch lining
	Transmission lining

(continued)

ASBESTOS USES

Asbestos Plastics:

- Flooring tiles (asbestos-asphalt tiles and, increasingly, asbestos-polymers of vinyl)
- Pressed or molded (thermal insulation and in electrical machinery)
- Resinated asbestos felt (manufacturing of wings and firing of missiles and expansion cones for nozzles of boost motors). Other uses in aircraft industry: nozzles for motor tubes, missile tailpipes, and missile-heat barriers; fuselages for guided missiles, fuel tanks for fighter bombers, cabin floors, etc.
- Radar (large molded reflectors and scanners)

Asbestos Acid-Resistant Compositions:

- Used mostly in chemical industry

Table 2 1967 LIST OF MANUFACTURED ASBESTOS PRODUCTS (Sullivan and Athanassiadas, 1969)

Industry and Product Description	Quantity Measure
Miscellaneous Nonmetallic Mineral Products	
Asbestos Products	
Asbestos Friction Materials	
Brake Linings	
Woven, containing asbestos yarn, tape, or cloth	Linear feet
Molded, including all nonwoven types	Cubic feet
Clutch facing	
Woven, containing asbestos yarn, tape, or cloth	Thousand pieces
Molded, including all nonwoven types	Thousand pieces
Asbestos-Cement Shingles and Clapboard	
Siding shingles and clapboard, including accessories	Squares
Roofing shingles	Squares
Asphalt Floor Tile	Thousand square yards
Asphalt floor tile	
Vinyl Asbestos Floor Tile	Thousand square yards
Vinyl asbestos floor tile	
Asbestos Textiles and Other Asbestos-Cement Products	
Asbestos textiles	
Yarn, cord, and thread	Pounds
Cloth	Pounds
Other asbestos textiles, including roving, lap, wick, rope, tape, carded fibers, etc.	Pounds
Asbestos-cement products	
Flat sheets and wallboard, all thicknesses converted to ¼" basis	100 square feet
Corrugated sheets	100 square feet
Pipe, conduits, and ducts, including pressure pipe	Short tons

(continued)

1967 LIST OF MANUFACTURED ASBESTOS PRODUCTS

Industry and Product Description	Quantity Measure
Asbestos felts	
Roofing-asphalt or tar saturated	Short Tons
Other	Short Tons
Other asbestos and asbestos-cement products, including millboard and prefabricated housing components	
Gaskets and Insulation	
Gaskets, All Types	
Gaskets (for sealing nonmoving parts) Asbestos, asbestos-metallic, and asbestos-rubber	
Packing (except leather, rubber, and metal) and Asbestos Insulations	
Asbestos compressed sheet	Pounds
Packing (for sealing moving parts) Asbestos, asbestos-metallic, and asbestos-rubber	Thousand pounds
Insulation materials containing asbestos pipe insulation	
Cellular and laminated	Linear feet
85 percent magnesia	Linear feet
Diatomaceous silica, calcium, silicate, expanded silica, and asbestos fiber	Linear feet
Other pipe insulation	Linear feet
Block insulation, including sheet and lagging	Thousand board feet
85 percent magnesia	
Diatomaceous silica, calcium silicate, expanded silica, and asbestos fiber	Thousand board feet
Other block insulation, including celluar and laminated	Thousand board feet
All other asbestos insulation	

TABLE 3 ASBESTOS APPLICATIONS

Raw Asbestos

Yarn	Thread
Wick packing	Rope packing
Felt	Paper (plain and corrugated)
Millboard	Millboard
Insulating wire	Compressed sheet packing
85% Magnesia pipe covering, blocks and locomotive lagging	High temperature insulation (molded of various types)
Compound for encasing of motor windings	Molded composition for electrical and other purposes
Molded brake lining and brake blocks	Automobile bodies and railway sleepers (molded composition)
Reinforcement in plastics	Filler in plastics
Flooring	Pottery and sculpture
Asbestos cement products	Plaster and stucco
Paints, varnishes and fillers	Sprayed asbestos (acoustical)
Filling for asbestos mattress insulation	Insulation of batteries (loose fiber)
Insulation of walls and floors (loose fiber)	In foundations (to resist shock)
Insulation in underground conduits (loose fiber)	Packing for explosives or other materials
Wadding in cartridges and timing devices	Filter fibers and filter pads
Potential asbestos fiber for filtering	Coating for welding rods
Fireproof smoking (spores are placed on asbestos)	Sewer pipe
Asphalt floor tile	Automobile body undercoating
Adhesive	

Asbestos Yarn

Cloth	Tape, electrical and other
Brake lining	Clutch facings
Packing, valve stem, braided and other	Gas mask filters
Gaskets and gasket cloth	Tubing
Wick for oil burning apparatus	Rope
Twine or sewing thread	Stocking for lead cable
Electric fixture wire covering	Electric cable covering
Tying gas mantles	Spark plugs
Edges for hair felting	Steam hose
Fire-retardant hose	

Asbestos Cloth

[illegible] ure, [illegible] and [illegible]	Bedding, folded and satched
[illegible]	Gaskets
[illegible]	Substitute for canvas on manufacture where temperature [illegible] high (lagging cloth)
Clothing such as gloves, leggings	Helmets
	Aprons
	Berets
Drapery	Hangings for fire stops
Blankets for fire fighting	Blankets in electrolyzer cells
Bags and diaphragms (in oxygen producing)	Mailbags
Awnings	Rugs
Theatre curtains	Theatre scenery
Floor lining in theatres	Portable motion picture booths
Motion picture screen	In acoustical treatment
In acetylene welding	Gun grips
Asbestos cloth wipers in commutators	Facing for dryer felt
Filtering (fruit juices, acids, etc.)	Filter in dust collectors
Oil filters (in automobiles)	Protectors for gas bags in balloons
Oven insulation	Lining in motors
Lining of laboratories, cooling chambers and other rooms	Plastics
Lining of automobile footboards	Padding for laundry presses and mangles
Padding, prison cells	Wrapping oil tanks and oil lines in engines
In various medical test apparatus	Umbrellas and shields (protecting firemen)
Sand bags (for pressing hats)	Conveyor belting
In hay curing to preserve aroma and color	In cheese making to control temperature
Insulation against noise and vibration (especially in airplanes)	Fittings for airplanes
Ironing board covers	

Asbestos Felt

In acoustical work	Protection of underground pipe
On paper machines	Noise insulation
Padding in presses	Plastics
Adhesives	

Asbestos Tape

Wick for oil burning apparatus	Belts for conveying hot glass or other articles
Pull strings for ovens	Insulating locomotive steam pipe at bends, etc.
Insulating armatures	Winding coils
Winding bus bars	Insulating underground cables

Such laboratories uses, as insulation for flasks, test tubes, retorts; for straps in diffusing materials

In glass manufacture for wrapping tines of forks to take bottles from ovens

Insulating electric wires on planes and ships

Wick Packing

As packing	For piping of wire, armor plate or galvanized materials

Insulation of exhausts on automobiles	Making sheets
Tubes, rods and mats	Construction air ducts or linings of paper ducts

Asbestos Millboard

Stoves and heaters	Safes
Garages	Motion picture booths
Electric switch boxes	Dry cleaning machines
Gas meter enumerators	Hoods of automobiles
Incubators, brooder stoves	Ovens and dry kilns
Asbestos-cement wallboard	Ceiling over boilers, smoke stacks, etc., for fire protection
Gaskets, plain and metallic	Paddles in glass mills
Washers in electrical apparatus	Tent shields and stove pipe rings
Insulated doors (between metal and wood core)	
Table pads and mats	Stove mats

Asbestos-Cement, Flat Sheets, and Wallboard

Interior sheathing (of factories, refrigerator rooms, etc.)	
Partitions, movable and fixed	Exterior sheathing (half-timber effect)
Brick-type siding	Portable buildings
Roofs and sides of small buildings	Semiportable motion picture booths
Fireproof liner on insulated board	Fire protection around engines
Lining of tackless cookers	Backing for dies (in molded glass)
Brake shoes for elevators	Hoods over machines or vats (from which vapor rises)
Mounting of test instruments and boards	Laboratory table tops
Switchboards	Cabinets and panel box work
Insulators between phases and on arc deflectors	Miscellaneous uses in electrical apparatus
Electric meter casings	Spark arresters
Lining for bleaching and other tanks and vats	Backgrounds and cutouts for window displays
Blockout or bombproof board	

Asbestos Paper

Air cell and other pipe coverings	Boiler jackets
Asbestos felt roofing	Asbestos built-up roofing
Asbestos protected metal roofing	Gaskets, plain and metallic
Wick in oil burning apparatus	Tubes in electrical industry
Wrapping of electrical wire	Wrapping of hot air pipes
Linings of stoves and heaters	
Linings of:	
Filing cabinets	Cartridges
Soldiers' helmets	Carpets
Auto mufflers	Radiator covers
Drum controllers	Cookers
Electric appliances	
Armored car roofs	Motors
In enameling ovens to catch drip	Insulation of ovens and dry kilns
Dry battery in electrolytic cell	Tank covers
Reinforcing aluminum foil for insulation	Filtering
In window glass machinery to guide hot sheets; to shield hot glass from flying fragments	
In welding and other processes for protection from heat	In chemistry and physics in many various ways
In annealing (crumpled paper)	Reinforced with cotton thread for automobile tops
Covering of rockwool blankets which must be sewed	Wrapping of wires and cables

Asbestos Cement Pipes

For carrying of water, sewage, gas and special liquids
As gas vent pipes
Conduits for electric [illegible] etc.
Purlins, rafters, trusses, etc. [illegible] wartime buildings

Asbestos Composition Material

Insulation compounds
Electric wire insulation
Lamp sockets, rheostat backings, switch parts, arc deflectors, resistance mountings and other electrical uses
Underground insulation
Phonograph records, buttons and other small objects made of plastic
Heater cord insulation
Missile and aircraft plastics
Flooring
Sealing of percussion caps in large cells

Asbestos Products in Theatres

To localize fires in location
For wall sections in sets to prevent reverberation
Firebox in fireplaces
Blankets or ears for lights or sun arcs
Dust on cobwebs, old wine kegs, etc
Insulation for maintaining even temperature
To protect nearby buildings when fires are set
Insulation of camera [illegible] against sound
Dressing winter scene as snow
Noise insulation

[illegible] "Asbestos," Philadelphia, Pennsylvania throughout Report. [illegible]

Appendix D

RESEARCH RECOMMENDATIONS

(1) Working Group on Asbestos and Cancer (Report and Recommendations) D-1

(2) Research on Health Effects of Asbestos D-10

(3) Report of the Advisory Committee on Asbestos Cancer to the Director of the IARC (recommendations for further research) D-14

(4) Research Perspectives Concerning Asbestos Minerals and Their Effects on Biological Systems D-18

D-1

Working Group on Asbestos and Cancer

Report and Recommendations of the Working Group Convened Under the Auspices of the Geographical Pathology Committee of the International Union Against Cancer

Contents

List of delegates
Terms of reference
Association of asbestos dust exposure and cancer
Recommendations on problems requiring epidemiological study
1. Importance of fiber type
2. Relation to dust dosage
3. Effects of removal from dust
4. Further investigations of mesothelial tumors
5. Population groups requiring study
6. Epidemiological methods and criteria of disease
Recommendations relating to pathology and experimental pathology
1. Diagnosis of asbestosis
2. Diagnosis of mesothelial tumors
3. Contribution of experimental pathology
4. Proposal for reference panels
Recommendations relating to physics and chemistry
1. Proposal for establishing reference samples of types of asbestos
2. Methods of identification of asbestos in tissues

List of Delegates

Delegates:

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Submitted for publication March 2, 1965; accepted March 10.
Place of Meeting: Barbizon Plaza Hotel; Dates: Oct 22-23, 1964.

Reprint requests to Department of Occupational Health, Graduate School of Public Health, University of Pittsburgh, Pittsburgh, Pa 15213 (Dr. Mancuso).

* Invited, unable to attend, sent apologies.

The Group met and then divided into three Working Parties: Epidemiology (E); Pathology (P); and Physics and Chemistry (C); with the terms of reference suggested by the Planning Group which met in London in February 1964.

The Working Parties agreed on their reports which were then discussed and modified at the final Plenary Session (Chairman—Dr. H. Stewart).

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Terms of Reference

I. *Epidemiology.*

A. To investigate the incidence of mesothelial tumors of the pleura and peritoneum in groups and/or regions where exposure to only one type of asbestos fiber has occurred.

B. To investigate the risk of bronchial carcinoma in populations exposed to asbestos dusts where the incidence of asbestosis is known or believed to be low.

C. To investigate the incidence of other tumors.

II. *Pathology and Experimental Pathology.*

A. Establish criteria for diagnosis of mesothelial tumors, assemble material to assist in standardization of diagnosis, and form consultative panels.

B. Develop a standard of grading of fibrosis of the lung due to asbestosis.

C. Develop a standard method of assessing semi-quantitatively the amount of asbestos fibers and/or bodies in sputum, fresh lungs, and fixed tissue.

D. Collate work in various countries.

III. *Physics and Chemistry.*

A. Investigate the usefulness of providing in one center a set of standards of the main types of asbestos fibers and their extracted organic matter for distribution to centers investigating the biological, physical, and chemical properties of this material; if it is regarded as useful and practical suggest a center.

B. Suggest a minimum list of characteristics by which differences between these samples should be identified.

C. Suggest standard methods for identification of types of asbestos in the lung in (a) large samples, and (b) tissue sections.

The Association of Exposure to Asbestos Dust and Cancer

The main types of asbestos of commercial interest are amosite, anthophyllite, chrysotile, crocidolite, and tremolite. There is evidence of an association between exposure to asbestos and malignant neoplasia. This has been established mainly on information from Germany, Italy, South Africa, the United Kingdom, and the United States of America.

The types of tumors which have been shown to be associated with exposure to asbestos dust are:

(1) carcinoma of the lung and
(2) diffuse mesothelioma of the pleura and peritoneum.

There is some suggestion of an association also with gastrointestinal carcinoma, and possible ovarian tumors.

The latent period between first exposure to the dust and detection of the related tumors is many years, usually 20 or more. Instances up to 60 years have been reported. For this reason, further cases of these associated tumors will be expected to occur for many years to come, even if dust exposures are now greatly reduced.

Present evidence indicates that the associated carcinomas of the lung are not limited to exposure to any one type of asbestos fiber. How-

ever, further investigations are urgently needed to establish whether the degree of risk is importantly related to the type of fiber inhaled.

In the case of mesotheliomas, evidence from several countries suggests that exposure to crocidolite may be of particular importance, but it cannot be concluded that only this type of fiber is concerned with these tumors, and further investigation of this problem is needed.

Certain types of asbestos fibers in the virgin state have been found to contain oils, waxes, and other organic matter. In addition, asbestos fibers readily absorb hydrocarbons subsequent to mining. Small or trace amounts of various elements such as nickel and chromium are also found associated with some types of fiber. The possible role of such associated materials in the development of tumors following exposure to asbestos dust is not yet clear.

These findings, when considered in relation to the great increase in the use of asbestos for many purposes in all countries, suggest that a more serious and widespread hazard from exposure to asbestos dust may exist than is widely appreciated.

Recommendations on Problems Requiring Epidemiological Study

1. *That the importance of fiber type on the risk of developing asbestosis, carcinoma of the lung, and mesothelial and other tumors be investigated.*

International and intranational comparative studies of mining and other populations exposed to only one type of fiber are recommended. Among the countries in which and between which studies should, if possible, be made are the following:

Australia	Crocidolite
Canada	Chrysotile
Cyprus	Chrysotile
Finland	Anthophyllite
Italy	Chrysotile
South Africa	Amosite
	Chrysotile
	Crocidolite
United States	Chrysotile
	Tremolite
USSR	Chrysotile

The studies of the effect of exposure to different types of fiber within a country are likely to be of special value, but studies of groups exposed to apparently similar fibers in different parts of the same country are also likely to be informative.

2. *That the relationship of dust dosage (including concentration and duration of exposure), and the composition and physical state of the dust to the incidence of asbestosis, carcinoma of the lung, mesotheliomas, and other cancers be studied.*

Comparative studies in factory populations in the asbestos textile and other manufacturing processes using asbestos are likely to be useful, especially when there are records of past dust measurements. In any prospective studies of new entrants, the measurement of dust by a standardized method should be regarded as an essential part of the investigation.

3. *That the effects of removal from further exposure to asbestos dust be investigated.*

It is important to establish the subsequent morbidity and mortality from asbestosis, and the mortality from cancers associated with exposure to asbestos in population groups no longer exposed to the dust.

4. *That further investigations be made of past and all future cases of diffuse mesothelial tumors of the pleura and peritoneum to establish any association with asbestos and other factors.*

These tumors should be diagnosed on the criteria suggested by the Panel on Pathology (see below) and reviewed by a panel of pathologists with experience of these rare tumors. The tumor and lungs should be investigated for the presence of asbestos by physical and chemical methods (see below).

5. *That studies of morbidity and mortality be extended to asbestos-exposed populations that have not so far been widely investigated.*

A. It is recommended that special attention be directed to surveys in:

(*a*) the insulating industry, including that in ships,
(*b*) the asbestos cement industry,
(*c*) the asbestos products industry, and
(*d*) other plants in which asbestos is regularly used, such as certain paper, paint, and plastic factories.

B. It is also recommended that, since incidental exposure to asbestos dust may occur in certain trades and occupations, attention be directed to

(*a*) handling and transporting asbestos,
(*b*) the building industry,
(*c*) pipe fitting, and
(*d*) ship building and breaking.

C. It is recommended that surveys be made to study environmental and community exposures, including populations near mines and factories and elsewhere.

D. It is recommended that general population surveys be made nationally and internationally to establish by standardized methods, in areas of presumed high and low exposure to asbestos dust, the prevalence of asbestos bodies and fibers.

E. It is recommended that surveys of asbestosis in domestic and wild animals be extended to areas of high and low exposure.

6. *Epidemiological methods.*

A. General:

(*a*) In addition to the usual information about the individual collected in such surveys, special attention should be directed to a detailed, social (including smoking habits), occupational, environmental, and medical history from early childhood to elucidate any possible exposure to or association with any type of asbestos or other dusts. A study of the family unit or household may be of interest in view of the occasional reports of significant neighborhood and household exposures.

(*b*) In view of the association between exposure to asbestos dust and pulmonary fibrosis and its complications, it is important to obtain as much information as possible about morbidity and mortality from *all* causes with particular attention to asbestosis, chronic bronchitis and emphysema, bronchiectasis, diffuse interstitial fibrosis, pneumonia, tuberculosis, cor pulmonale, carcinoma of the lung, diffuse mesothelial tumors of the pleura and peritoneum, gastrointestinal tumors, and ovarian tumors.

(*c*) The principal epidemiological surveys likely to be used are (1) retrospective, (2) cross sectional, and (3) prospective, or a combination of these. In most of the surveys one or preferably more control groups will be needed. It is strongly urged that early and full consultation with statisticians be made at all stages from planning to analysis of the findings.

B. Clinical Criteria:

The need to establish the minimal clinical information to be obtained in surveys of workers exposed to asbestos was agreed. A small panel met informally after the main working party and their recommendations are as follows:

(*a*) Symptoms: It was agreed that in all surveys the presence or absence of cough, sputum, dyspnea, and chest pain should be recorded as a minimum. This should be recorded using a standardized questionnaire.

The British Medical Research Council Questionnaire on Respiratory Symptoms (1960),[1] with the additional questions relating to chest pains in the WHO Questionnaire on Cardiovascular Disease (1962)[2] is suitable for this purpose, and these questionnaires have been widely used internationally for interview surveys. The Cancer Society Questionnaire in the Cancer Prevention Study has been widely applied in the United States. It contains questions about a wide range of symptoms and diseases and was designed for self-completion.

(*b*) Signs. It was agreed that when physical examination was possible, the minimal observations should include the presence or absence of *clubbing of fingers, cyanosis, and basal rales in the chest.*

It was agreed that the measurement of sputum volume (first hour on rising) and degree of purulence recorded in a standard way (Miller)[3] was useful in association with the questionnaires for assessing the prevalence of bronchitis, and this may be relevant to the disability caused by asbestosis.

The epidemiological usefulness of examinations of sputum for asbestos bodies and fibers is at present uncertain, but needs investigation.

C. Classification of Chest Radiographs of Asbestos-Exposed Individuals:

There is no international or national standardized classification of the radiological appearances of asbestosis. It is recommended that a scheme based if possible on an extension of the International Labor Office (ILO) Classification (1958)[4] be developed.

Possible means of doing this were presented at the New York Academy of Sciences Conference on the Biological Effects of Asbestos (1965)[5] by Finnish, German, South African, and British contributors. The aim should be to specify separately and record semi-quantitatively the principal radiological features seen in asbestos-exposed groups, but exposure to mixed types of dust is not uncommon and the appearances may, therefore, include those caused in part by other pneumoconioses.

The classification should be purely descriptive of the radiological features and not imply pathological change or extent of disability. It is probable that the type and severity of alterations in radiological features such as pleural plaques, etc, vary with the type of dust exposure and other factors so that a classification based on the principles in the ILO Classification for Pneumoconiosis, in which there is a semi-quantitative assessment of several qualitatively different types of abnormality, may be expected to be useful.

It is recommended that a working group be set up to develop and test a new international classification.

D. Lung Function Assessment.

The preferred lists of lung functions to be used will vary according to the type of survey and the facilities available. A list of minimal and additional tests likely to be of use is as follows: minimal—forced vital capacity (FVC) and forced expiratory volume over 1 second ($FEV_{1.0}$); additional—transfer factor (diffusing capacity) of lung for carbon monoxide (single breath method), lung compliance, standard exercise test, peak expiratory flow, and airways resistance.

Recommendations on Pathology and Experimental Pathology

1. *Diagnosis of asbestosis.*

A. Macroscopic Examination:

(*a*) At necropsy the parietal pleura should be stripped, if possible, with the thoracic contents. It is desirable that at least one lung be inflated with fixative and whole lung sections be prepared.

(*b*) It is recommended that special note be made of the following:

(*1*) *Pleura* for thickening and plaques (defined as localized areas of stiff horn-like material).[6] The site and size of all pleural lesions should be recorded.

(*2*) *Lungs* for the presence of interstitial fibrosis, bronchiectasis, cystic change, tuberculosis, pneumonic consolidation and tumors. The site of any tumor should be recorded as precisely as possible.

(*3*) *Mediastinal tissues* should be examined for evidence of neoplastic infiltration and for tuberculosis.

(*4*) *Peritoneum,* parietal and visceral fibrosis in the peritoneum such as parietal plaques and "sugar-icing" of the spleen should be recorded.

B. Microscopic Examination:

It is recommended that at least six sections be examined from the lungs before the degree of asbestosis is decided and these blocks should be taken from specific sites and identified in the following standard manner:

(*a*) apex of right upper lobe, pleural surface;

(*b*) right middle lobe, lateral pleural surface;

(*c*) right lower lobe, middle of, basal surface;

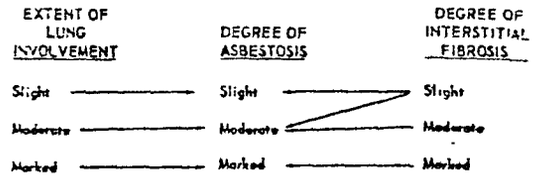
(*d*) left upper lobe, central section;

(*e*) lingula, central section; and

(*f*) left lower lobe, central basal section. In addition, sections be taken from the bronchi and peritracheal and peribronchial lymph glands.

It is presumed that all examining pathologists will take further sections of any suspicious or abnormal tissue.

C. Assessment of the Severity of Asbestosis: The need to assess this in some standard way was agreed. It was recommended that the assessment should be based on the severity of interstitial fibrosis and the amount of tissue involved. The proposed scheme is as follows:



A category of minimal asbestosis is also proposed to describe slight focal fibrosis in the region of the respiratory bronchioles associated with the presence of asbestos bodies; such changes are commonly confined to sections taken from the bases of the lower lobes.

This scheme puts more emphasis on the extent of the lesions than the degree of fibrosis (which should be averaged for the six sections). Thus, a lung with moderately extensive disease but only slight severity of fibrosis is graded as "moderate asbestosis." The use of an average assessment of the six sections makes it impossible to have a grading of slight involvement and moderate or marked degree of fibrosis.

D. The Detection and Significance of Asbestos Bodies and Fibers:

(*a*) Sputum. The presence of asbestos bodies and fibers is an indication of the exposure to asbestos dust and not evidence of asbestosis. It is therefore suggested that the bodies should be referred to as "asbestos bodies" and not by the previously used term "asbestosis bodies". Because of their sporadic appearance and in the case of fibers their relation to recent dust exposure, the Group were of the opinion that quantitative assessment of bodies and fibers in sputum was not, in the light of present knowledge, a very useful procedure but might become more useful when further investigated.

In sputum detection by direct examination under a coverglass and the use of phase contrast, oblique illumination or narrowed condenser diaphragms is proposed. If sputum concentration is used antiformin or Eusol treatment is recommended. If this technique is used for

large-scale comparative epidemiological surveys, the exact method should be standardized.

(*b*) Lungs. From fresh lungs, the highest positive results are obtained from smears from the base of a lower lobe (of the thickness of a thick blood smear as for malarial parasites), air dried and mounted in balsam. A rough quantitative examination by low power magnification is easy and practicable. For fixed lungs, the smear technique is of limited value and unstained sections 30μ thick are recommended.

(*c*) For investigation of asbestos fibers in lung sections, microincineration, acid treatment, and examination by phasecontrast are suggested. Morphologically the fibers appear as straight rods of varying lengths and thickness, but with longitudinal shredding and in the thicker fibers smaller fibrils may be recognized. While there are other structures described as pseudo-asbestos bodies, or curious bodies, it was the view of the Group that in practice, little difficulty is found in distinguishing the genuine from the others. These other types usually have a carbon-black center, a shape which is other than linear, but the body that can mimic an asbestos body completely is the small one found in talcosis, which may be tremolite, a form of asbestos.

E. Chemical Analysis of Lung Tissue. Where possible, blocks of tissue from these six areas chosen for histology should be taken and the amount of collagen relative to total proteins estimated by the standard hydroxyproline methods. The results of collagen estimations should be expressed in absolute amounts and as percentages of defatted dried lung tissue.[7]

2. *The diagnosis of diffuse mesothelial tumors.*

A. Macroscopic:

(*a*) The salient characteristic of the diffuse mesothelioma is its predilection to spread along the serosal membrane in which it occurs. In the pleural cavity, the entire surface may become replaced by a continuous layer of tumor due to symphysis of the pleural surfaces. This is uncommon in the peritoneum where the surfaces often remain separate but covered by isolated plaques and nodules or diffuse infiltration. Only those mesothelial tumors in which serosal spread is unequivocal should be termed "diffuse". A few benign diffuse mesotheliomas have been described. Almost all diffuse mesothelial tumors show evidence of malignancy by direct infiltration of adjacent tissues and organs and metastases to regional lymph nodes.

(*b*) The differentiation from metastatic tumor is the main problem in diagnosis and can only be made with complete certainty by the exclusion of all other sources of tumor at necropsy. Because of the tendency of the tumor to surround and infiltrate subserosal organs, these organs most commonly come under suspicion as points of origin. The possibility that the primary growth may have been surgically removed must be borne in mind.

B. Microscopic:

Diagnosis is possible because the growth commonly shows histologic patterns which are infrequent in other tumors and especially those which might metastasize to serosal membranes. Particularly helpful is the presence in some diffuse mesotheliomas of a mixed structure of malignant elements of both epithelial and mesenchymal character, or other diverse combinations. Growths in which only one type of cytoarchitecture is present may also have a highly distinctive pattern. For example:

(*a*) a tubular or tubulo-papillary pattern in which the tumor cells show marked uniformity and are cubical or flattened;

(*b*) masses of collagen in which there are either clef-like spaces lined or occupied by tumor cells, or fine hyaline strands which form complex meshworks and laminated bundles. Other examples of these tumors may have an entirely non-specific structure presenting the appearance of a spindle cell sarcoma or of an anaplastic tumor.

Because of the difficulty in clearly distinguishing on histologic grounds alone, some of these growths from metastatic tumors, cases diagnosed from biopsy material should be called "probable mesotheliomas." In epidemiological studies precise details of the pathological evidence on which the diagnosis was based should be stated.

C. Histochemistry:

(*a*) Most of the mucoid material within mesotheliomas, although often intimately associated with the surfaces of the tumor cells, is extracellular. Intracellular or intratubular mucin of an adenocarcinoma will usually take mucicarmine or PAS stains. The absence of these reactions in a tumor which contains mucoid material can, when taken with the other features, be useful additional evidence for a mesothelial tumor.

(*b*) Hyaluronic acid is often present in mesothelial tumors. The demonstration of its removal from the tissue sections by specific hyaluronidase preparations is a useful histo-

chemical test, but since the acid is soluble in water, the test requires that the tissues be fixed in a special precipitating fixative, such as formol alcohol acetic acid (Wagner et al, 1962).[8] It also appears likely that the quantitative measurement of hyaluronic acid in effusions, where this polysaccharide has been isolated and chemically characterized, may well become a reliable method for assisting in the diagnosis of mesothelioma, but it is emphasized that positive results for both the histochemical and chemical tests for hyaluronic acid are found in only a proportion of cases of mesothelioma and they should not be used as sole diagnostic criteria.

D. Exfoliative Cytology:

The contribution to the diagnosis of diffuse malignant mesothelioma by exfoliative cytology of serous fluids requires that the exfoliated neoplastic mesothelial cells sufficiently resemble exfoliated nonneoplastic mesothelial cells for them to be recognized as having a mesothelial origin; they also possess the generally accepted features of malignancy. The latter are not often present so a definite diagnosis of mesothelioma is then difficult.

Usually mesothelioma cells, while atypical, do not appear malignant but still show evidence of mesothelial origin. From cytology of the serous fluid it is possible to be strongly suspicious and in a few cases confident of the diagnosis of mesothelioma, but usually its presence can only be reported as possible.

The diagnosis of malignant mesothelioma by exfoliative cytology requires a familiarity with the nonneoplastic mesothelial cell. Mesothelial hyperplasia and hypertrophy can easily be mistaken for malignant mesothelioma and vice versa. It may be imprudent to do more than suggest malignant mesothelioma if there is not good supporting clinical, radiological, or biochemical evidence. The exfoliated malignant mesothelioma cell must also be distinguished from the adenocarcinoma cell, by far the commonest malignant cell recovered from serous fluids. This cell is well described in standard texts of exfoliative cytology.

E. The Use of Tissue-Culture in the Diagnosis:

The various manifestations of mesotheliomas in some cases cause difficulty in distinguishing such tumors from bronchogenic carcinoma, metastatic ovarian carcinoma, fibrosarcoma, etc. It is therefore recommended that, where possible, biopsy specimens of pleural and peritoneal neoplasms be studied after short-term passage in vivo and in vitro to determine whether the rate of growth and/or morphology after transplantation can provide useful criteria for a differential diagnosis of mesotheliomas. To achieve this it is recommended that clinical pathologists seeing these tumors cooperate with workers in experimental carcinogenesis who are using tissue-culture methods.

3. *The contribution of experimental pathology.*

It was agreed that various types of asbestos induce in many species of animals lesions similar to those seen in human cases of asbestosis, mesothelioma, and possible carcinoma of the lung, but the need for more precisely planned experiments was emphasized.

The desirability of using healthy animals of known response to asbestos under quantitative conditions of exposure by inhalation, feeding, and parenteral injection at several sites was agreed. Experiments in great variety are being undertaken in many parts of the world, particularly in Canada, Great Britain, South Africa, and the United States. The prospect of providing standardized samples of chrysotile, amosite, crocidolite, tremolite, and anthophyllite asbestos for experimental work was welcomed.

It was agreed that there was a need for improving methods of identifying the type of asbestos in submicroscopic fibers in tissues. Further studies of the rate of formation and resistance to destruction of asbestos bodies in different species of animals may be useful.

It is recommended that there be closer collaboration between clinical and experimental pathologists and other scientists in the field of experimental pathology, biochemistry, and biophysics, as applied to the problems of the biological action of asbestos.

4. *Proposal for pathology reference panels.*

It is recommended that central consultation and reference panels be set up on regional, national, and international levels. These panels will:

A. Assist in establishing standards for pathological classification of asbestosis.

B. Serve as consultation centers for diagnosis of mesotheliomas and other tumors associated with exposure to asbestos.

C. Serve as general exchange of pathological material related to asbestosis and its associated tumors.

D. It is suggested that a comprehensive atlas on the pathology of mesotheliomas should be prepared.

Recommendations Relating to Physics and Chemistry

1. *Reference samples of asbestos for experimental work.*

It is anticipated that there will be an expansion of demand for asbestos of various types for biological and other studies. It is at present impossible to predict the biological effects of differences in mineral composition, size distribution, associated organic matter, and trace metals in different samples of asbestos. Also, fibers from a particular mine may vary in composition and in the amount of absorbed material.

It is therefore recommended that:

A. Standard reference samples, of respirable size, of amosite chrysotile, crocidolite, tremolite and anthophyllite be prepared from as pure parent material as possible and held at the Pneumoconiosis Research Unit (PRU) in Johannesberg for distribution to centers requiring them. (These standards should also serve as references for comparison with larger amounts of material—such as may be required for inhalation or chemical extraction). It is proposed that samples of chrysotile from different countries—for example, from Arizona, Havelock (Swaziland), Quebec, and Shabani (Southern Rhodesia) be included in the reference collection.

B. The standard samples be analyzed and characterized quantitatively by (*a*) chemical and spectrographic analysis; (*b*) optical and electron microscopy, for determination of shape, size distribution, and optical properties such as refractive indices, extinction angle, etc; (*c*) x-ray diffraction analysis by the powder technique; (*d*) specific surface measurement by low temperature gas adsorption; and (*e*) the determination of amount and type of organic matter present.

C. Oils and waxes isolated from asbestos be prepared and also distributed through the PRU, Johannesburg.

D. When the standards have been collected and prepared, the PRU, Johannesburg, will notify workers of their existence through the UICC Bulletin and any other appropriate channels.

2. *Identification and quantitative assessment of asbestos in tissues.*

In tissue sections it may be possible to identify only the type of asbestos present. For quantitative studies of the amount present in any organ such as the lung, it is necessary to analyze representative samples of the organs.

It is recommended that:

A. *Tissue sections* should be treated to remove organic material, for instance, by ashing or treatment with active oxygen; but this will not remove the asbestos bodies completely, and chemical treatment may be necessary to free the fibers. The best method for this is not known, but treatment with acetic acid may be useful. Identification of the type of fiber can only be made on free asbestos fibers and not on fibers inside asbestos bodies. It is recommended that methods of distinguishing asbestos from other fibers which may be present be further investigated. This can probably best be done by phase contrast or polarized light microscopy. It is also recommended that the treated sections be examined by electron microscopy for recognition of submicroscopic fibers.

B. *For large samples of tissue,* acetic acid, hydrogen peroxide, and formamide methods be tried as they appear to be superior to ashing, but the best method of extraction of mineral matter from tissue is not yet known and needs further study. However, the quantitative determination of asbestos in the residue obtained in this way is difficult but could be based on chemical analysis, x-ray diffraction, or fiber counts. It is recommended that methods for concentrating such asbestos and separating different types of asbestos from each other be further investigated.

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Research on Health Effects of Asbestos

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ASBESTOS AS A CURIOUS MATERIAL was known several centuries B.C., especially for its ability to withstand flame. The physical and chemical properties of asbestos together with its fibrous structure made it a unique material with a wide range of potential industrial applications. It was not until the end of the last century, however, that it gained importance as an industrial resource. The study of the use of asbestos in a number of technological areas and its contribution to new products is the precursor of the special science of industrial mineral fiber technology.

The recommendations in this report resulted from a meeting sponsored by the Occupational Health Program of the Public Health Service's National Center for Urban and Industrial Health, on December 7 and 8, 1966, under the Chairmanship of Murray C. Brown, M.D. Copies of this paper may be obtained from the Occupational Health Program, National Center for Urban and Industrial Health, USPHS, DHEW, Cincinnati, Ohio.

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Asbestos is essential in today's industrial technology including national defense, aerospace, and civilian consumer use.

Asbestos is a general term applied to a group of fibrous crystalline hydrated silicate minerals. Although a number of different types of asbestos minerals exist, only four or five are of commercial importance. Each differs somewhat from the others in chemical composition, physical properties such as ability to withstand heat and chemical erosion, crystalline structure, fiber dimension, and degree of fiber harshness and brittleness.

The worldwide production of asbestos has greatly expanded since the turn of the century, the over-all consumption in this country leveling off for the period 1958 to 1963 at around 750,000 short tons annually. Of this tonnage, approximately 93% was chrysotile, 3.5% crocidolite, 2.5% amosite, and 1% anthophylite and tremolite.

Even though asbestos has been in industrial use for well over 50 years, much is unknown regarding its health effects and safe levels of exposure.

It has been known since the early nineteen hundred's that excessive exposure to asbestos gives rise to the disabling pulmonary disease "asbestosis." More recently, evidence has been developed that the incidence of respiratory tract and other malignancies in asbestos workers is excessive. A major problem in studying the health effects of asbestos is the long latent period of 20 or more years from initial exposure to the onset of disease. Also in the mid-nineteen thirties and earlier, there was little dust control and the workers were often exposed to massive levels of dust from asbestos and other associated materials in the manufacture of asbestos products. Thus, the causative agents of the resultant disease are essentially unknown. Included in these potential sources of causative agents, either alone or in combination, are asbestos fibers themselves, materials associated with the fibers in the ores such as trace minerals and polycyclic aromatic oils, materials added during processing such as metals, tars and pitches, and concomitant external exposures to tobacco smoke or other air pollutants.

A salient point is that in subsequent years when heavy dust exposures were reduced, disease also diminished. This definitely indicates that with sufficient knowledge of the agent(s) responsible for the disease, along with dose-response data, safe levels of exposure can be established.

Research to elucidate the importance of the asbestos minerals as hazards to health fall into two broad categories: *first*, studies to provide answers

urgent questions involving public policy and control efforts; and *second*, long-term studies to provide more information as to the physical and chemical factors of fibrous materials as related to their interaction with animals and man so that safe working and living environments can be assured. Consider, for example, the program to evaluate reports of the presence, to some extent, of asbestos bodies in the lungs of a third or more of the American population.

Before public policy regarding the production and use of asbestos can be stated and implemented, we need answers to many questions: do these asbestos bodies truly represent responses to asbestos fibers, or are other fibers also involved? Where do these fibers come from, and what is their potential significance in terms of health? Is there an increasing incidence of mesothelial tumors in our population and is this in any way related to asbestos minerals? Do fibrous minerals play a major or minor role in the causation of lung cancer? Are certain forms of asbestos or other fibers more important in these relationships, and what co-factors are important?

These pressing questions cannot be definitively answered on the basis of present data. A strong supported long-term program is needed to provide the information regarding the pathogenesis of asbestosis and the other effects that appear associated with the inhalation of asbestos dust. More precise data on the physical and chemical characterization of the asbestos minerals which lead to their being inhaled and retained in the body, in their carrying with them other chemicals, in their migration, may open up unsuspected avenues of biological research.

Objectives

Research directed to answering the following questions is needed in order to safeguard the workers' health, yet permit the benefit of asbestos in today's industrial technology. The information gained will also have direct application in furthering the safe use of the many new synthetic fibers being introduced into industry as the result of the rapidly expanding science of industrial fiber technology.

1. What is the nature and pattern of disease in workers exposed to the different types of asbestos fibers and how do they relate to the magnitude and duration of exposure?

The answers to the above are basic to defining related health problems and setting up research on a rational basis for their solution. They should provide data evidencing etiologic factors involved and their interrelationship, the dose-response relationship of the agent(s) to the disease, the criteria for establishing safe levels of exposure, and the basis for establishing medical and environmental surveillance wherever asbestos is encountered and handled. It will also provide useful information for evaluating possible risks from inhaled fibers in those not occupationally exposed.

2. How are the diseases and other manifestations observed in workers exposed to asbestiform fibers characterized clinically and pathologically, and do they differ when exposure involves one type of asbestos or another?

Far more information is needed on the pathogenesis of asbestos and on other responses to asbestos fibers in man. This information should be based on careful serial studies and correlations of clinical, physiologic, radiographic, and histologic changes. Results of these studies would relate to the prevention of asbestos-related disease and would give useful information on the biologic response to other respirable fibers. The findings would supplement current criteria for diagnosis, prognosis, and management of disease, continued employability, fair adjudication of compensation claims, and effective rehabilitation. They would also provide information important in maintaining surveillance programs for asbestos workers and in improving control measures.

3. What are the factors in the pathogenesis of the diseases associated with the inhalation of asbestos minerals and what are the primary etiologic factors involved? Although in many instances it is the predominant ingredient, generally and with only few exceptions, asbestos is formulated with other materials in the preparation of asbestos products. Even in the mining and milling of asbestos, recent studies have shown that these operations are associated with exposures to potentially injurious agents (such as trace minerals of nickel, cobalt, manganese, zirconium, and titanium), polycyclic aromatic compounds from some ores, and metals abraded from processing equipment due to the harshness of the fibers. These same injurious agents may be carried in degrees in the milled fiber and subsequently in increased degrees as processing of the fiber continues.

In the past, studies related resulting diseases to fiber exposure only. Thus, the etiologic agents resulting in the diseases observed in past studies are generally unknown. They may have been one or more of the fibrous forms of asbestos, trace minerals in the ore, polycyclic aromatic com-

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pounds associated with the ore, additives in processing (such as metals, coal tars and pitch), smoking, other air pollutants, or some combination of these factors. A fresh look into both the clinical and animal research of the past and a new approach to current research to further define related agents in the light of our more recent information is indicated.

4. What chemical and physical characteristics of asbestos fibers relate to their respirability, mobility, clearance, and immobilization in the body and how do the types of asbestos differ in these respects?

Most of the research relating to the respirability and retention, mobility, and clearance of materials from the lungs has been done on particulates which have random movements since they are generally spherical. Fibers, however, having a much greater length-to-diameter ratio, have direction and orientation in their movement and many behave quite differently than particulates. Fibers that are harsh and rigid may have tissue penetration potential. Through this mechanism they may, as carriers, transport toxic agents to other tissue sites and, thus, have a causal relationship heretofore not evident. The behavior of fibers in lungs and other tissues must be understood and related to the respective physical and chemical characteristics of fibers so that patterns of response can be described and predicted.

5. How can asbestos fibers *in vivo* and *in vitro* be differentiated as to type and how can they be distinguished from non-asbestos fibers?

Respirable fibers are ubiquitous. They may be either natural or synthetic and from animal, vegetable, or mineral origin. Modern technology is introducing increasing numbers of synthetic fibers into industrial use.

It has been known for some time that asbestos fibers in the lungs give rise to asbestos bodies. Recently, similar-type bodies have been found in the lungs of a large percentage of individuals coming to autopsy in general urban hospitals. This finding, even though the number found in any individual may be relatively small, has given concern as to its significance as well as to the identification of the causative fibers and their environmental source. Methods must be developed for isolating, identifying, and quantitating fibrous materials in the lungs and other tissues and in the associated ferruginous bodies.

6. What levels of exposure to the etiologic agents associated with asbestos-related diseases can be regarded as safe?

Defining safe exposure levels is the prime objective of the research. When safe levels are determined, necessary measures can be taken to keep exposures within the recommended limits.

7. How can exposures be prevented?

The aerodynamic properties of fibers will differ depending upon the specific physical and chemical properties of the fibers. Their behavior in air is much less understood than that of particulates spherical in shape. Information on the behavior of fibers is needed for the design of ventilation control equipment and the design of process equipment to minimize the dispersion of fibers into the air.

8. What environmental and medical surveillance procedures are recommended where asbestos fibers are encountered or handled?

Surveillance of the working population at risk to detect early changes before damages to health have occurred is an essential part of any occupational health program in industry. Environmental monitoring of exposure levels as well as continuing information on the health status of the working force is an important segment of a surveillance program. The continued development and expanded application of surveillance procedures will assure the use of asbestos with minimum risk to health.

Projects

The answers to the above questions can come only from widely-based interrelated research directed to the health response of the worker in his specific environment. The research, although directed specifically to the asbestos worker and his environment, should result in findings applicable in the understanding of a wide range of allied occupational diseases, especially those relating to fiber exposures. This research on health effects of asbestos should encompass, as a minimum, projects as outlined below.

1. *Epidemiology:* (a) Longitudinal studies of groups of workers in different employment categories with contrasting exposures to different types of asbestos fibers by magnitude and duration, singly and in combination with other associated materials capable of producing injury or eliciting a synergistic response to establish interrelationships between health patterns of the workers and environmental exposures.

(b) Studies of the relation between exposure to asbestos minerals and clinical symptoms, pulmo-

nary changes demonstrable by pulmonary function and work tests, and chest roentgenographic shadows suggestive of asbestosis.

(c) Studies of records of morbidity and morality patterns and trends in groups of workers with contrasting exposures to asbestos and other associated materials; also a search for common genetic or hereditary patterns relating to the disease.

(d) Analysis of selected postmortem tissues of workers with work histories in industries having contrasting exposures to different types of asbestos and other associated materials during and after periods of massive dust exposure. Also, studies must be conducted on workers in these categories who died from an exposure-associated disease as well as those who showed no obvious indication of associated disease.

(e) Sputum study of asbestos workers to correlate and quantitate magnitude and duration of exposures with the occurrence of asbestos bodies.

(f) Study of contrasting population groups with respect to geographical areas, air pollution, employment patterns, etc., for presence of pulmonary ferruginous bodies ("asbestos bodies") to determine if these correlate with disease patterns observed.

(g) Study of ecological factors that may have a bearing on the disease or be interrelated with causative agents, including community exposures.

2. ***Clinical and human pathology:*** (a) Comprehensive study of selected individuals with different patterns and progression of disease with respect to: (1) impaired pulmonary vascular circulation, both by tests of function and by angiography; (2) pleural thickening in relation to reduced function, physical signs, altered roentgenographic patterns, and pleural tumors; (3) impact of viral infections on persons with asbestos exposures; (4) sites of pulmonary fiber depositions and injury; (5) immunochemical changes; (6) the nature of the emphysema so often associated with asbestosis; (7) the role of chronic bronchitis and other causes of pulmonary obstructive disease in altering the prognosis of asbestosis; (8) correlation between roentgenographic evidence of disease and the capacity of the cardiopulmonary system to fulfill its required function.

(b) Establishment of a mesothelioma case registry, including uniform criteria for diagnosis and epidemiologic follow-up of reported cases.

(c) Development of a uniform classification for reading chest roentgenograms of persons exposed to asbestos and other fibers; correlation of roentgenologic patterns with clinical, physiologic, and histologic changes.

(d) Study to detect individuals who may be hypersusceptible, either on an acquired or a genetic basis.

3. *Animal experimentation and tissue culture:* (a) Determination of respirability, sites of retention, mobility, penetration, and migration to other tissue, and clearance of pulmonary fibers in relation to their chemical and physical properties.

(b) Study of mechanism of formation and meaning of ferruginous bodies arising from respired pulmonary fibers from different sources.

(c) Study of the chemical and physical characteristics of various types of asbestos fibers, singly and in combination with other associated injurious materials and their capacity to give rise to different forms of cancer; evaluate additive, enhancing, or inhibiting action of fibers and carcinogens from cigarette smoke and other sources.

(d) Study of potential of pulmonary fibers as carriers of carcinogenic and other agents from lungs to other tissue sites.

(e) Development of dose-response data as an aid to developing safe exposure levels.

(f) Investigation into the effects of asbestos and other fibers, and of associated injurious materials, on cellular physiology, enzyme suppression, and genetic pattern.

(g) Study of immunochemical changes, biochemical tests, etc., that may further characterize the exposure-response pattern and serve as predictive tests.

4. *Chemical and physical characteristics:* (a) Study of the positive identification of individual fibers, both *in vivo* and *in vitro;* the nature and quantity of other contaminants such as minerals, metals, and oils associated with the fibers including mechanism of association.

(b) Study of solubility of fibers and associated contaminants in tissue fluids particularly as related to blood and urine levels of associated materials.

(c) Study of sources and identification of respirable fibers responsible for ferruginous bodies seen in lungs and general population of non-asbestos workers.

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Report of the Advisory Committee on Asbestos Cancers to the Director of the International Agency for Research on Cancer

In 1964 the Geographical Pathology Committee of the International Union against Cancer (UICC) set up a working group on asbestos and cancer and later issued a Report and Recommendations (1965). A further meeting was held at the International Agency for Research on Cancer (IARC), Lyon, France, on 5 and 6 October 1972. This was organized jointly with the Medical Research Council Pneumoconiosis Research Unit. The report and recommendations given here will also be published by IARC in 1973, together with the complete proceedings of the meeting. The Committee consisted of three panels—Epidemiology, Pathology, and Physics and Chemistry.

The panels met in separate sessions and at the final session (Chairman Dr J. C. Gilson) prepared this report to the Director of the International Agency for Research on Cancer.

Terms of reference

1. The Committee was to report on the present evidence relating exposure to asbestos dust to cancers, especially that obtained since the meeting of the UICC Working Group on Asbestos Cancers in 1964.
2. The Committee was to make recommendations for further research and indicate priorities for work of immediate and long-term value.

Co-ordination of international co-operation

Following the meeting of the UICC Working Group on Asbestos and Cancers in 1964 a sub-committee of the UICC Commission on Geographical Pathology and Environmental Carcinogens (Chairman Dr J. Higginson) was formed to co-ordinate work required to achieve the recommendations.

In April 1970 agreements between the UICC and the IARC led to the winding up of the UICC sub-committee and the IARC taking on responsibility for the sub-committee's work and extending it by supporting certain projects on asbestos cancers in several countries. The Agency has done this as part of their wider programme of investigating environmental carcinogens. Common memberships between the UICC sub-committee and the committee advising the IARC ensured continuity of policy.

In October 1972 the IARC held an international conference with 137 participants from 20 countries to review all the evidence relating asbestos to cancers. Subsequently the Advisory Committee prepared its report which is divided into two sections, first, a general review in the form of answers to a number of important general questions about the relation of asbestos to cancers of different sites and, secondly, recommendations for further research.

General review

1. Are all major commercial types of asbestos able to cause lung carcinoma?

Yes. Since 1964 the evidence of a causal relationship has been increased by epidemiological studies showing exposure-response relations for the incidence of lung carcinomas. The production of lung carcinomas in certain animals by all types of asbestos supports this conclusion. The epidemiological evidence in man, however, shows that there are clear differences in risk with type of fibre and nature of exposure.

2. Is there evidence of an increased risk of lung carcinoma at low levels of exposure to asbestos, such as have been encountered by the general population in urban areas?

The evidence of an exposure-response relationship based in part on past dust measurements and in part on the type of job within the industry suggests that an excess lung carcinoma risk is not detectable when the occupational exposure has been low. These low occupational exposures have almost certainly been much greater than that to the public from general air pollution.

3. Since 1964 has the evidence relating past exposure to asbestos and mesotheliomas changed?

The evidence has been greatly strengthened by further prospective and retrospective mortality studies in many countries of populations exposed to asbestos. There is evidence that all commercial types of asbestos except anthophyllite may be responsible. Evidence for an important difference in risk in different occupations and with the type of asbestos has increased. The risk is greatest with crocidolite, less with amosite, and apparently less with chrysotile. With amosite and chrysotile there appears to be a higher risk in manufacturing than in mining and milling. There is also evidence from population studies that a proportion of cases of mesothelioma have no known association with exposure to asbestos.

4. Is there evidence of an increased risk of mesothelial cancers at low levels of exposure to asbestos, such as have been encountered by the general population in urban areas?

There is evidence of an association of mesothelial tumours with air pollution in the neighbourhood of crocidolite mines and of factories using mixtures of asbestos fibre types. The evidence relates to conditions many years ago. There is evidence of no excess risk of mesotheliomas from asbestos air pollution which has existed in the neighbourhood of chrysotile and amosite mines. There are reported differences on incidence of mesothelioma between urban and rural areas, the causes of which have not been established. There is no evidence of a risk to the general public at present.

5. Since 1964 has the evidence changed on the importance of other factors such as cigarette smoking, waxes, oils, and trace elements as contributory factors to the cancer risk?

The evidence has accumulated indicating:

(1) Cigarette smoking is an important factor enhancing the lung carcinoma risk in asbestos-exposed workers, in both men and women. Asbestos workers have specially strong grounds for giving up smoking to protect their health. No association has been demonstrated between cigarette smoking and mesotheliomas.

(2) Animal experiments designed thus far to test the importance of waxes and oils as contributory factors in the production of mesothelioma have shown that these contaminants are unlikely to be relevant.

(3) From animal experiments there are no good clues suggesting that trace elements are likely to be a major factor in the production of asbestos cancers.

6. What other types of cancer are related to exposure to asbestos?

Prospective surveys of occupational groups exposed to asbestos have in general shown a small excess risk of some other types of cancers (in addition to bronchial and mesothelial), especially those of the gastrointestinal tract. The excess of these tumours is relatively small compared with that for bronchial cancer. Evidence for an association with ovarian tumours has not been supported by the first large mortality survey of women previously exposed to asbestos.

7. Is there evidence of an increased risk of cancer resulting from asbestos fibres present in water, beverages, food or in the fluids used for the administration of drugs?

Such evidence as there is does not indicate any risk.

8. Is there evidence of a risk of lung fibrosis from low levels of exposure to asbestos such as have been encountered by the general population in urban areas?

There is at present no evidence of lung damage by asbestos to the general public. The amount of asbestos in the lungs of members of the general public is very small compared with the lungs of those occupationally exposed. It is greatest where asbestos is mined or worked and lowest in rural areas.

9. Has the relationship between asbestos exposure and the development of pleural plaques been established?

Pleural plaques have been associated with past exposure to all commercial types of asbestos. But additional factors, other than asbestos itself, are involved. The plaques may remain fibrous or become calcified. Not all pleural plaques are associated with asbestos.

Recommendations for further research

Projects which the panels rated high in priority are marked *; those which will require close co-operation between the Panels are marked -.

Epidemiology

The panel agreed that asbestos-related cancers occur in several sites in the body. The incidence of the different cancers varies with a number of definable factors and for other reasons, such as competing causes of death. Epidemiological studies will usually

provide information on more than one type of cancer. Research directed at only a single type may, on occasions, be useful, but in general the inevitable uncertainties, in some cases in the differential diagnosis of, for example, peripheral lung carcinomas and pleural mesotheliomas, and between peritoneal mesotheliomas and other intra-abdominal cancers, will require that more than one type is studied at the same time

The panel recognized that some of the epidemiological projects could be pursued only if there was close co-operation between epidemiologists, pathologists, physicists and chemists, and others, because their success will depend upon the development of improved techniques, some of which are referred to in the recommendations of the other two panels

Projects

(1) Further development of objective methods for early detection and surveillance of effects caused by asbestos Topics for particular study include

(a) immunological techniques for screening for fibrosis and neoplasia,

(b) functional tests of changes in the peripheral airways,

(c) detection of pleural thickening,

(d) assessment of the specificity of small irregular opacities in the chest radiograph as defined in ILO U/C Classification, 1971,

(e) tests of the usefulness of different techniques of chest radiography, including the use of 100 mm films,

(f) development of statistical procedures for analysis and presentation of serial observations

(2) Evaluation of the usefulness of early detection in the prevention of progressive fibrosis and asbestos cancers, also in the identification of hazardous conditions Routine health surveillance of [illegible] populations should be designed to assist epidemiological studies and should include measurement and recording of environmental dust levels Surveillance of new entrants could be particularly valuable Arrangements should be made to register workers so that their morbidity and mortality experience can be studied even after cessation of exposure to asbestos

(3)* Assessment of excess cancer risks following exposure to only one type of fibre

(a) *Chrysotile* The much higher cancer risk reported for chrysotile textile workers compared with [illegible] How much is explicable by differences in size of airborne fibres and past dustiness? There is need to make more use of past dust records for relating to indices of disease

(b) *Amosite* The excess lung carcinoma and mesothelioma risks apparently much greater in the manufacturing and application sections of the industry than in the mining and milling of this type of fibre What are the important factors in this reported difference?

(c) *Crocidolite* Further studies are required in occupational groups exposed only to crocidolite or amosite or chrysotile in manufacturing and application parts of the industry to establish more clearly differences in risks due to different fibres.

(4)*† Studies of the amount and type of asbestos in the lungs of cases of mesothelioma (if possible by cell type) in (a) a national survey of mesotheliomas, and (b) representative samples of cases arising in groups with a definable past exposure.

(5)* Studies of secular changes in the incidence of pleural and peritoneal mesotheliomas nationally and internationally

(6)* Epidemiological studies to investigate the association between past exposure to asbestos and cancer of sites other than lung, pleura, and peritoneum

(7) Studies of secular trends in the asbestos content of the lungs in the general population

(8)*† Studies to relate amount and type of asbestos in the lung and estimates of past dust exposure and interval since last exposure.

(9) Experimental and epidemiological studies to investigate possible differences of effect of continuous low and intermittent high exposure to asbestos

(10) Opportunities afforded by intercurrent deaths should be used to interrelate radiographic appearances, lung pathology, respiratory function, and dust content and type in asbestos workers Standardized techniques and classification recommended by the panels should be used

(11) Investigation of the prognostic significance and aetiological factors in the development of calcified and uncalcified pleural plaques in different environments

(12) Investigation of talc-exposed groups in mining and manufacturing to establish any differences in morbidity or mortality which might be related to the amount and shape of the fine respirable particles

(13) Development of cost/benefit analyses to study the health, safety, social, and economic interrelations of the use of asbestos.

Pathology and experimental pathology

The panel reviewed the progress made on the 1964 UICC recommendations It was agreed that considerable progress had been made on the majority of the recommendations. Some require further study, or modification of previous methods of investigation; these are included in the list of recommendations which follows The recommendations are divided into

three categories; morbid anatomy and histology, clinical research, and experimental studies.

Morbid anatomy and histology

Projects

1. *Asbestosis*

(1)* Further consideration should be given to methods for determining the amounts, types, and structural features of asbestos in tissue. A subcommittee should be established with members of the Physics and Chemistry Panel and others to accelerate work on this problem.

(2) The methods for assessing the severity of asbestosis should be tested for consistency by different observers

2. *Carcinoma*

(1)*† An investigation of whether reduction of asbestos exposure to levels below those producing asbestosis also abolishes excess risk of carcinoma was considered important.

(2) A comparison of lung carcinomas in persons occupationally exposed to asbestos and those not so exposed, including both cigarette smokers and non-smokers, in respect of sites of origin and cytology of tumours and presence or absence of asbestosis, would be of value

3. *Mesothelioma*

(1) The International Panel of Pathologists[1] and National Panels established following the 1964 meeting[2] have served a useful purpose It is recommended that panels be established in other countries and membership of the International Panel be extended The main purpose of these panels is to ensure uniformity of diagnostic criteria and recording of histological types of diffuse mesothelioma Collaborative study of histology slides in National Panels is recommended The diagnosis of mesothelioma can be made by exfoliative cytology of the pleural fluid If the cytological diagnosis is made by a competent cytologist, biopsy may be unnecessary.

(2) To improve consistency of diagnosis there is an urgent need for a comprehensive atlas on mesotheliomas or, alternatively, for inclusion of an enlarged section on mesotheliomas in the new edition of the WHO Monograph on Tumours of the Lung Criteria for diagnosis by exfoliative cytology and a description of the fine structure of mesotheliomas should be included

[1] The International Panel of Pathologists: Dr A. Kaufman (USA), Professor D. Magnus (Canada), Dr E. Mecklin (Finland), Professor W. T. L. McCaughey (Eire), Professor H. Otto (FRG), Dr H. Planteydt (Netherlands), Dr J. Rohrsch (GDR), Professor F. Santi (Italy), Professor I. Webster (South Africa), and Dr J. C. Wagner (UK) as Secretary

[2] Great Britain, South Africa, United States, Canada, Netherlands.

Clinical research

(1)*† Monitoring by immunological methods of populations exposed to asbestos should be investigated to ascertain whether it is possible to recognize those who are developing, or will develop, tumours.

(2) The use of chromatographic methods for the study of mucopolysaccharides and other tumour-associated substances in pleural fluids should be explored. Sensitive methods might be developed and applied to identify secretory products of mesotheliomas in blood and urine

Experimental studies

(1)* Information is required about the role of fine particles, especially the influence of fibre size, in the induction of tumours These studies should be extended to include fibres other than asbestos. A sub-committee should be established to review the need for, and arrange the distribution of, [illegible] samples of asbestos and other fibres in addition to UICC reference samples

(2)* The fate of inhaled particles of various sizes, shapes, and chemical compositions should be studied to determine more precisely the quantities and sites of initial deposition, change within the body, and later retention. The feasibility of increasing fibre elimination by various methods should be explored. Studies should be made of means of reducing the fibrogenicity and carcinogenicity of fibres already retained in the lungs.

(3) The use of cell and organ culture, including mesothelial tissue from man and other species, should be further investigated with a view to developing methods of screening dusts for fibrogenic and carcinogenic properties.

(4) Further studies should be carried out to determine the nature of the combined effect of tumour induction when animals are exposed to asbestos dust and cigarette smoke [illegible] chemical carcinogens, including those [illegible] systematically, such as nitrosamines

(5) Inoculation experiments should be extended to test various types of fibre, of special interest are the forms of chrysotile and crocidolite, including the finer grade materials.

(6) It was felt that studies of the pathological effects of asbestos on species other than rodents would be of value

(7) The effect of long-term ingestion of fibres of various sizes, shapes, and chemical compositions should be studied

(8) Effects of fibres and associated metals on the metabolism of target organs should be investigated

Physics and chemistry

The panel reviewed the progress made on the

UICC Recommendations. The proposals for the preparation and characterization of the UICC reference samples of asbestos had been satisfactorily implemented, and the panel recommended that a list of references to papers featuring the samples should be distributed to investigators in this field. Considerable progress had been made on methods of identifying the type of fibre in tissues but a quantitative method when several types of fibres were present had yet to be developed.

The panel discussed the further contribution that physical and chemical studies can make to research on the biological effects of asbestos and other fibrous materials. Of especial interest are the effects of fibre size and shape on the retention of material in the lungs, the site of deposition, the migration of fibres within the body, and their carcinogenic or other biological activity. The following recommendations were made:

Projects

1. *Materials for experimental work***

(*a*) Supplies of asbestos from relevant sources should be obtained where there is evidence of variation in geological form, trace element content or significant biological findings.

(*b*) Small samples of various fibrous materials should be prepared for studies on the influence of fibre size and shape on carcinogenicity. For this purpose the samples should be milled to different degrees of fineness.

(*c*) For investigations on the influence of particle shape and size, on the inhalation and subsequent fate of asbestos fibres a chrysotile and an amphibole of fibre length greater than the UICC samples should be prepared.

2. *Methods***

(*a*) There is an urgent need for the quantitative assessment, size analysis, and characterization of particles and fibres in the lungs and other organs. Details of available methods should be circulated, international comparisons undertaken, methods standardized, and new techniques developed.

(*b*) No methods are at present available for the preparation of fibres in narrow ranges of diameter and length in sufficient quantities for inoculation experiments. Techniques for these purposes are urgently required, especially in view of the advantages such graded samples could provide for investigations of the influence of these physical factors on the carcinogenicity of fibres of different materials.

(*c*) Since the degree of dispersion of fibres (especially chrysotile) used in inoculation studies may have a marked influence on their carcinogenicity, methods are required for quantifying dispersion.

(*d*) Inhalation studies require precise control of the characteristics of the dust clouds. Improved methods of dispensing fibrous dusts in such investigations need to be developed.

(*e*) Methods are available for collecting the important size fractions of dust clouds in inhalation studies when the particles are of compact shape. Similar methods must be developed for fibrous particles.

(*f*) The present membrane filter methods of measuring the levels of airborne asbestos dust require standardization. This should be done by interlaboratory trials on a continuing basis. Particle counting by electron microscopy should also be developed. Gravimetric assessment methods and the automation of particle counting should be explored.

3. *Inhalation studies*†

Considerable information is now available on the deposition, retention, and migration of particles of compact shape. Recently developed methods, especially radioactive tracer techniques, should be used to obtain similar knowledge for fibrous particles. This information is needed to identify the biologically important size fraction and to help interpretation of epidemiological and pathological studies.

4. *Occupational and environmental studies*

The use of both fibre counts and gravimetric methods for assessing asbestos dust concentrations should be encouraged. Data collected over an extended period will be particularly valuable in identifying the parameters of the dust which can be correlated with epidemiological evidence on the health hazard.

5. *Physics and chemistry panel*

It is recommended that an international panel be established to assist in implementing these recommendations. The panel would periodically review requirements for materials for experimental work, provide guidance on physical and chemical problems, and arrange national and international standardization trials.

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Research Perspectives Concerning Asbestos Minerals and Their Effects on Biological Systems

by Arthur M. Langer*

The interaction of asbestos minerals with biological materials is under intensive investigation throughout the world today. Physical scientists should be responsible for the selection of fibers, and their varietal types, for biological studies; they should characterize these experimental materials physically and chemically to the level of sophistication which currently exists in their fields; they should develop definitive assay methods to monitor changes in such characteristics after biological residence; they should actively participate in the formulation of theories or mechanisms of particle interaction in biological systems.

Physical scientists should begin the characterization of minerals in the environment and the determination of ambient fiber levels in air and potable water supplies. Such characterization of the environment requires standardized instrumentation and preparation techniques. Acquisition of data in numbers large enough to achieve statistical significance requires the development of automated counting strategies. Instrumentation and software have yet to be developed. The training of physical scientists in environmental areas is lagging behind current national needs and must be accelerated.

Introduction

There is an urgent need for the physical scientist to take a leading role in the field of particle–biological systems interaction. There are many reasons for this: the physical scientist is more familiar with asbestos complexity and its behavior in a range of media; he has developed techniques for sampling and analysis of fiber at all levels of contamination; he has developed the instrumentation for fiber characterization and recognizes the statistical shortcomings in present day quantitation; he recognizes the need for precisely determining all of the chemical and physical parameters of materials used experimentally. Most important, interaction mechanisms of particles in biological systems may be clarified from the direction and perspective of the particle-end of input. Conventionally, most of the work in this field was directed toward host or tissue response rather than the nature of the materials. In accordance with the principle of biological interaction, it is imperative to have knowledge before disease stigmata appear, in addition to final response. Etiologic mechanisms may be established by prediction of response based on particle property.

What are the needs in this area that the physical scientist might fulfill?

The Need to Define Asbestos

The term "asbestos" should be explicitly defined to all experimental biologists concerned with fiber effects. The term as presently used refers to a group of flexible, silicate mineral fibers which possess, more or less, physical and chemical characteristics which render them "useful" as insulators, filtering agents, etc. Frequently, asbestos is explained as a "generic" term which includes a specific number of mineral entities. However, what is generally unknown to the biological scientist is that asbestos minerals themselves are not pure materials, but

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occur as mixtures of varying complex crystal–chemical systems. For example, the mineral amosite is actually a member of the grunerite–cummingtonite solid solution series; crocidolite is a member of the glaucophane–riebeckite series; anthophyllite is also a member of the grunerite–cummingtonite series with additional aluminum; both tremolite and actinolite are called separate asbestos minerals, but actually they are end-members of the tremolite–actinolite solid solution series. The amphibole asbestos minerals are themselves extremely complex and never occur as chemically pure end-members. Manganese is a frequent minor element occurrence. Also, a number of other elements may be present in these minerals in substantial amounts. The asbestos minerals thus possess a range of chemical compositions which gives rise to differences in their physical properties. The chemistry of asbestos mineral fibers should be defined in mineral terms, so that similar non-economically exploited fibers will not escape notice as being potentially biologically active. The term asbestos should remain, but an awareness of its true mineral character should be created. This will be particularly important as mining and milling operations are examined in regard to their silicate minerals and their possible biological hazards. Asbestos names, and their component mineral names, should enter the biological literature. Future Lake Superiors may be avoided.

Workers in biological fields should be aware not only of the chemical nature of asbestos, but of the relationship between chemical and physical properties. That is, small changes in cation substitution, especially at specific structural sites, may greatly influence such properties as mineral cleavage or surface charge. These properties may have great biological significance in terms of mechanisms of interaction.

The Need to Determine Effects of Differing Media on Asbestos Stability

Work should begin concerning the alteration of asbestos fiber after residence in potable water. This has recently arisen after study of fibers in the sediments of Lake Superior. Fibers observed in older sediments were not identical with those in the freshly discharged ore tailings found at Silver Bay. There are indications that an ion-leaching process at the surface of the asbestos fiber removed iron from the structure, leaving an altered, highly reactive surface. If these observations are correct, then less stable asbestos mineral phases, especially chrysotile and crocidolite may alter considerably after prolonged residence in natural lake waters. The possible biological effects of such altered fibers should be investigated at this time.

The Need to Determine Biological Effects of Different Forms of the Same Fiber

There is presently being mined a new type of chrysotile deposit commonly referred to as the Coalinga-type. In this occurrence, unlike vein serpentine deposits, chrysotile occurs as mats of individual fibrils in massive lenses. From the end-products which use such material, the dusts generated are far more fine-grained than one normally encounters in those which are mined from vein deposits. The number of fine fibers and individual fibrils, smaller than 5 μm in length, are more numerous. Biological workers guided by physical scientists should be presently engaged in research defining the long-term effects incumbent upon the inhalation of such large numbers of small fibers. The effects which should be studied include both lung scarring and carcinogenic potentials.

The Need to Determine the Biological Effects of Different Fibers on the Organism—Organ-Cellular Levels

The physical scientist should work with experimental biologists in determining the effect of fiber type, chemical range, size range, surface area, surface charge, etc., on living systems. These systems should be both *in vivo* and *in vitro* models, and should include all possible interaction effects. The thrust of the work should be toward the prediction of interaction phenomena based on particle property rather than observation of results. A review of the interaction of silica and other important silicate minerals in living systems should be implemented.

The Need to Know More About Ambient Levels of Asbestos Contamination

The question arises concerning how extensive asbestos contamination in the environment real-

ly is. More information is urgently needed regarding the ambient levels of chrysotile in community air, in potable water supplies, and in human tissues. More must be learned about the sources of the asbestos fiber, including their kinds and amounts. Data are needed concerning the chemistry and physical properties of these particles and whether or not they had undergone any alteration in the environment. In an ongoing study in our laboratory, we have demonstrated the presence of chrysotile asbestos within the Greenland ice cap. Ice dated from these areas have yielded samples which go back several centuries in time. Although we know nothing of time changes as yet, we are afforded the opportunity to determine if the ambient backgrounds we now observe are the products of natural degradation of rocks or are the products of industrial usage in the twentieth century.

Concerning potable water supplies, the last major study concerning suspended mineral phases in waters was carried out in the early part of this century. This work was done by light microscopy and is at best, qualitative. Earth scientists must redo a study of this kind and on the sublight microscopic level. Ingestion of small particles, those which may easily migrate to other anatomical sites, may be of greater biological importance.

The Need to Determine Tolerable Fiber Levels in Biological Systems

Materials which are widely used in construction trades, pharmaceutical trades, etc., which might contain asbestos as a natural contaminant, should be scrutinized by both the biological and physical scientist. For example, asbestos in talc varies from major contaminant to a trace. No talc we have examined contains an absolute zero level of fiber. If a biologically acceptable level exists, it should be determined.

The Need to Standardize Instrumentation: Collection and Identification of Fiber

The instrumental techniques required for the collection and analysis of asbestos fiber in gas, liquid, or solid media need to be standardized. For example, the sampling of particulates from air should be restricted to filtration, either membrane or polycarbonate, rather than impingement or impaction devices. Analytical methods should include both light and electron microscopy and their range of instrumental techniques. More important, however, the accumulated data from all laboratories in the United States should be sent to a central governmental agency which would be responsible for the appropriate collation and evaluation of such information and its dissemination back to the various laboratories and interested governmental agencies. In order properly to evaluate such information, standard samples should be analyzed by a number of laboratories for comparison purposes. A prerequisite for such comparison is the implementation of standard sampling, preparation and analytical techniques. This is of critical importance in the areas of low-level fiber contamination.

The Need to Develop Expertise in More People

There is an urgent need for more laboratories to expand the training of technical staff for the areas of fiber analysis. The number of samples which may be processed by a single laboratory is extremely small, being limited by the requirements of time, instrumentation, and the number of individuals capable of doing the analysis. Although the instrumentation problem is readily soluble by monetary support, the qualified people required for future work should be trained immediately. These individuals are in short supply now and will be in even shorter supply as facilities develop in the future.

The Need for Automation

There is an urgent need at the present time for an automated system to be developed for the identification, characterization and enumeration of asbestos fibers in various media. This would increase the number of samples studied and yield statistically acceptable confidence levels in quantitative work. Instrumentation has now evolved to the point where automation is feasible; environmental problems have evolved to the point where quantitation is urgently needed.

All of the above research must be carried out by physical scientists working in the field of environmental medicine. There is a most urgent need for the recruitment of such individuals into this field. Most important, there exist today

very few laboratories in the United States which can properly analyze materials for their asbestos fiber content. Because this field is so rapidly expanding, these laboratories, including instrumental and human resources, will quickly be overwhelmed by such work.

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16. ABSTRACT

This report reviews much of the available information on asbestos through 1973 as well as some more recent documents relating to health effects and environmental exposure. Current federal and state regulations on asbestos emissions, effluents, and occupational exposure are cited. Analytical methodology and control technology are reviewed. In addition, general information on uses and mining, milling, and reprocessing industries is provided along with consumption figures and emissions estimates associated with each category. Gaps in the knowledge about asbestos (especially health effects) are pointed out and research recommendations of various investigators and scientific groups are compiled to indicate need for further research activities to allow meaningful evaluation of the environmental hazard present by asbestos.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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