III. BIOLOGIC EFFECTS OF EXPOSURE TO ASBESTOS

Asbestos is a generic term that applies to a number of naturally occurring, hydrated mineral silicates incombustible in air and separable into filaments. The most widely used in industry in the United States is chrysotile ($3MgO.2SiO_2.2H_2O$), a fibrous form of serpentine. Other types include amosite $(FeMg)SiO_3$); crocidolite ($NaFe(SiO_3)_2.FeSiO_3.H_2O$); tremolite ($Ca_2Mg_5Si_8O_{22}(OH)_2$); anthophyllite $(MgFe)_7Si_8O_{22}(OH)_2$); and actinolite ($CaO.3(MgFe)O.4SiO_2$).

Extent of Exposure

Almost one million tons per year of asbestos are used in the United States. In 1965, approximately 74 percent of the asbestos produced was used in the construction industry (532,300 tons) while 26 percent was used in non-construction industries (187,400 tons). Approximately 92 percent of the half million tons used in the construction industry is firmly bonded, i.e., the asbestos is "locked in" in such products as floor tiles, asbestos cements, and roofing felts and shingles; while the remaining 8 percent is friable or in powder form present in insulation materials, asbestos cement powders, and acoustical products.[1] As expected, these latter materials generate more airborne fibers than the firmly bonded products. The 187,400 tons of asbestos used in non-construction industries in 1965 were utilized in such products as textiles, friction material including brake linings, and clutch facings, paper, paints, plastics, roof coatings, floor tiles, and miscellaneous other products.

Mining and milling of asbestos in the United States is a small industry, employing fewer than a thousand workers. The health and safety

aspects of mining and milling operations are not covered under the Occupational Safety and Health Act of 1970.

The construction industry has, in recent years, applied asbestos insulation materials by spraying, a method of application that generates more airborne asbestos fibers than older conventional methods. This technique at present utilizes only a small percentage of the total asbestos produced and its use is decreasing.

There are approximately 40,000 field insulation workers in the United States who are exposed to asbestos dust. The activities of these workers cause secondary exposures to an estimated three to five million other building construction and shipyard workers.[2]

Since the dust exposure to the individual worker is extremely variable and the number of asbestos workers at any one location is small, the primary and secondary asbestos dust exposures to all workers have never been satisfactorily estimated.

An estimated 50,000 workers are involved in the manufacture of asbestos-containing products. This figure does not include secondary manufacture of products which contain asbestos, such as electrical or thermal insulation, or products which include previously manufactured components containing asbestos.[3]

The following information, furnished by the Pennsylvania Division of Occupational Health, shows the number and variety of plants using asbestos in which potential exposures can occur. These figures are based on a survey of a total of 18,439 manufacturing plants in that

State as of August 22, 1969, and represents about 1.4 percent of all manufacturing operations in Pennsylvania. Service facilities such as garages are not included.

	No. of Plants
Insulation, including cutting, drilling, and tape manufacture	75
Manufacturing and processing	16
Brakes and friction	10
Cement, clay	18
Miscellaneous*	146
TOTAL	265

*Gaskets
Signs
Safety equipment
Laminated material
Paint and roofing materials
Shipbuilding and shipbreaking
Impregnating resin and urethane
Textile
Undercoating material
Ironing board covers
Flooring

Early Historical Reports

The widespread use of asbestos fibers did not begin until the last quarter of the nineteenth century.[2] With the increasing use of asbestos materials and increasing reports of asbestos related disease there developed concern over the role of these minerals as factors in human disease. Differentiation of the type of asbestos fiber was not made in most studies related to occupational exposure. In the United States the exposures of greatest concern usually involve more than one type of fiber, although chrysotile predominates. To refine our knowledge of the biological actions of asbestos, it is imperative that the character of the exposure as to concentration, size, and type of fiber be known. At present, data of this complexity are scanty or often non-existent with respect to human exposure.

The first record of a case of asbestosis was reported in England by Montague Murray in 1906.[4] The first complete description of asbestosis and of the "curious bodies" seen in lung tissue appeared in 1927 when Cooke[5] reported on a case of asbestosis and McDonald[6] reported on the same and another case. Each author gave reasons for believing that these "curious bodies" originate from asbestos fibers that reach the lungs.

Many of the people exposed to asbestos dust develop the disease "asbestosis" if the dust concentration is high or the duration of their exposure is long. This has been documented by the following studies: Merewether and Price, 1930; Fulton et al., 1935; and Dreessen et al., 1938. In 1918, Hoffman[7] reported that it was the practice of

American and Canadian insurance companies not to insure asbestos workers due to the assumed health-injurious conditions of that industry. In 1917, Pancoast, Miller and Landis[8] reported on X-ray appearances of pneumoconiosis in 15 individuals exposed to asbestos.

Mills' publication[9] in 1930 was the first report on a case of asbestosis published in the United States, and in that same year, Lynch and Smith[10] reported on "asbestosis" bodies* found in the sputum of asbestos workers. In Merewether's review of asbestosis,[11] emphasis was placed on the relation of asbestosis to dusty working conditions.

The clinical aspects of asbestosis are well documented. Gloyne[12] discussed the pathology of asbestosis and methods for diagnosing asbestos bodies and asbestosis. Selikoff and Hammond[13] analyzed 1,975 autopsies in three large New York City hospitals and found asbestos bodies in 942 (47.7%). Broadly considered, 40 percent of housewives, 50 percent of "white collar" males, and 50 percent of "blue collar" males showed asbestos bodies; but males who had a history of shipyard or construction work had higher incidence of asbestos bodies, i.e., 90 of 129 cases or 70 percent. Selikoff's observations also suggest that asbestos bodies were as frequently present 38 years ago as now.

Although a large percentage of the lungs of adult urban dwellers may be found to contain ferruginous bodies (depending on the method of examination), the significance of this is as yet unknown.

*"Ferruginous bodies" is a more descriptive term. This and other aspects of the biologic effects of asbestos are well documented in the Annals of the New York Academy of Science.[1]

The core fibers have not been systematically identified to indicate how many are asbestos bodies, and there are little data bearing on possible health effects associated with the low concentrations of fibers found in ambient air.

An abnormality, occurring with unusually greater frequency in populations exposed to inhalation of asbestos fiber, is that of localized thickening, or plaques, of the pleura with or without calcification of the plaques. The role of the asbestos fiber in this manifestation is not clear.

The medical aspects of exposure to asbestos and the development of the occupational disease, asbestosis, are characterized by:

(1) A pattern of roentgenographic changes consistent with diffuse interstitial fibrosis of variable degree and, at times, pleural changes of fibrosis and calcification.

(2) Clinical changes including fine rales and finger clubbing. These may be present or absent in any individual case.

(3) Physiological changes consistent with a lung disorder.

(4) A known history of occupational exposure to airborne asbestos dust. In general, a considerable time lapse between inhalation of the dust and appearance of changes as determined by X-ray.

The several clinical abnormalities listed above appear to occur with unusual frequency in those environments where airborne asbestos fibers, often in association with other substances, exist. One of these abnormalities, a diffuse chronic inflammation and scarring

of the lung, is the one recognized early in this century and referred to as "asbestosis."

Epidemiological Studies

Harries[14] in 1968 suggested that first impressions would lead one to believe that only workers continuously exposed to asbestos are at risk of developing asbestosis, however, a number of trades experiencing intense intermittent exposures are also suspect. These other trades involve work with asbestos insulation in confined spaces onboard ship. Work in these trades has been accepted by the Pneumoconiosis Panel of the United Kingdom as associated with asbestosis. Selikoff,[15] however, in a study of 232 former insulation plant employees reported positive X-ray findings among individuals having had known exposures to asbestos as short as one day (Table XXVII).

In the late 1940's a frequency of bronchogenic cancer greater than that expected on the basis of the general male population was manifest among persons who worked in the manufacture of asbestos products.[16] This excess of bronchogenic cancer was also demonstrated among a group of workers in the United States exposed to airborne asbestos fibers in the installation of insulation.[17,18] Among 632 asbestos insulation installers observed from 1943 to 1967 there were 99 excess deaths (above that expected on the basis of the U. S. white male population) for three types of malignancies-- bronchogenic (63), gastrointestinal (26) and all other sites combined (10). Elmes and Simpson[19] recently reported findings of similar magnitude among men employed as insulators and pipe coverers in Belfast. Newhouse[20] found an excess of lung cancer

in a study of over 4,500 male workers employed at an asbestos factory making both textile and insulation materials. This excess of lung cancer was demonstrated among those workers with jobs which entailed heavy exposure irrespective of the duration of employment.

More recent observations by Selikoff in the United States indicate a lung cancer risk for workers exposed to amosite asbestos in the production of insulation material.[21]

The possibility that the carcinogenic role of asbestos is solely that of a cocarcinogen has been suggested by Wright.[2] This suggestion stems from the observation by Selikoff and associates[17] that among 370 asbestos insulators, exposure to asbestos dust does not greatly increase the risk of bronchogenic cancer in the absence of regular cigarette smoking. More recent observations among this same group of workers,[22] however, demonstrate that this interpretation is largely a function of sample size as one lung cancer death vs. 0.02 expected was observed among non-smokers as contrasted with 27 vs. 2.83 expected among cigarette smokers. Moreover, Decoufle[23] demonstrated that the excess of lung cancer mortality among several subgroups of retired asbestos workers could not be explained by cigarette smoking alone.

Concerning mesothelioma, 80 percent of the cases studied in South Africa and the United Kingdom have been shown to have an occupational or para-occupational association with asbestos fibers.[2] In the United States, Selikoff and co-workers have reported the occurrence of 14 deaths from mesotheliomas among 532 asbestos insulation workers studied in retrospect from 1943 to 1968 compared to no deaths which

would be expected in the same number of similar individuals in the general population.[17,18] Information is insufficient at this time to set an exposure standard (other than zero) which would assure prevention of mesothelioma in all workers, as the disease may occur following a very limited exposure 20-30 years earlier.

An increased rate of occurrence of mesothelioma of the pleura or peritoneum was reported in some populations in 1959 and in subsequent years. The possibility that asbestos may play a role in this distribution has been raised. Investigations of the distribution of mesothelioma in populations occupationally exposed to asbestos indicate a strong relationship between exposure to asbestos fiber and the presence of mesothelioma.[18,20,24,25]

Neoplasms, such as mesothelioma, may occur without radiological evidence of asbestosis at exposure levels lower than those required for prevention of radiologically evident asbestosis. This may be of particular importance when consideration is given to short-term, high levels of exposure, and may result in the development of mesothelioma before or after completion of a normal span of work either in or out of the asbestos industry.

This is illustrated by several case studies, including two cases of malignant mesothelioma, one a "family" and the other a "neighborhood" case.[26] In another "family" case, a woman washed the overalls of her three daughters at home; all three daughters worked for an asbestos company with possible heavy exposures to asbestos.

The time lapse between onset of exposure and mesothelioma in 344 deaths among asbestos insulation workers was studied. Mesothelioma developed after a longer lapse of time from onset of exposure to asbestos than was the case in the development of asbestosis (Table XXVIII).[15] Knox[27] reported 4 cases of mesothelioma in men and women with less than 10 years exposure, one with only seven months exposure, with the latent time for the development of the mesothelioma from 23 to 53 years.

D. L. Cran[28] indicated that mesothelioma did occur in cases of asbestosis, but that in most cases of mesothelioma that he had seen, the occurrence of asbestosis was not found. He postulated that the difference being the long periods of exposure required to produce asbestosis, while mesothelioma could occur long after a short intensive exposure. The 27 cases of mesothelioma in children under 19 years of age indicates the latent time period for development of mesothelioma may be shorter than first estimated.[29]

Fifteen cases[30] of pleural mesothelioma associated with occupational exposure were reported in Australia. The relationship between the mesothelioma development and asbestos was based upon occupational histories and finding of asbestos bodies in the tissue. In some of these cases, the relationship to occupational exposure could not be developed with any degree of certainty, but included patients whose exposure was as short as six months. No patient was regarded clinically or radiologically as suffering from asbestosis; one person had pleural plaques that were radiologically visible.

Stumphius,[31] between 1962 and 1968, found 25 cases of mesothelioma on Walcheren Island. Of these cases, 22 had been employed in the shipyard trades. Stumphius noted that the shipyard employed about 3000 men. This would result in a rate of mesothelioma of approximately 100 per 100,000 males per year. He also noted that the rate for Dutch provinces with heavy industry is 1.0 per 100,000 per year.[31] In the same study, examination of sputum from 277 shipyard workers showed that 60% had asbestos bodies. The frequency varied from 39% of those with no obvious exposure to 100% among those with slight but definite asbestos exposure.

McEwen[32] found that the incidence of mesothelioma in Scotland was similar to that found in other parts of the United Kingdom and confirmed the association between the development of the tumor and occupational exposure to asbestos.

In 1968 Stumphius and Meyer[33] concluded that asbestos exposure may lead to asbestosis, to carcinoma of the lungs and digestive tract, and to mesothelioma. They further stated that there may be no indication of definite exposure to asbestos. It must be pointed out that a clear picture of the relationship between the type of asbestos and the production of asbestosis, neoplasms, and mesotheliomas is not defined in the exposures reported. In many cases mixed exposures have occurred; e.g., the cases from the Naval dockyards in Great Britain where exposures have occurred in unknown amounts to crocidolite and amosite.

Animal Toxicity

Experimental Animal Studies. Experimental exposure of animals to asbestos has been in progress for more than 40 years. During this time, a precise experimental animal model, from which could be derived dose-response relationships that could be used in estimating the appropriate value for a work place air standard has not yet been reported.

The rate of development of asbestotic pulmonary fibrosis and of induction of pleural mesotheliomas is so slow that the animals die before onset of the condition. Accordingly, to develop either condition, experimenters have had to use inordinately high exposure levels or abnormal modes of administration or both, thus nullifying the animal model. The classical demonstrations of diffuse pulmonary fibrosis in guinea pigs with accompanying asbestos bodies by Gardner and Cummings[34] and by Vorwald et al.[35] became possible only by using fiber levels of from 1,400 to 5,000/cc (39 million to 138 million fibers/cubic foot); and the uniform production of mesotheliomas in rats by Wagner and Berry[36] was attained only after administering the asbestos by intrapleural injection at the extraordinarily high dose of 20 mg.

Stanton et al.[37] were unable, even when aided by chemical means, to induce neoplasms of any type in a tumor-susceptible strain of rats at low dosages of asbestos (type unspecified); but Gross et al.[38] did produce in rats malignant pulmonary tumors of several types from exposure at very high doses (ca. 22,000 fibers/cc 86 mg/m^3) of chrysotile asbestos that had been hammermilled to an increase in cobalt of 145%; nickel, 82%; and chromium, 34%.

Differences in animal responses to "harsh" and "soft" chrysotile asbestos were seen by Smith et al.[39]: granulomatous and fibrous pleural adhesions were thicker, and pleural mesotheliomas appeared more rapidly in response to harsh chrysotile. (Harsh chrysotile was characterized as appearing in thicker bundles and was hydrophobic whereas the soft chrysotile was hydrophilic).

There are no experimental animal dose-response data that can be used in estimating a work place air standard for asbestos.

Contributions to Occupational Exposure Standards from Animal Studies. Of possible value in estimating occupational exposure limits are data regarding the relative disease-producing potency of the various forms and types of asbestos.

Wagner[40] found in the three species exposed (guinea pigs, rabbits, and monkeys) that amosite produced more marked interstitial fibrosis than chrysotile and the lesions occurred earlier. No statement on relative potency of crocidolite could be made because of the impure nature of the test specimen. On the other hand, amosite was found by the same investigator[36] to be about one-half as potent in the production of mesotheliomas in rats as chrysotile and crocidolite, if numbers and rate of production are used as indicators. An incidental finding was no evidence for difference in effect between natural and oil-extracted forms of crocidolite, a subject considered as a possible factor in the induction of asbestos cancers.[41]

Naturally Occurring Effects in Lower Animals. No evidence appears to exist that domestic or wild animals can provide criteria for standards,

or for controlling asbestos emissions, although a few confirmatory reports have been made that asbestosis can occur in such animals. Webster[42] has demonstrated fibrosis with associated asbestos bodies and fibers in wild rodents in South Africa, in one of a troop of baboons, and in two donkeys that had either worked in, or lived around, crocidolite mines or mills. And Schuster[43] reported pulmonary asbestosis, without asbestos bodies, in a dog that had lived for about 10 years in a London asbestos factory as a rat catcher. The magnitude or the type of exposure was not reported in any instance.

Factors Influencing Pathogenesis-- Experimental Animal. Experimental animal studies have been informative in elucidating the factors that modify or explain the biologic action of asbestos. At least six factors have been investigated: (1) fiber length and bundle size; (2) cytotoxicity; (3) red cell hemolytic activity; (4) asbestos hydrocarbons; (5) morphologic changes; and (6) trace metals in asbestos.

(1) Fiber length and bundle size. The relation between length of fibers and of fibers to motes (nonfibrous particles) and asbestos induced disease has been one of continuing experimental inquiry. Gardner and Cummings[34] and Gardner[44] found that longer fibers appeared to have a greater fibrogenic effect, although fibrosis developed in animals exposed to dusts which were composed of but one to 1.5 percent fibers. The high exposure concentration of 100 mppcf (ca. 3,600 fibers/cc) makes any decision on the relative potency of fibers vs. motes virtually impossible; however, when animals were exposed to short-fiber asbestos dust, although the type and rate of tissue reaction

were essentially the same, the extent of involvement was very much less than that of longer fibers. Inasmuch as exposure concentrations in these comparable studies were about the same, the conclusion can reasonably be made that longer fibers are more fibrogenic, but that the motes are not without fibrogenic potential.

In experiments with rabbits, King, Clegg, and Rae[45] using Rhodesian chrysotile fibers averaging 2.5 μm and 15 μm in length, concluded that the shorter fibers produced generalized interstitial fibrosis, whereas the longer fibers produced nodular lesions. This finding was not confirmed by one of the investigators (King) in another animal species.[46] Later repetition of the investigations, with "fine" chrysotile and amosite (85% and 82.6% respectively, less than 1 μm in length) by Wagner[40] yielded definite fibrosis with both dusts, thus confirming the original work of Gardner that short fibers or motes have fibrogenic potential.

This experimental work has significance for industrial air standards in indicating the need to support additional research on the "greater than 5 μm in length" specific requirement and the more general relation of fiber length to cancer induction, which has never been determined experimentally.

(2) Cytotoxicity. Both chrysotile and crocidolite were found to be markedly toxic to guinea pig macrophages *in vitro*.[47] The fibrous fraction showed a high, and the particulate, a moderate toxicity, thus providing evidence in conformity with the relative biologic potencies of fibrous and nonfibrous forms found in *in vivo* studies.

(3) Hemolytic Activity. In a similar effort to discover the initial stages of biologic activity of asbestos, and in particular to account for the iron-staining character of asbestos bodies, the hemolytic action of four asbestos types was determined. Whereas chrysotile proved to be potently hemolytic, crocidolite, amosite and anthophyllite were either completely inactive or only weakly.[48] No attempt was made, however, to correlate the greater hemolytic activity of chrysotile with the iron-staining intensity of its asbestos bodies relative to those from other asbestos forms.

(4) Asbestos Hydrocarbons. As chrysotile proved to be most adsorptive of iron, so was it most adsorptive of benzpyrene; compared with 100% adsorption for chrysotile, crocidolite and amosite absorbed from solution 40% and 10% respectively.[49] On this basis, chrysotile should prove the most potent cocarcinogen of the three forms if its action is mediated through exogenous benzpyrene. This has not been demonstrated as yet in humans. A 10% desorption from chrysotile by serum in three days was demonstrated,[49] a condition considered an essential first step in hydrocarbon carcinogenesis.

(5) Morphologic Changes. Electron microscopy of animal tissues has greatly enlarged understanding of the processes that occur following contact of pulmonary cells with asbestos. Examination by light, phase, and electron microscopy by Suzuki and Churg[49] of subcellular tissue of hamsters intratracheally exposed to chrysotile revealed the successive steps that occurred in the cytoplasm of certain pulmonary cells. Particularly informative for the mode of chrysotile action was the description of the formation and the ultrastructure of the asbestos

body, and the indication that instilled fibers tend to split longitudinally with time. The suggestion that chrysotile breaks up into short fragments on the evidence that the majority of the fibers found in the alveoli were less than one-sixth the injected length, one and two years later, is open to the alternative interpretation that, inasmuch as longer particles are more readily phagocytosed, what is actually observed is the residual, smaller, nonphagocytosed chrysotile.[50] Thus, despite the detailed, in-depth information furnished by electron microscopy, no body of knowledge yet exists that permits the assigning of relative risk factors to fibers of differing lengths.

In respect to asbestos bodies, it should be noted that "ferruginous bodies" produced in guinea pigs in response to other fibrous material, fine fibrous glass and ceramic aluminum silicate were identical in fine structure to that of asbestos bodies,[51] thus rendering firm diagnostic decisions difficult in cases of multiexposures to different fibrogenic fibers in the electron and light microscopic range.

(6) Trace Metals. Harington and Roe[41] and later Cralley et al.[52] reported large amounts of nickel, chromium, manganese, and iron are intimately associated with certain forms of chrysotile. On the possibility that trace metals may be associated with the induction of asbestos, cancer studies in animals were performed[53] which supported the hypothesis that, in the induction of asbestos cancers, trace metals play an active cocarcinogenic role along with the exogenously derived carcinogen benzpyrene, while asbestos plays a passive role as a metal carrier.

Correlation of Exposure and Effect

Available information on the relationship of asbestos exposure and the risk of asbestosis and/or bronchogenic carcinoma is somewhat

extensive, indicating a strong association between the diseases and such exposure under a variety of conditions[2,15,22,28] and evidence of dose-response relationship.

Enterline and associates[54] have recently demonstrated convincing evidence for an exposure-response relationship between asbestos as measured in terms of million parts per cubic foot years (mppcfyr), and the risk of malignant and non-malignant respiratory disease. Specifically, the risk of respiratory cancer increases from 166.7 (standardized mortality ratio) at minimal exposures to 555.6, at accumulative exposures in excess of 750 mppcfyr (Table XXX).

Knox et al.[27] suggested that in one asbestos plant where environmental levels varied between 1 and 8 particles/cc > 5 μm in length, the risk to bronchial carcinoma may have been largely eliminated, but that insufficient data were available to estimate the extent of the risk that may remain. The different textile operations were fiberizing, carding, spinning, weaving, and plastering. When environmental samples collected by operation in 1961 and 1966 were summed, the averages were between 4 to 6 fibers/cc. Operational averages were from a low of 2.5 fibers/cc in weaving to a high of 6.5 fibers/cc in carding.

In 1968, Balzer and Cooper[55] reported asbestosis among insulation workers exposed at levels not exceeding the time-weighted average of 5 mppcf.

McDonald et al.[56] reported in May 1971, on 129 primary thoracic neoplasms in the workers employed in Quebec chrysotile asbestos mines and mills out of a total of 9304 former employees; five of these cases were mesothelioma. The authors concluded that the additional data

supports evidence of other studies that even heavy exposure to asbestos in mining and milling carries only modest risk of contracting lung cancer and less still of contracting malignant mesothelioma. McDonald et al. suggest that any increased risk of respiratory cancer or pneumoconiosis at a dust-index below 200 would not be detectable and would still be in doubt below 400. At a dust index of 200 an employee could work for 40 years at a dust concentration of 5 mppcf. The author assumes that the fiber content of the dust is about 10% and he states that this is equivalent to about 12 fibers/cc.

Wright[57] pointed out that others have noted the striking differences in the health experiences of workers in mines and mills as compared to other workers, specifically in comparison to insulation operations, but that he felt the question was still unresolved. In contrast to populations exposed to mixed environments, those engaged in the mining and milling of asbestos fibers showed no augmented frequency of bronchogenic cancer.[2]

Selikoff,[15] however, indicated that McDonald's "heavily exposed" group had 5 times as much lung cancer as the "lightly exposed" workers. Furthermore, lung cancer among insulation workers was found to be about 7 times greater than expected compared to the general non-exposed population.[15] A non-exposed group was not reported by McDonald.[56]

Although it has been suggested that the risks associated with asbestos exposure may be less in mining than in industrial operations, additional study will be necessary to confirm if such is true, based upon the comparison made by Selikoff.[15]

Consideration must be given to McDonald's analysis of levels of exposure of 12 fibers/cc. At this level, he assumes that some degree of asbestosis may occur. The mathematical assumption made to arrive at this environmental level leaves a great deal to question, even without attempting to relate this information to the asbestos industry in general. Two primary considerations lack the evidence necessary to make general comparisons of these data with other reported work: the assumption as stated by McDonald[56] that the fiber content of the dust is 10%, and the method used to convert from mppcf to fibers/cc is not explained in the paper.

Murphy et al.[58] found that asbestosis was 11 times more common among pipe coverers in new ship construction than among a control group. The asbestosis was first found after 13 years of exposure or about 60 mppcf years. The prevalence was 38% after 20 years. The asbestosis was defined by the presence of at least three of the following signs: (1) basular rales in two or more sites, (2) clubbing of the fingers, (3) a vital capacity of less than 80% of the predicted, and (4) roentgenography consistent with moderately advanced, or advanced asbestosis, and (5) dyspnea on climbing one flight of stairs. The environmental level was based upon samples collected in an impinger and all the results were time-weighted average exposures and these were averaged over several different operations. The highest average concentration was with hand-saw cutting at 10.0 mppcf and the lowest average was 0.8 mppcf when mixing mud. The average of all operations was 5.2 mppcf. One-hundred and one workers were

in the exposed group with 94 used as controls matched for age, duration of employment and smoking habits. Both amosite and chrysotile were used in these operations while crocidolite was not. Murphy states that in his study no asbestosis was found for men exposed to 60 mppcf-years while 20% of those exposed for 75 to 100 mppcf-years were considered to have asbestosis. Consideration must be given to averaging the time-weighted average values of the environmental samples over what seem to be several different sampling locations or operations. Were workers who were classified as suffering from asbestosis exposed in the hand-saw cutting, or mixing mud, or both, and for what time interval? Answer to this question would have a major effect upon the relationship between the development of asbestosis and environmental levels, and the relation of these impinger counts to fibers/cc.

In a recent unpublished paper, Williams, Baier, and Thomas compiled data from the Pennsylvania Department of Health files on exposure levels at various textile processing operations in two plants. The data included dust concentrations from 1930 through 1967 in one plant and from 1948 through 1968 in the second plant. Even though controlled exposures were for the most part below 5 mppcf and in many cases below the 1968 ACGIH Notice of Intended Change to 2 mppcf, 64 cases of asbestosis were reported from these two asbestos textile plants. The authors conclude that: "If asbestosis is to be prevented, airborne asbestos dust must be stringently controlled in the working environment. From these data a TLV of 3 mppcf would provide inadequate protection and the proposed 2 mppcf may not be substantiated."

Thus, considerable evidence exists indicating that the prevention or reduction of the occurrence of asbestosis among workers requires that the concentration of asbestos fibers to which they are exposed be reduced.

There is at this time, however, only scant correlation of epidemiological data with environmental exposure data upon which a definitive standard can be established.

Champion[26] reported two cases of malignant mesothelioma in two men, 31 and 32 years old, following exposure to asbestos. In the first case, the only documented exposure of the patient was from his father, who at 68 years of age, had severe asbestosis following employment as a pipe lagger in Scotland. In this case, no special precautions were taken to protect the children from contact with the father's work clothing, which was washed at home. The man smoked about 20 cigarettes per day for sixteen years and had a brief history of breathlessness and other signs which could have been related to asbestos exposure. The second case involved a patient who had moved to Asbestos, Quebec, where he lived for the next 23 years. This patient had worked for 10 years as an asbestos prospector and had worked for a short period in open-pit mining. Seven years before his death in 1968, he moved away from the area and became a salesman in a department store. The patient smoked 20 to 30 cigarettes per day for 14 years. In this case, it was believed that he was exposed only to chrysotile and primarily in mining operations. Champion's two cases seem to support earlier data of family cases[15] with reasonably short and/or low levels of exposure.

Murphy et al.[59] presented data concerning two cases of workers exposed to asbestos. One case on biopsy confirmed mesothelioma and the other case had extensive pleural calcification. Both workers had frequently sanded asphalt and vinyl tile floors prior to installation of new floor covering. A technique to simulate normal work practice was developed and levels of 1.2 and 1.3 fibers/cc >5 μm in length resulted. The authors noted that under other work conditions these values may be higher. In the case involving mesothelioma, the worker was 44 years old and had no other history of occupational exposure to asbestos, although he had worked in a shipyard in a "non-dusty" gyroscope repair area from 1945-1947. The repair area would practically have to be considered a clean room operation in view of the precision involved in gyroscopic instrument repairs. He had smoked one package of cigarettes a day between the ages of 17 and 30 and had worked from 1948-1967 as a floor tile installer. The second case involved a 61-year-old worker who had been a floor tile installer for the last 30 years and had smoked one pack of cigarettes per day for the last 45 years. This second patient had no history of other asbestos exposure different from the first; however, some question may be raised of a possible neighborhood exposure even if it only concerned going to work. The possibility of such exposure must be considered in view of the neighborhood case noted by Selikoff,[15] Table XXIX.

The possibility of the development of asbestos-related diseases in floor tile installation must be considered, and special attention must be given to this operation when considering the low levels of

exposure that may be related to these two cases. If even in actual practice, levels were found to be 10 times those found by the investigators, it would substantiate the low levels of exposure recommended in this standard. The time interval for sanding as compared to tile installation must be small, and, if this is true, then, in fact, any level found would be very low if based on a time-weighted average exposure. This increases the weight of consideration that must be given to this possibly exposed occupational group and the relationship of these low exposures to asbestos to the development of disease.

Consideration must also be given related to the effect that may have resulted from exposure to other material in the floor tile. The level of, and effect of such material as asphalt and any decomposition products from sanding must be considered.

Isolated clinical case reports are difficult to interpret in terms of dose-time response relationship and can only be used to indicate other possible problem areas and to highlight what may prove to be practicable areas for further study.

IV. ENVIRONMENTAL DATA

The use of asbestos has changed with the addition of new products and with changes in the industrial processes. These changes and a growing awareness of the health effects from exposure of the worker to asbestos have resulted in a changing work environment within the asbestos industry. The lack of environmental data for previous years and the changes in technology used to collect samples, now and in the past, have resulted in the availability of comparable environmental data for only the last few years. Thus, the scant data and the long latent period for the development of bronchogenic cancer and mesothelioma do not permit the establishment of the dose-response relationship at this time. However, as has been indicated, the development of the diseases has been proven in workers exposed to asbestos and environmental data does exist for the last several years.

Table XIV shows the average concentration of asbestos fibers to which a number of insulation workers were exposed in 1969. The results shown are not time-weighted averages, but are averages of concentrations found for individual exposures during the time samples were collected (usually 15, 30, or 60 minutes). Although the average concentrations are reasonably low, with the exception of spraying, individual exposures varied from 0 to 100 fibers/cc. The latter occurred during a 60-minute period while a workman sprayed asbestos fiber on a turbine.

McClure[60] summarized results of a preliminary survey conducted by the U. S. Department of Labor during the period July, 1969, to January, 1970, at nine private shipyards as follows: 37 of 74 samples

collected during various operations of preparing and applying insulation were above 2 fibers/cc (50%) and 19 of 74 were about 12 fibers/cc (26%). These were not time-weighted average exposures, but represented average fiber concentrations during the sampling period. Furthermore, none of these samples represented workers' exposures while tearing out old insulation and lagging--an operation that has been previously found to produce more dust than the application of the insulation.

A summary of some of the environmental data collected by NIOSH is presented in Table I through XII. The environmental data presented in this document represent only that collected in the last few years and reported in fibers/cc>5 μm as counted by phase contrast light microscopy. As pointed out by Ayer et al.[61], "It is obviously impossible to give any single ratio that would accurately represent all processes at all times in each plant." As a result, little correlation, if any, can be made between early data (collected with an impinger where settled particles were counted) with current data (collected with a personal sampler and counted under a microscope equipped with a 16 mm 10X objective).

These data represent only the levels found during the time the samples were actually being taken. The sampling times were usually between 15 minutes to one hour, and should not be considered as time-weighted average exposures even though credence could be given to this approach due to the large number of samples collected.

Levels of exposure in the manufacture of asbestos are given in Table I through XII. In a total of 7 asbestos cement pipe plants, a range of individual samples was from 13.4 in coupling finishing, to levels too low to count in pipe forming, curing, pipe finishing,

coupling finishing, packing and miscellaneous operations (Table I).

It should also be noted in Table I that when consideration is given to feasibility of engineering control, in coupling finishing, the individual highest sample was 13.4 and the lowest and second lowest samples were zero. Warehousing and mixing (6.3 fibers/cc>5 μm) and packing (6.1 fibers/cc>5 μm) were the highest means by operation (Table II), and the lows were both 0.4 fibers/cc>5 μm. These data indicate the possibility of controlling these operations to below the proposed standards.

These wide ranges of individual samples and means by operations were also shown in asbestos friction plants (Tables III and IV), cement shingle, millboard, and gasket operations (Tables V and VI), insulation (Tables IX and X), and from asbestos paper, packing and asphalt products (Tables VII and VIII).

In textile operations, while the individual low and second lowest concentrations were, in all cases, below 1.0 fiber/cc (except fiber preparation, 1.4 fibers/cc), the means by operations exceeded 2.0 fibers/cc in fiber preparation (7.4 fibers/cc), carding (6.1 fibers/cc), spinning (3.7 fibers/cc), and twisting (3.2 fibers/cc). In the second lowest group, all operations except finishing exceeded 2.0 fibers/cc. These values, when considered with the highest means and highest individual samples (143.9 fibers/cc in carding and 123.2 in weaving), indicate that present methods of control practiced in the textile industry are not adequate for the standard proposed.

This is probably true in insulation operations as well. Even though levels were below the level of 2.0 fibers/cc>5 μm, the individual samples and operational means were high.

The individual sample high (Table IX) was 208.4 in finishing and 188.9 fibers/cc in mixing. Table XXV shows that in at least one insulation plant, 100 percent of all samples taken were less than or equal to 2 fibers/cc>5 μm, and in one other, all but the mixing operations met the 5 fibers/cc>5 μm value. In textiles, under present operating conditions, none of the plants met the 2 fibers/cc>5 μm criteria (Table XXV). This does not imply that industry could not meet the proposed standard of a time-weighted average exposure of 2.0 fibers/cc>5 μm, but only that it is not meeting it at the present in the insulation and textile plants, and it probably could meet the standard if given time to clean-up the plant operations.

Secular trends indicate that there is a wide variation between a few samples taken over large intervals of time. The evaluation of these trends, if indeed they are trends, would be open to question. however, it does point out that much can be done in the improvement of plant operations. It is not reasonable to associate these differences with changes in field sampling methods, counting techniques, or locations of sampling devices when similar trends are not apparent in cement pipe (Table XV), friction (Table XVI), or shingle, millboard and gasket operations (Table XVII). Variation in trends in insulation and textile plants (Tables XIX to XXI) indicate stable plants in some areas and not in others. The comparatively low values in textiles is somewhat surprising.

At most of the operations in the well-controlled plants, it is possible to meet the proposed standard with only small changes in engineering practices (Table XII). This is also true to a lesser degree

in friction operations (Table XXIII), and shingle, millboard, and gasket operations (Table XXIV), and true in only a few operations in textiles and insulation operations (Tables XXV-XXVI).

It must be noted that in asbestos plants having the same operations, some have been able to meet the proposed standard, while others have exhibited environmental values at higher levels, which suggests the need for engineering control - not the lack of engineering feasibility to meet the standard.

It will not be easy to control exposure in the insulation and textile industries, where higher levels of asbestosis, lung cancer, and mesothelioma are known to occur. There is a high priority requirement to protect the workers in these industries to assure that excessive asbestosis, lung cancer, and mesothelioma will not continue and, at the same time, give the worker the type of protection that is required at once. Table XIII gives an indication of the dramatic reduction in time-weighted average exposures that could be accomplished if peak or ceiling exposures were eliminated. In this case, reducing the peaks in insulation operations to the ceiling of 10 fibers/cc reduced the time-weighted average to near 2 fibers/cc.