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AIRBORNE ASBESTOS FIBER CONCENTRATIONS IN ASBESTOS MINES AND MILLS IN THE UNITED STATES

by

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L. A. Schutz,[1] Walter Bank,[1] and George Weems[2]

ABSTRACT

Personnel of the Bureau of Mines have conducted investigations in the principal asbestos mines and mills in the United States, to determine the concentration of airborne asbestos fibers in the workplace, and to establish the exposure of workers to such fibers. The surveys were conducted using the sampling and evaluation method recommended by the National Institute for Occupational Safety and Health. The method consists of collecting the airborne sample on filters and, after appropriate sample preparation, counting the fibers utilizing phase contrast microscopy. The results of the investigation show that fiber concentrations are low in the asbestos mines but high in the asbestos mills, ranging well above 5 fibers/ml of air based on a count of fibers greater than 5 μm in length.

INTRODUCTION

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 ($3MgO \cdot 2SiO_2 \cdot 2H_2O$), a fibrous form of serpentine. The other principal mineralogic type, amphibole, includes amosite [$(FeMg)SiO_3$]; crocidolite [$NaFe(SiO_3)_2 \cdot FeSiO_3 \cdot H_2O$]; tremolite [$Ca_2Mg_5Si_8O_{22}(OH)_2$]; anthophyllite [$(MgFe)_7Si_8O_{22}(OH)_2$]; and actinolite [$CaO \cdot 3(MgFe)O \cdot 4SiO_2$].

Chrysotile asbestos occurs chiefly in serpentinized peridotite and is distributed in the United States in two principal belts; the eastern belt extends from Maine to Alabama, and the western belt extends from Washington to California, where numerous masses of ultramafic rocks were intruded in Paleozoic and Mesozoic time, respectively. The principal mine in the United States is located at Belvidere Mountain in Vermont. Minor amounts of asbestos have been produced from other deposits in these belts and from scattered occurrences of chrysotile elsewhere. Recently, increased activity toward development for short-fiber chrysotile has occurred in California.

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[1] Mining engineer.
[2] Supervisory chemist.

Chrysotile also occurs in bedded limestone, metamorphosed close to intrusions of diabase. The principal occurrences of this type are in Arizona, where small quantities of long-fiber, low-iron chrysotile have been mined from numerous small deposits.

Several species of amphibole occur in fibrous forms; in the United States only anthophyllite and tremolite are known to have commercial importance. As both the anthophyllite and tremolite occur in ultramafic rocks, associated greenstone, and amphibolite, the overall distribution of amphibole asbestos in the United States is like that of chrysotile. The deposits are generally small and erratic in distribution; a list of States identifying known asbestos deposits with associated basic rock formations is presented in appendix A. The occurrence of asbestos and/or asbestiform fibers is relatively widespread throughout the United States and, while the asbestos is not recovered for commercial purposes, the fibers can be present in the mine or mill atmosphere and may constitute a potential health hazard to miners and mill workmen.

The fact that asbestos or asbestiform fibers may be associated with the mining of other minerals complicates the problem of evaluating the health hazard of dusts.

Almost 1 million tons of asbestos is used in the United States each year. Analysis of production data indicates that approximately 74 percent of the asbestos produced (532,300 tons) was used in the construction industry, while 26 percent (187,400 tons) was used in the nonconstruction industries. Approximately 92 percent of the 532,300 tons used in the construction industry is firmly bonded, in such products as floor tiles, asbestos cements, roofing felts, and shingles; the remaining 8 percent is friable or in powder form present in insulation materials, asbestos cement powders, and acoustical products.[3] The 187,400 tons of asbestos used in nonconstruction industries in 1965 was utilized in such products as textiles, friction material including brake linings and clutch facings, paper, paints, plastics, roof coatings, floor tiles, and other miscellaneous products. Mining and milling of asbestos in the United States is a small industry, employing fewer than 1,000 workers, and produces 125,300 short tons of asbestos, or approximately 17 percent of the total asbestos used in the United States.

Based on the results of asbestos surveys completed, the principal health hazards occur in the milling process with only minor problems existing in the mines.

The National Institute for Occupational Safety and Health (NIOSH) has developed criteria for a recommended standard for occupational exposure to asbestos. The criteria include consideration of the following factors: environmental, medical, labeling, personal protective equipment and clothing, apprisal of employees of hazards from asbestos work practices, and monitoring and recordkeeping requirements.

[3] Hendry, N. W. The Geology, Occurrences, and Major Uses of Asbestos. Ann. N.Y. Acad. Sci., v. 132, Art. 1, 1965, pp. 1-766.

The occupational safety and health aspects of the mining and milling of asbestos ores are covered by provisions of the Federal Metal and Nonmetallic Mine Safety Act (30 U.S.C. 725 et seq.), under which provisions the Bureau of Mines has promulgated applicable regulations.

In 1967, the published Threshold Limit Value[4] was 5 million particles per cubic foot (mppcf) for dusts containing asbestos when collected conventionally with the impinger or midget impinger and counted with the standard light-field counting method. The number concentration represented the visible fragments (small) of asbestos fibers, plus the many associated mineral dust particles.

In 1968, the published "Notice of Intended Changes" proposed that (1) the mppcf be reduced to 2 mppcf and (2) an alternative figure of 12 fibers per milliliter of air (fibers/ml) based on a count of fibers greater than 5 (micrometers) in length be adopted. This figure was based on the membrane filter method at 430X magnification phase contrast illumination.

The aforementioned intended changes were retained in 1969; in 1970, the published proposed changes (1) eliminated entirely the midget impinger sampling method and its number concentration figure and (2) recommended that the alternative value be changed from 12 fibers/ml greater than 5 microns in length to 5 fibers/ml greater than 5 microns in length.

In 1971 and 1972, the "Notice of Intended Changes" retained the 1970 proposal and specified the membrane filter method with 400-450X magnification phase contrast illumination.

To evaluate the degree of the health hazard, the sample results included in this report were compared with the value of 5 fibers per milliliter (fibers/ml) as defined by NIOSH in the document "Criteria for a Recommended Standard . . . Occupational Exposure to Asbestos."

It appears that control practices in current mining and milling operations can be modified to meet the "5 fibers/ml greater than 5 μm in length" standard. However, in order to meet a standard of "2 fibers/ml greater than 5 μm in length," the asbestos industry will probably have to develop new processes, or drastically modify present dust control measures. Meeting the latter standard will be more difficult for mills and processing plants than for mines.

DESCRIPTION OF SURVEY

During the latter part of 1971, a program was instituted to conduct investigations in all the active asbestos mines and mills in the United States. Three of the four known active mills and two of the six open-pit mines in California were surveyed. Total employment at the four active mills and the six open-pit mines was reported to be 294.

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[4]American Conference of Governmental Industrial Hygienists. Threshold Limit Values for 1967, Recommended and Intended Changes. 1967.

In Arizona, two of the three known active underground mines and one of the three active mills were surveyed. Total employment at the three mines and three mills was reported to be 25.

The single active open-pit mine and mill in Vermont was surveyed. Total employment in the asbestos mine and mill was 201.

The only known active asbestos open pit in North Carolina was surveyed. Total employment was four.

In Maryland, the one known asbestos mill was surveyed. Total employment was eight.

Total employment for all known active asbestos mines and mills was 541. Of this total, 488 were employed at the mines and mills surveyed. A total of 656 samples was collected and evaluated in these surveys. Table 1 lists asbestos mines and mills surveyed in the United States, their location by city and State, employees at each, and samples collected during the survey at each location. Table 2 lists the average asbestos fiber exposures for the job classifications that were found at the mines and mills.

TABLE 1. - Asbestos mines and mills surveyed, with listing of employment and sampling data

Location	Number of mines		Number of mills	Employees	Number of samples collected		
	Open pit	Underground			Breathing zone	General atmosphere	Total
Mines:							
Burnsville, N.C.	1	-	-	4	17	0	17
Hyde Park, Vt.	1	-	-	58	10	-	10
Coalinga, Calif.	1	-	-	7	41	0	41
Copperopolis, Calif.	1	-	-	36	55	0	55
Total, open pits	4	-	-	105	123	0	123
Globe, Ariz.	-	1	-	11	15	0	15
Do.	-	1	-	2	2	0	2
Total, underground	-	2	-	13	17	0	17
Total, mines	4	2	-	118	140	0	140
Mills:							
Baltimore, Md.	-	-	1	8	59	1	60
Hyde Park, Vt.	-	-	1	143	55	2	57
King City, Calif.	-	-	1	50	50	9	59
Coalinga, Calif.	-	-	1	31	47	10	57
Copperopolis, Calif.	-	-	1	135	205	57	262
Globe, Ariz.	-	-	1	3	20	1	21
Total, mills	-	-	6	370	436	80	516
Grand total, mines and mills.	4	2	6	488	576	80	656

TABLE 2. - Average of asbestos fiber exposures (daily weighted averages) in mills and mines

Occupation	Total samples	Asbestos fibers/ml (>5 μm in length)		
		Highest exposure	Lowest exposure	Average exposure
Mill:				
Blender, bagger, and packer...	132	24.8	2.7	11.3
Palletizer and car loader.....	31	18.1	1.2	10.0
Crusher and dryer operator....	32	20.3	7.1	11.0
Foreman......................	32	15.8	4.3	8.3
Laboratory technician.........	33	17.4	4.5	8.8
Laborer......................	37	17.3	8.2	12.1
Maintenance man...............	50	16.9	3.8	8.4
Mill operator................	50	17.9	4.7	11.5
Other........................	39	10.5	2.3	6.0
Mine:				
Driller......................	31	7.8	1.0	2.8
Explosives man...............	6	.6	.1	.3
Heavy equipment operator......	55	1.7	.5	1.1
Maintenance man..............	7	.5	.1	.3
Truck driver.................	20	.8	.2	.5
Other........................	21	.8	.04	.5

Sampling methods and evaluation procedures employed in the surveys of asbestos mines and mills are described in appendix B.

DISCUSSION OF SURVEY RESULTS

A summary of the surveys of asbestos mines and mills is presented in figures 1 and 2. Only daily weighted average exposures are listed in these tables. An analysis of figure 1 indicates the "Laborer" occupation has the highest average exposure with 12.1 fibers/ml. (This is due in part to the cleanup work being done by sweeping.)

Following closely in order are mill operators at 11.5 fibers/ml, blenders, baggers, and packers at 11.3 fibers/ml, crusher and dryer operators with 11.0 fibers/ml, palletizers and car loaders with 10.0 fibers/ml, laboratory technicians with 8.8 fibers/ml, maintenance men with 8.4 fibers/ml, foremen with 8.3 fibers/ml, and the lowest average exposure of 6.0 fibers/ml, including the miscellaneous category. Averages for <u>all</u> the occupational classifications were above 5 fibers/ml.

Figure 2 lists exposures of the various occupations in open-pit and underground mines. None of the averages were above 5 fibers/ml.

While a few of the individual samples in some mills were extremely high (to more than 550 fibers/ml), the average of the highest were recorded at the blending, bagging, and packing operations where controls were not well

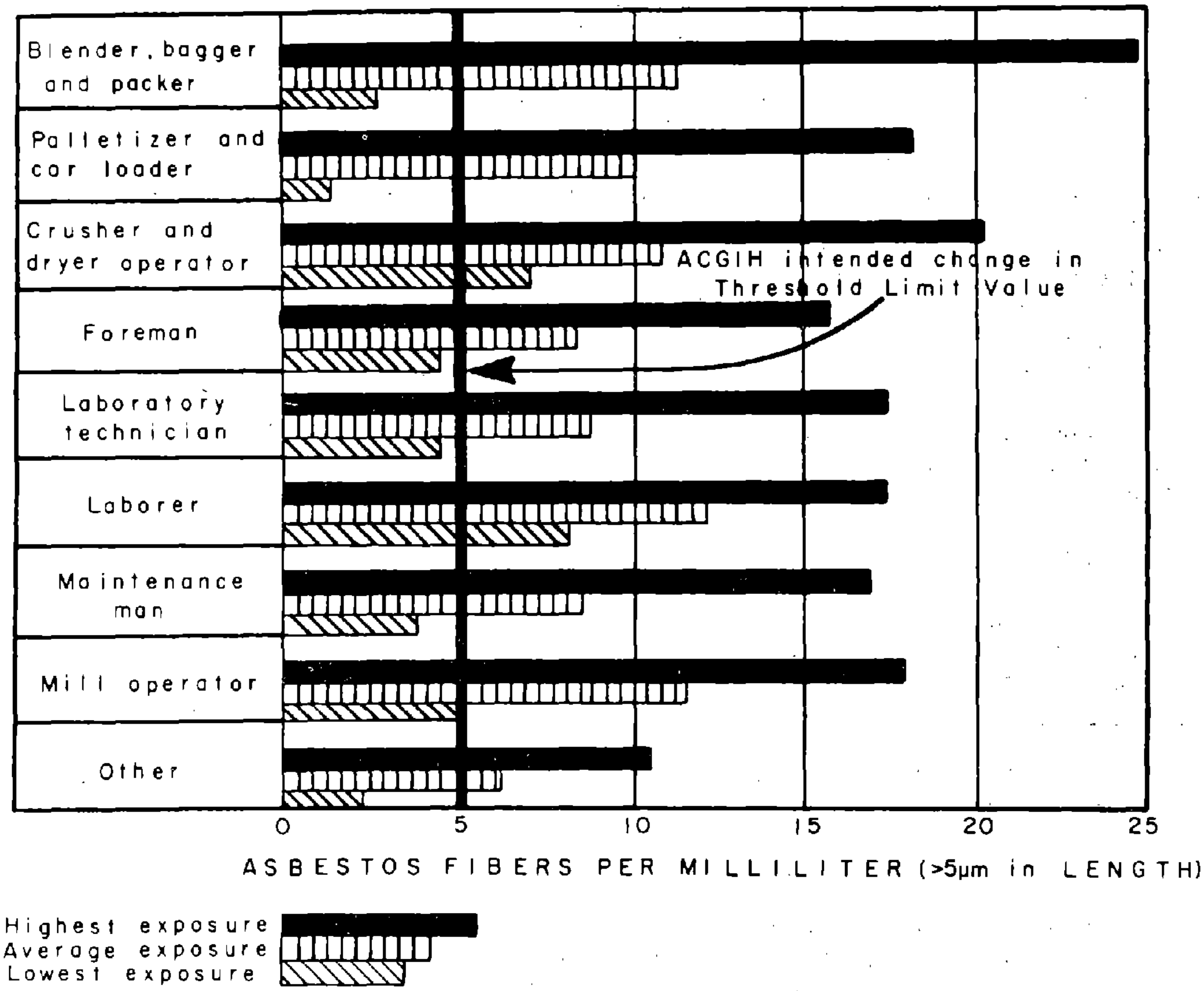

FIGURE 1. - Asbestos fiber exposures (daily weighted averages) in mills.

designed and maintained. Crushing and drying operations were second, with palletizer and car loader operations running third; mill operators, fourth; laboratory technicians, fifth; laborers, sixth; maintenance workers, seventh; foremen, eighth; and miscellaneous operations, ninth. All were well above the value of 5 fibers/ml. In the mines, dry-drilling, without dust collection, resulted in one high average exposure of 7.8 fibers/ml.

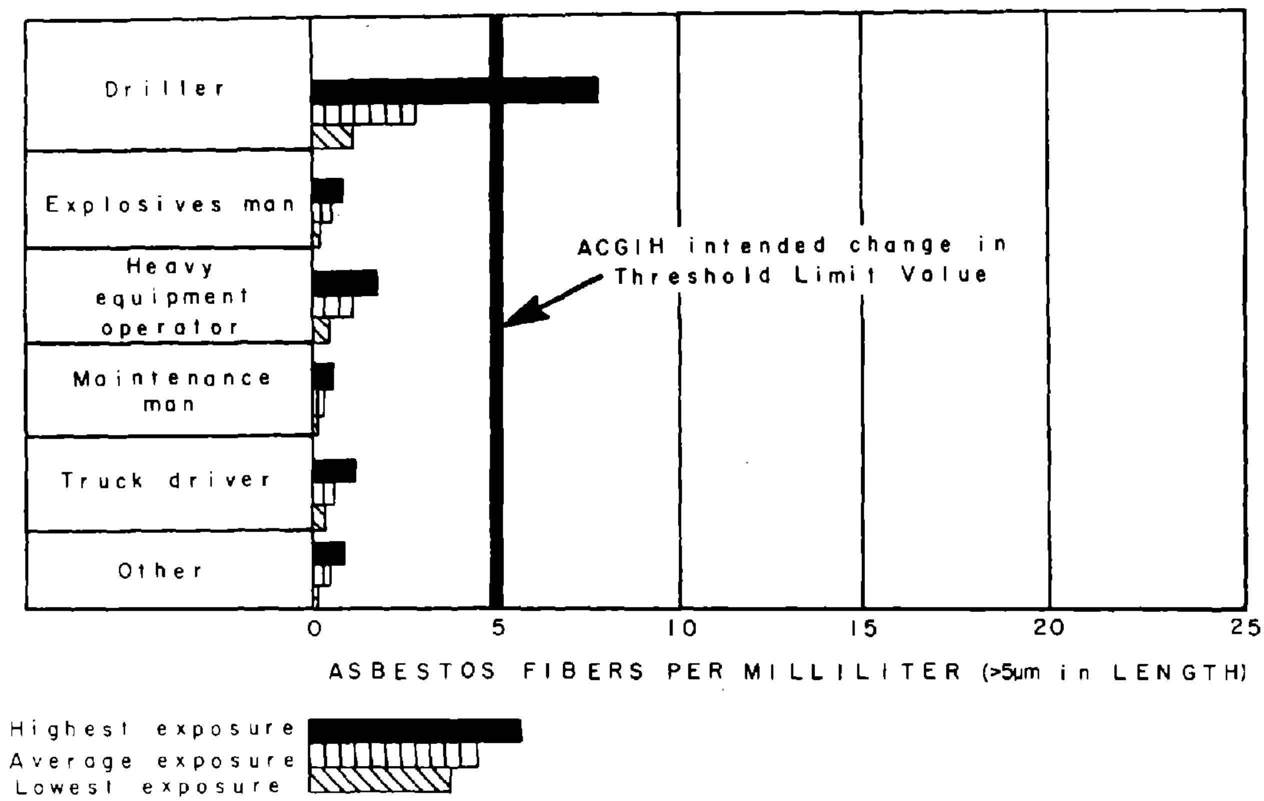

FIGURE 2. - Asbestos fiber exposures (daily weighted averages) in mines.

CONCLUSIONS

1. Some operators are adequately controlling the amount of asbestos fibers in the breathing zone of workmen; however, many are using inadequate control measures and practices which result in workmen being exposed to asbestos fiber concentrations above 5 fibers/ml.

2. The fact that asbestos or asbestiform fibers may be associated with the mining of other minerals complicates the problem of evaluating the health hazards of dusts in mines and mills throughout the United States. (Dust surveys are now routinely including sampling procedures to determine whether this hazard exists.)

3. It is believed that operators of most mills and mines should be able to meet a "5 fibers/ml of fibers greater than 5 μm in length" standard by following practices such as, but not limited to, those listed below:

a. Installing and using effective and efficient control systems and collectors to prevent dust from becoming airborne.

b. Establishing a rigid maintenance program for process and dust control equipment.

c. Packaging the finished product in airtight containers.

d. Modifying processing machinery or replacing it with equipment designed to achieve adequate dust control.

e. Enclosing all conveyor belts, screens, crushers, and other operations, and using exhaust ventilation and collectors to minimize airborne dust.

f. Using vacuum cleaning systems for cleanup work to eliminate airborne dust from sweeping.

g. Following established recommended practices for the use of respiratory protective equipment.

h. Using accepted permissible methods for controlling dust when drilling in pits and mines.

i. Implementing methods for keeping dust at stockpiles, roads, millyards, and plant areas from becoming airborne.

j. Providing enclosed cabs with filtered air systems for operators of mobile equipment used in mill and mine surface areas.

4. New techniques such as the wet-milling process presently being investigated by some operators should be evaluated as a possible aid in complying with lower standards being considered.

APPENDIX A.--OCCURRENCE OF ASBESTOS WITH ASSOCIATED BASIC ROCK FORMATIONS IN THE UNITED STATES

The following listing of States indicates known asbestos deposits, with associated basic rock formations:[1]

Alabama.--Short-fiber amphibole asbestos; associated basic intrusive rocks.

Arizona.--Chrysotile in serpentine.

California.--Chrysotile in serpentine and in peridotite; tremolite and amphibole and anthophyllite asbestos in serpentine, greenstone, and schist. Some short-fiber and unknown varieties of asbestos in serpentine. Cross-fiber chrysotile in ultrabasic intrusion, in serpentinized saxonite, serpentinized limestone, and chloritized shale. Slip-fiber tremolite and amphibole and actinolite in quartz schists, in serpentine, and in limestone and dolomite.

Connecticut.--Slip- and cross-fiber chrysotile and some pyrophyllite asbestos associated with serpentine.

Georgia.--Long-fiber anthophyllite asbestos associated with peridotite, with talcose and chloritic schist, with pyroxenite, and with biotite-granite gneiss. Cross-, slip-, and mass-fiber amphibole asbestos with biotite granite and hornblende gneiss, and talcose rock associated with granite. Anthophyllite asbestos associated with harzburgite.

Idaho.--Slip-fiber and brittle mass-fiber anthophyllite asbestos in altered harzburgite and in altered dunite.

Maine.--Slip- and cross-fiber chrysotile in serpentine.

Maryland.--Slip-fiber tremolite associated with basic igneous rocks; also anthophyllite and low-quality amphibole asbestos.

Massachusetts.--Chrysotile asbestos in ultramafic rock; amphibole asbestos; fibrous anthophyllite in blocks of saxonite, enclosed in granite; also amphibole asbestos.

Montana.--Brittle tremolite asbestos associated with vermiculite in dike-like masses of pyroxenite; woodlike-fiber anthophyllite in altered peridotite dikes in Precambrian schist and gneiss; chrysotile asbestos in limestone similar to Arizona deposits.

New York.--Chrysotile asbestos veins in serpentinized zones in dolomite; slip- and cross-fiber chrysotile in serpentine.

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[1] Chidester, A. H., and A. F. Shride. Asbestos in the United States (Exclusive of Alaska and Hawaii). U.S. Geol. Survey, 1962, 11 pp., with accompanying map MR-17.

North Carolina.--Chrysotile asbestos associated with ultramafic igneous rocks and with dunite and with a large mass of enstatite and in peridotite; anthophyllite asbestos and mass-fiber anthophyllite asbestos associated with altered dunite, with serpentinized dunite, and with chlorite in an amphibolite.

Oregon.--Chrysotile asbestos veins in serpentine; short cross-fiber chrysotile asbestos in serpentine; anthophyllite and weak slip- and cross-fiber anthophyllite asbestos along shear zones in schists and greenstones; slip-fiber and iron-free tremolite asbestos in dunite.

Pennsylvania.--Unknown variety of asbestos associated with ultramafic igneous rocks.

Rhode Island.--Crocidolite asbestos.

South Carolina.--Asbestos of unknown variety associated with dikes of pyroxenite altered to amphibolite, in magnesian rocks, in basic igneous rocks, in partly metamorphosed amphibolite, in aphanitic hornblende slates.

Texas.--Tremolite and long brittle tremolite asbestos fibers in the shear zone between hornblendite and mica-quartz schist, in serpentine; small veinlets of chrysotile and small deposits of amphibole asbestos.

Vermont.--Cross- and slip-fiber chrysotile asbestos in serpentine and in unserpentinized dunite and peridotite.

Virginia.--Asbestos of unknown variety associated with ultramafic rocks; asbestiform anthophyllite occurring with tremolite; amphibole asbestos and slip-fiber amphibole asbestos; slip-fiber anthophyllite asbestos associated with hornblende and olivine.

Washington.--Cross-fiber chrysotile asbestos in serpentine and in diopside and serpentine; cross-fiber and slip-fiber asbestos of unknown variety in serpentine and in peridotite; silky fibers of amphibole asbestos, fibrous soapstone with amphibole asbestos in shear zones cutting greenstone, short fibers of amphibole asbestos; talcose asbestos in serpentine dike; anthophyllite asbestos in biotite gneiss; tremolite asbestos in dolomite.

Wisconsin.--Cross-fiber chrysotile asbestos veins in peridotite.

Wyoming.--Slip-fiber chrysotile and amphibole asbestos in veins associated with serpentine cut by metadiabase dikes and surrounded by granite gneiss; brittle-fiber amphibole asbestos and talc in a sequence of metamorphic rocks and amphibole asbestos in serpentine.

APPENDIX B.--SAMPLING METHODS AND EVALUATION PROCEDURES[1]

Air Sampling Methods

In the study of asbestosis conducted by Dreessen, midget impinger count data were used as an estimate of dust exposure. All of the dust particles seen, both grains and fibers, were counted since too few fibers were seen to give an accurate measurement. The resulting count concentration was a measure of overall dust levels rather than a specific measurement of the asbestos concentration. This method was satisfactory at that time since exposures were massive and the control measures installed to reduce overall dust levels also reduced the asbestos dust levels.

As dust levels were reduced, it became necessary to measure the biologically appropriate attribute of the dust cloud. At equal levels of overall dustiness, the concentration of asbestos could vary considerably from textile manufacture (75-85 percent) to insulation (5-15 percent). Furthermore, if the limit were lowered below the 5 mppcf used previously and dust counts were taken by the impinger technique, it would be necessary to consider the effect of background dust, which could be as high as 1 mppcf.

A number of methods for measurement of asbestos dust concentrations have been used in the NIOSH epidemiological study of the asbestos product industry. Based on these data, the preferred index of asbestos exposure is the concentration of fibers longer than 5 μm counted on membrane filters at 430X magnification with phase contrast illumination. This index is utilized in the method adopted as the standard field sampling method by the Public Health Service. Fibers longer than 5 μm are counted in preference to counting all fibers seen in order to minimize observer and/or microscope resolving power variability. Furthermore, the British define a "fibre" as a particle, "of length between 5 μm and 100 μm and having a length-to-breadth ratio of at least 3:1, observed by transmitted light by means of a microscope at a magnification of approximately 500X."

Although the British have refrained from standardizing on a single method of measurement, recent measurements have been performed by a method essentially identical to the fiber-count method described in detail below, and the British hygiene standards for use with their asbestos regulations are stated in these terms.

Principles of Sampling

A dust sampling procedure must be designed so that samples of actual dust concentrations are collected accurately and consistently. The results of the analysis of these samples will reflect, realistically, the concentrations of dust at the place and time of sampling.

[1] U.S. Department of Health, Education, and Welfare. Criteria for Recommended Standard, Occupational Exposure to Asbestos. Publication HSM 72-10267, sec. VIII, appendix I, 1972, pp. VIII-1 through VIII-8.

To collect a sample representative of airborne dust that is likely to enter the subject's respiratory system, it is necessary to position a collection apparatus near the nose and mouth of the subject or in his "breathing zone."

The concentration of dust in the air to which a worker is exposed will vary, depending upon the nature of the operation and upon the type of work performed by the operator and the position of the operator relative to the source of the dust. The amount of dust inhaled by a worker can vary daily, seasonally, and with the weather. To obtain representative samples of workers' exposures, it is necessary to collect samples under varying conditions of weather, on different days, and at different times during a shift.

The percentage of working time spent on different tasks will affect the concentration of dust the worker inhales since the different tasks usually result in exposure to different concentrations. The percentage can be determined from work schedules and by observation of work routines.

The daily average weighted exposure can be determined by using the following formula:

$$\frac{(\text{Hours} \times \text{conc. task A}) + (\text{Hours} \times \text{conc. task B}) + \text{etc.}}{\text{8 hours (or actual hours worked)}}$$

The concentration of any air contaminant resulting from an industrial operation also varies with time. Therefore, a longer sampling time will better approximate the actual average.

With the following recommended sampling procedure, it is possible to collect samples at the workers' breathing zones for periods from 4 to 8 hours, thus permitting the evaluation of average exposures for a half or full 8-hour shift--a desirable and recommended procedure. Furthermore, dust exposures of a more normal work pattern result from the use of personal samplers. In evaluating daily exposures, samples should be collected as near as possible to workers' breathing zones.

Collecting Sample

The method recommended in this report for taking samples and counting fibers is based on a modification of the membrane filter method described by Edwards and Lynch. The sample should be collected on a 37-mm Millipore type AA[3] filter mounted in an open-face filter holder. The holder should be fastened to the worker's lapel.

Air is drawn through the filter by means of a battery-powered personal sampler pump similar to those approved by NIOSH under the provisions of 30 CFR 74. The filters are contained in plastic filter holders and are

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[3]Mention of commercial products does not constitute endorsement by the Public Health Service, the U.S. Department of Health, Education, and Welfare, or the Bureau of Mines.

supported on pads which also aid in controlling the distribution of air through the filter. To yield a more uniform sample deposit, the filter-holder face caps should be removed. Sampling flow rates from 1.0 liter per minute (lpm) up to the maximum flow rate of the personal sampler pump (usually not over 2.5 lpm) and sampling times from 15 minutes to 8 hours are acceptable provided the following restraints are considered:

1. In order to obtain an accurate estimate of the number of fibers, the statistical error resulting from the random distribution of the fibers must be kept to an acceptably low level. Since fiber counts follow a Poisson distribution, a count of 100 fibers in a sample would have a standard deviation of $\sqrt{100}$, or 10 fibers, or ±10 percent. Thus, the 95-percent confidence limits would be approximately 2 standard deviations, or ±20 percent. Since the 37-mm filter has an effective collecting area of 855 mm^2 and the projected field area of the Porton reticle is 0.005 mm^2, each field represents 1/171000 of the sample. Based on this ratio, the following number of fields must be counted to measure the various limits in various sampling times:

Sampling time, minutes	Flow rate, lpm	Number of fields for 100 fibers		
		0.2 fiber/ml	2.0 fibers/ml	10 fibers/ml
10	2	4,350	435	91
15	2	2,860	286	<u>58</u>
30	2	1,430	143	<u>29</u>
90	1	1,000	100	20
90	2	500	<u>50</u>	10
240	1	260	<u>26</u>	<u>7</u>
240	2	180	<u>18</u>	4
480	1	180	<u>18</u>	4

2. Do not count a field containing over 20 fibers because, in addition to the fibers being counted, there are also present a number of grains, which interfere with the accuracy of the count.

Based on these restraints--that is, number of fields to be counted and maximum number of fibers per field--acceptable sampling parameters for the various limits are underlined in the above table.

The following conclusions may be drawn from this analysis:

1. The short-term limit should be for a period of at least 15 minutes and preferably 30 minutes.

2. The 2.0-fiber/ml limit may be evaluated over periods of from 90 to 480 minutes.

As many fields as required to yield at least 100 fibers should be counted. In general, the minimum number of fields should be 20 and the maximum 100.

Mounting Sample

The mounting medium used in this method is prepared by dissolving 0.05 g of membrane filter per ml of 1:1 solution of dimethyl phthalate and diethyl oxalate. The index of refraction of the medium thus prepared is ND = 1.47.

To prepare a sample for microscopic examination, a drop of the mounting medium is placed on a freshly cleaned, standard (25 mm X 75 mm) microscopic slide. A wedge-shaped piece with arc length of about 1 cm is excised from the filter with a scalpel and forceps and placed dust-side-up on the drop of mounting solution. A No. 1-1/2 coverslip, carefully cleaned with lens tissue, is placed over the filter wedge. Slight pressure on the coverslip achieves contact between it and the mounting medium. The sample may be examined as soon as the mount is transparent. The optical homogeneity of the resulting mount is nearly perfect, with only a slight background granularity under phase contrast, which disappears within 1 day. The sample should be counted within 2 days after mounting.

Evaluation

The filter samples mounted in the manner previously described are evaluated in terms of the concentration of asbestos fibers greater than 5 μm in length. A microscope equipped with phase-contrast optics and a 4-mm "high-dry" achromatic objective is suitable for this determination. 10X eyepieces, one of which contains a Porton or other suitable reticle at the level of the field-limiting diaphragm, should be used. The left half of the Porton reticle field serves to define the counting area of the field. Twenty fields located at random on the sample are counted, and total asbestos fibers longer than 5 μm are recorded. Any particle having an aspect ratio of three or greater is considered a fiber.

The following formulae are used to determine the number of fibers per milliliter:

$$\frac{\text{Filter area (mm}^2\text{)}}{\text{Field area (mm}^2\text{)}} = K \tag{1}$$

$$\frac{\text{Average net count} \times K}{\text{(flow rate ml/min) (min sampled)}} = \text{fibers/ml} \tag{2}$$

For example, assume the following: Area of the filter used was 855 mm^2, counting area of one field under the Porton reticle was 0.005 mm^2, average net count per field of 20 fields was 10 fibers, and sample was collected at 2 liters per minute for 90 minutes. Then,

$$\frac{855 \text{ mm}^2}{0.005 \text{ mm}^2} = 171{,}000 \tag{1}$$

$$\frac{10 \text{ fibers} \times 171{,}000}{2{,}000 \text{ ml/min} \times 90 \text{ min}} = 9.5 \text{ fibers/ml} \tag{2}$$

Calibration of Personal Sampler

The accuracy of an analysis can be no greater than the accuracy of the volume of air which is measured. Therefore, the accurate calibration of a sampling device is essential to the correct interpretation of an instrument's indication. The frequency of calibration is somewhat dependent on the use, care, and handling to which the pump is subjected. Pumps should be calibrated if they have been subjected to misuse or if they have just been repaired or received from a manufacturer. If hard usage is given the instrument, more frequent calibration may be necessary.

Ordinarily, pumps should be calibrated in the laboratory both before they are used in the field and after they have been used to collect a large number of field samples. The accuracy of calibration is dependent on the type of instrument used as a reference. The choice of calibration instrument will depend largely upon where the calibration is to be performed. For laboratory testing, a 1-liter burette or wet-test meter should be used. In the field, a rotameter is the most convenient instrument used. The actual setup will be the same for all of these instruments. The calibration instrument will be connected in sequence to the filter unit which will be followed by the personal sampler pump. In this way, the calibration instrument will be at atmospheric pressure. Connections between units can be made using the same type of tubing used in the personal sampling unit. Each pump must be calibrated separately for each type of filter used, if, for example, it has been decided to use a filter with a different pore size. The burette should be set up so that the flow is toward the narrow end of the unit.

Care must be exercised in the assembly procedure to insure adequate seals at the joints and that the length of connecting tubing be kept at a minimum. Calibration should be done under the same conditions of pressure, temperature, and density as will be encountered. The rotameter should be used only in the field as a check if the diaphragm or piston pumps are not equipped with pulsation dampeners. The pulsating flow resulting from these type pumps causes the rotameter to give results which are not as accurate as that obtained with a burette or wet-test meter. Calibration can be accomplished with any of the other standard calibrating instruments, such as spirometer, Marriott's bottle, or dry-gas meter. The burette and wet-test meter were selected because of their accuracy, availability, and ease of operation.