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Measurement of Dust Exposures in the Asbestos Textile Industry

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Data obtained from environmental surveys of nine asbestos textile mills, which represent the baseline for the textile segment of the Public Health Service epidemiological study of asbestos processing industries, are presented. From these data concentration ranges are derived which yield significant differences between typical sample groups. Variance ratio tests of different methods of counting and analysis were made and count weight ratios based on magnesium analyses for asbestos were calculated.

Introduction

THE DIVISION of Occupational Health of the U.S. Public Health Service has been conducting an epidemiological study of the asbestos products industry since January of 1964. This study was prompted by the need to refine and update earlier work done in these industries in relation to asbestosis[1,2] and to appraise the association of asbestos with other health hazards suggested by a number of investigators.[3-6] The procedures and objectives of this study have been discussed in earlier papers[7,8] and the relationships between impinger counts and fiber concentrations on membrane filters have been presented.[9]

The environmental field study phase commenced with an asbestos textile plant in January, 1964, and the last of the textile plants to be included in the study was surveyed in June, 1965, thus completing the asbestos textile baseline. The nine plants surveyed account for over 80% of the workers in the industry and provided a cohort of over 2500 employees exposed to asbestos dust in varying degrees.

The conduct of this study was somewhat more complex than previous studies of dusty trades by the Public Health Service in that both the exposure itself and methods of characterizing the exposure had to be studied simultaneously. In order to accomplish this, a large number of samples were required (Table I).

The analysis of these data by manual methods would have involved an excessive burden and, consequently, the major portion of the data were transcribed onto punch cards for computer processing. In addition to facilitating routine calculations of dust concentrations, computer processing made possible detailed statistical analyses which would otherwise have been prohibitively time-consuming.

This paper summarizes the baseline asbestos textile dust count data and gives some observations on sampling methods and strategy and count-weight relationships. Other data, resulting from analyses for polynuclear aromatic hydrocarbons, trace metals, etc., will be included in later papers.

TABLE I

Numbers of Samples Collected in Asbestos Textile Plants

	Membrane Filter	Impinger
Breathing zone	608	605
Personal	810	2
General air	478	508
Total	1,896	1,115

TABLE II

Mean Dust Concentration by Plant and Operation
Impinger, mppcf

Operation	A	B	C	D	E	F	G	H	I	All*
Fiber prep.	5.0	1.5	2.6	2.5		0.5	1.7	2.5	0.6	2.3
Carding	2.2	1.2	2.7	1.8		0.6	0.7	3.2	0.3	1.2
Spinning	2.2	0.7	3.4	3.0		0.5	2.0	1.3	1.1	1.2
Twisting	1 3	2.3	2.5	5.4		0.4	3.9	1.5	0.4	1.9
Winding	1.2	0.9	2.0	1.7		0.4	3.0	0.4	0.4	1.0
Weaving	1.3	0.5	0.4	3.7	0.6	0.3	1.1	0.4	0.3	0.8
All*	2.7	1.3	2.2	2.8	0.6	0.5	1.7	1.1	0.5	1.3

* The "All" concentrations are the grand mean for all the samples in a plant or operation.

TABLE IV

Ratios of Fiber Counts by Method

	Impinger Total Fibers	Membrane Filter: Optical Total Fibers	Membrane Filter: Electron Microscope $> 3\,\mu$	Membrane Filter: Electron Microscope Total
Impinger	1	8	(32)	(100)
MF Total Fibers		1	4	13
Electron Microscope $> 3\,\mu$			1	3
Electron Microscope Total				1

Dust Concentrations

Tables II and III present the mean dust concentrations by plant and principal operation in all the plants surveyed. In all cases, the median was also calculated, and was usually in close agreement with the mean. The impinger concentrations include both grains and fibers, and the counts were made in accordance with the American Conference of Governmental Industrial Hygienists (ACGIH) procedure. Thus, these values may be compared to the existing Threshold Limit Value of 5 million particles per cubic foot (mppcf). The membrane filter (MF) samples were counted using a procedure described in detail by Edwards.[10]

Early workers in the study of asbestos exposure elected to count grains as well as fibers since too few fibers were seen in impinger samples. That fibers were not seen was not because they were absent, but because the 100X light field counting method used with the impinger did not reveal them. The ratios of fiber counts by different methods are shown in Table IV.

The ratios given in Table IV were obtained by dividing the concentration of fibers determined by the method given in the heading, by the fiber concentration as determined by the method listed at the side for a large number of the same or comparable samples. For example, the total fiber concentration as determined by optical membrane filter counts at 430X phase contrast was eight times that found on comparable impinger samples counted at 100X light field. These ratios are not necessarily meant to indicate any degree of equivalence, but only to show the relative magnitude of the numbers of

TABLE III

Mean Dust Concentration by Plant and Operation
Membrane Filter – fibers/cc

Operation		A	B	C	D	E	F	G	H	I	All
Fiber Prep.	(A)	38.1	12.3	23.3	34.0		8.1	7.6	35.5	11.8	21.2
	(B)	15.0	10.0	13.3	18.3		3.0	4.5	17.0	2.6	7.6
	(C)	7.1	3.4	5.8	8.2		1.1	2.0	9.3	1.2	4.2
Carding	(A)	18.1	13.6	20.6	32.9		6.0	17.2	28.2	8.3	14.9
	(B)	10.2	9.2	13.3	15.2		3.5	8.1	13.4	2.0	7.0
	(C)	4.3	4.1	5.9	8.4		1.6	3.2	7.1	0.9	3.7
Spinning	(A)	9.6	4.1	20.2	29.8		5.1	24.8	20.8	7.4	12.3
	(B)	6.6	3.2	18.9	15.7		3.5	10.8	10.5	1.8	6.2
	(C)	3.2	1.9	6.4	10.3		1.8	6.3	6.1	1.1	3.6
Twisting	(A)	9.3	6.9	15.8	51.4		4.8	25.9	16.7	3.1	14.0
	(B)	6.4	5.2	7.5	22.4		3.3	12.9	7.2	1.1	6.7
	(C)	3.7	3.3	4.7	18.8		1.9	7.8	4.1	0.7	4.7
Winding	(A)	11.7	4.4	9.6	28.6		4.5	25.7	7.9	3.6	9.9
	(B)	7.5	3.9	8.9	17.5		3.2	11.7	2.7	1.3	4.6
	(C)	4.7	1.7	3.4	11.9		2.0	7.3	1.6	0.9	3.4
Weaving	(A)	7.7	7.0	2.9	33.8	4.5	2.9	9.5	8.1	2.9	8.0
	(B)	4.8	3.1	2.3	17.8	3.9	2.2	5.7	3.0	1.5	3.6
	(C)	2.9	2.8	1.1	9.8	1.4	1.2	3.3	1.8	0.7	2.5
All	(A)	17.3	10.2	15.7	34.7	4.5	4.6	16.2	14.4	5.9	12.5
	(B)	8.5	7.5	9.4	12.1	3.9	3.0	8.1	6.3	1.7	5.6
	(C)	4.4	3.4	4.7	10.5	1.4	1.5	4.4	3.6	0.9	3.5

Note: A = total fibers; B = $> 5\,\mu$ fibers; C = $> 10\,\mu$ fibers

TABLE V

Significantly Different Dust Concentration Groups

Group	Impinger mppcf Grains & Fibers	Membrane Filter fibers/cc		
		Total Fibers	$> 5\ \mu$ Fibers	$> 10\ \mu$ Fibers
1	.1– .5	1– 5	.7– 3	.3– 1.5
2	.5–2.0	5–20	3.0–12	1.5– 6.0
3	2.0–8.0	20–80	12.0–48	6.0–24.0

fibers detected by the different methods. The ratios enclosed in parentheses were obtained by indirect comparisons since electron micrographs of impinger samples were not possible.

It is evident that most of the fibers, even those longer than 3 μ, are not counted by either the impinger or the optical membrane filter procedure, probably because they are too thin to be detected by light microscopy. However, enough fibers are found on membrane filters at 430X phase contrast to be a statistically useful index of the number of fibers present. Since it is probable that the significant biological property of asbestos is its morphology, only fiber counts on membrane filters are presented.

Regarding the interpretation of these data, some caution must be used to avoid assigning excessive significance to small differences. Some method of categorizing relative dustiness is needed for eventual correlation with health data to arrive at safe levels of exposure. Given the inherent variability of the environment and the variability in dust counting, broad ranges or classes of dust concentrations will be required. From the standard deviations calculated for each plant and operation group of samples, it was determined that a four fold difference in concentration was required to obtain a significance level of $p=0.05$ on typical sample sets. Based on this, the data fell rather conveniently into three arbitrary groups such that the probability of any value in a group not being significantly different from the middle value of an adjacent group does not exceed $p=0.05$ (see Table V). The ratios between corresponding groups by different count methods are based on the equivalence between impinger and filter count.

The groups are designated by number rather than low, medium and high, to avoid the implication that they can be compared with any existing standard. Using the concentration ranges given in Table V, a chart of the group numbers by plant and operation was prepared (Figure 1). The upper left triangle contains the group number as determined by impinger and the lower right by membrane filter total fiber counts. In 75% of the cases, the two methods lead to the same estimate of relative dustiness, and in cases where the groups are different, the differences never exceed one group and show no consistent trend.

Since our concern is with exposure, or body burden rather than with dust concentrations, a different grouping may be derived by the method of Roach.[11] It can be shown that:

$$\frac{\text{Coef. of Var. of Body Burden}}{\text{Coef. of Var. of Concentration}} \leq 0.59\left(\frac{t}{T}\right)^{1/2}$$

where t is the duration of the samples used in determining the concentration and T is the biological half-time of the contaminant. Since t never exceeded two hours and T is greater than six months, the ratio of coefficients of variation cannot be greater than 0.026. If the Coefficient of Variation of Body Burden obtained in this manner is used to estimate the standard error of the difference, ranges of concentration can be calculated such that the body burdens caused by sample means falling within one range are significantly different ($p<0.01$) from those caused by concentrations at the midpoint of an adjacent range (Table VI).

The same procedure illustrated by Figure 1 was applied using the body burden groups. As would be expected from the narrower limits of the classes, the agreement was not as good, with only 50% of the sets of samples yielding the same group by both methods. However, in less than 10% of the sets did the appraisal of dustiness differ by more than one group, in no case by more than two groups, and again these differences showed no consistent trend.

The general agreement between the groups gives one confidence that both methods are

IMPINGER / MEMBRANE FILTER TOTAL FIBERS	PLANT A	B	C	D	F	G	H	I
FIBER PREPARATION	3 / 3	2 / 2	3 / 3	3 / 3	2 / 2	2 / 2	3 / 3	2 / 2
CARDING	3 / 2	2 / 2	3 / 3	2 / 3	2 / 2	2 / 2	3 / 3	1 / 2
SPINNING	3 / 2	2 / 1	3 / 3	3 / 3	2 / 2	3 / 3	2 / 3	2 / 2
TWISTING	2 / 2	3 / 2	3 / 2	3 / 3	1 / 1	3 / 3	2 / 2	1 / 1
WINDING	2 / 2	2 / 1	2 / 2	2 / 3	1 / 1	3 / 3	1 / 2	1 / 1
WEAVING	2 / 2	2 / 2	1 / 1	3 / 3	1 / 1	2 / 2	1 / 2	1 / 1

FIGURE 1. Comparison of results by concentration groups.

measuring approximately the same thing in asbestos textile plants. However, if in the case of either the body burden or concentration method of grouping, the membrane filter total fiber count arrived at exactly the same decision as to relative dustiness as the impinger count, there would be no basis for distinguishing between these dust measurements by their relevance to disease parameters. Both would correlate, or not correlate, equally well with medical findings. Thus, the larger range of disagreement between methods in the body burden groups may be useful in establishing the relevance of the methods.

By either the concentration or body burden method, the results appear to be more uniform for different operations within a plant than for the same operation in different plants indicating that the engineering effort made toward good dust control within a plant is more of a determining factor than the difference between operations.

TABLE VI
Significantly Different Dust Concentration Groups Body Burden Method

Group	Impinger mppcf Grains & Fibers	Membrane Filter fibers/cc Total Fibers	$>5\ \mu$ Fibers	$>10\ \mu$ Fibers
1	0.1–0.2	1– 2	.6– 1.2	.3– .6
2	0.2–0.4	2– 4	1.2– 2.5	.6– 1.2
3	0.4–0.8	4– 8	2.5– 5.0	1.2– 2.5
4	0.8–1.6	8–16	5.0–10.0	2.5– 5.0
5	1.6–3.2	16–32	10.0–20.0	5.0–10.0
6	3.2–6.4	32–64	20.0–40.0	10.0–20.0

Sampling Methods and Strategy

All of the usual and some of the less frequently used methods of sampling for mineral dusts in industrial environments were used in this study, and the large numbers of samples of each kind permitted comparison of these methods.

One question which could be answered from these data is the relative variability of different count methods of analysis. To examine this factor, the variance ratio test[12] was applied to the sample groups by different count methods in each plant and operation. These methods included impinger grains and fibers versus membrane filter total fibers, total fibers versus $>5\ \mu$ fibers and total fibers versus $>10\ \mu$ fibers. In all cases, the variance ratio test indicated that the difference between the standard deviations by the different methods was not significant ($p>0.05$) and that none of the methods could be considered less variable than the others. This finding is interesting in that it had been assumed that membrane filter counts under phase contrast might be less variable than light field impinger counts, and that long (>10 μ) fiber counts might be less variable than total fiber counts since the long fibers should be more visible.

To investigate this matter further, groups of samples on which magnesium analysis for asbestos were performed (to be discussed later in this paper) were compared with total fiber counts made on the same samples. Since the precision of the magnesium analyses (<5% error) is very good, compared with dust counts, it was assumed that the variance ratio test would show less variability in the asbestos concentrations determined by magnesium analysis. However, this was not the case, and again the differences between standard deviations were not significant. From this outcome, it may be assumed that the sample variances are independent estimates of the same environmental variance. Thus, the variability observed is actually the variability of the environment; that is, the variability of the exposures of a group of workers doing nominally the same job at different times and places. The variability in dust counting, large as it is, may not be significant when compared to the actual variability of the workers' exposure.

Count-Weight Relationships

Chrysotile asbestos, which accounts for over 90% of the asbestos used in this country, is a hydrated magnesium silicate and has a relatively constant magnesium content of about 25%. With the aid of recently developed atomic absorption techniques, it is possible to analyze for magnesium with a sensitivity in the order of 0.1 micrograms (μgm). Consequently, magnesium analyses may be performed on membrane filter samples which are light enough to count, and this magnesium may be related to the weight of asbestos present on the filter. From the count and weight on the same sample, a direct count-weight ratio may be made.

Several potential sources of error are immediately apparent. Serpentine, the nonfibrous parent mineral from which chrysotile asbestos developed, is usually present in varying amounts with the fibrous asbestos and will contribute some magnesium but will not contribute to the fiber count. A second source of error is the ubiquitousness of magnesium and magnesium-bearing minerals. Magnesium is found in general air pollution, and significant amounts could be present in industrial dust from other magnesium-rich process materials.

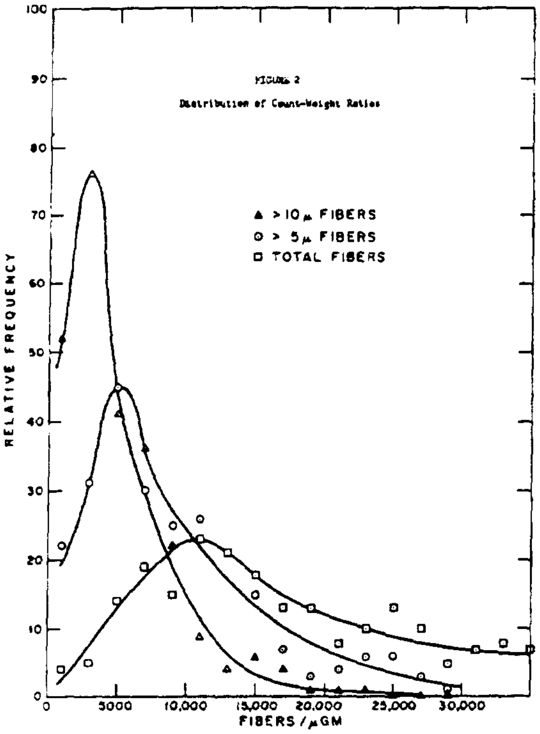

FIGURE 2. Distribution of count-weight ratios.

Little can be done to eliminate the first source of error, and a tendency to overestimate the mass of fibrous asbestos is unavoidable. Regarding the second source of error, air pollution survey data[13] revealed that the usual atmospheric concentrations of magnesium are several orders of magnitude lower than in-plant concentrations. Other magnesium-bearing process materials can be eliminated as a source in textile plants since the other materials do not contain significant amounts of magnesium.

Membrane filters from which a small wedge had been removed for counting were sliced in half with a sharp blade against a

TABLE VII
Count-Weight Ratios

Type Count	Fibers per μgm
Total fibers	11,000
> 5 μ fibers	5,000
> 10 μ fibers	3,000

brass die. From analyses of magnesium on these filter halves, the count-weight ratios in terms of weight of asbestos, for each type count, were calculated for each of the 250 samples analyzed. The frequency distributions of these sets of ratios are given in Figure 2.

Given the sources of error discussed above, and the natural variability of dust counts, a considerable spread in the count-weight ratios would be expected. This spread did occur, in fact, but a central tendency in each of the groups of data is apparent, and yield the approximate values shown in Table VII.

It would appear from Figure 2 that the count-weight ratios of the longer fibers exhibited less spread. However, the ratios were found to follow a log normal distribution with the same standard geometric deviation of 2.3 for all three type counts. Thus, each of the groups of ratios is equally disperse, and no one type of count is to be preferred as an estimate of mass.

An independent estimate of the count-weight ratio was obtained from size distributions on electron micrographs. Since the number of large fibers visible on these slides is small, though their contribution to the weight is very large, it was necessary to pool a number of electron micrographs of different samples, to obtain a statistically useful size distribution. From these data a typical mass median fiber volume of 50 cubic microns (μ^3) was obtained, which yields a count-weight ratio of 8000 fibers/μgm based on a density of 2.5 for chrysotile asbestos. This result is of the same order of magnitude as fiber ratios obtained from the magnesium analyses.

By applying the impinger-membrane filter equivalents obtained earlier to the weight count ratios given in Table VII, it was found that 1 mg/m^3 of asbestos by magnesium analysis as approximately equivalent to 1 mppcf by impinger. It should be emphasized that this relationship was developed by a very indirect method. However, it does indicate that asbestos mass concentrations may be higher than previously assumed.

A number of sets of simultaneous samples were taken with and without size selective presamplers. Thirty-minute samples on a pair of membrane filters, one of which was preceded by a horizontal elutriator with a 7.1 μ unit density sphere cut-off, were taken in each operation in each plant. While not all of the magnesium analyses are completed, preliminary results indicate that the respirable fraction of asbestos as determined by this elutriation is approximately 50 to 60%. Additional samples were taken in each plant using two pairs of membrane filters run for five to eight hours, with cyclones conforming to the Atomic Energy Commission criteria attached to one pair of filters. From these samples an estimate of respirable fraction of from 30 to 40% was obtained. In both cases the figures given are approximate; however, they do follow the usual performance of these presamplers, in that the cyclone passed a smaller fraction. If these respirable percentages are applied to the gross airborne asbestos by magnesium results, 1 mg/m^3 of the total dust would probably contain 0.5-0.6 mg/m^3 of dust passing an elutriator and 0.3-0.4 mg/m^3 passing a cyclone. Additional magnesium analyses are being performed so that mean mass concentrations by plant and operation can be compared with the groups established for impinger and membrane filter counts, to determine if mass concentrations yield the same relative hazard estimates.

Conclusions

The results of environmental surveys of nine asbestos textile plants reveal that dust concentrations as measured by impinger are generally below the Threshold Limit Value. Due to the natural variability of the environment, categories of significantly different dust measurements must be broad. Three significant groups were obtained from concentration data and six significant groups were derived from body burden considerations. Estimates of relative dustiness from membrane filter samples were in good agreement with those made from impinger samples by either concentration or body burden methods of grouping.

Variance ratio tests of different systems of measurement indicate that most of the variance seen is due to the variance of the population and that none of the methods of counting exhibit any significant superiority in terms of a lessened variance.

Count-weight ratios obtained by magnesium analyses of membrane filters were 3000 fibers $> 10\ \mu/\mu$gm or 5000 fibers $> \mu/\mu$gm or 11,000 total fibers/μgm. None of the sets of ratios exhibited any less dispersion than the others. A mass median fiber volume of 50 μ^3, obtained from electron micrographs, yielded a count-weight ratio of 8000 fibers/μgm which was of the same order of magnitude as the ratio obtained by magnesium analysis. Based on these ratios, a gross airborne mass concentration of asbestos equivalent to one mppcf would be on the order of 1 mg/m^3, and respirable mass concentrations, as determined by elutriator and cyclone, would be in the order of 0.5–0.6 mg/m^3 and 0.3–0.4 mg/m^3, respectively.

Hygienic criteria should be relevant to the disease-producing mechanisms, capable of accurate assessment of the environment, and convenient to use. The impinger is as convenient as any other method and in view of the large variance found in the environment, no less accurate than other measurements. However, it is difficult to reconcile the basing of the hygienic criteria on counts dominated by grains while the fibers are thought to be the causes of disease. In this respect the counting of fibers on membrane filters appears to have an advantage, especially in industries where asbestos is only a small fraction of the airborne dust. The relevance of magnesium analysis for asbestos is unknown and the method involves the use of sophisticated and expensive laboratory equipment not generally available in state, local and plant hygiene laboratories. However, it is hoped that the intensive study of total and respirable mass concentrations, made possible by this method, will lead to the development of a relevant and convenient mass sampling method.

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