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Electrostatic Effects on Airborne Asbestos Monitoring

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ELECTROSTATIC EFFECTS ON AIRBORNE ASBESTOS MONITORING

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ABSTRACT

ELECTROSTATIC EFFECTS ON AIRBORNE ASBESTOS MONITORING

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The affects of electrostatic forces on the Membrane Filter Method (MFM) used for airborne asbestos monitoring have been investigated for many years. Several studies have indicated that these forces interfere with the collection of asbestos fibers on the membrane filter, which results in an underestimated analysis of the airborne concentration. By varying the electroconductivity of the extension cowls on the filter cassettes, it was speculated that the significance of the electrostatic forces could be statistically analyzed. Four sets of filter cassettes with grounded conductive (GC) extension cowls, ungrounded conductive (UC) extension cowls, grounded nonconductive (GN) extension cowls, and ungrounded nonconductive (UN) extension cowls were used to collect airborne asbestos samples at rates of 1.4 liters per minute and 9 liters per minute. The membrane filter from each cassette was analyzed to determine the fibers per cubic centimeter (fibers/cc) of air sampled. The cowls from each sample were then washed onto clean filters and analyzed to determine the fibers/cc collected on the cowls. The proportion of the fibers on the cowl per fibers on the original filter was calculated for each sample and the results statistically evaluated. The findings of this study indicated that a significant number of asbestos fibers were collected on the sides of all extension cowls regardless of their electroconductivity. This reduces the total number of fibers collected on the membrane filter and produces an inaccurate evaluation of the ambient airborne asbestos concentration.

ACKNOWLEDGEMENTS

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INTRODUCTION

STATEMENT OF THE PROBLEM

Increased awareness of the harmful affects of inhaling minute quantities of airborne asbestos fibers has dictated the necessity for greater precision in measuring the ambient concentrations of airborne asbestos fibers to which individuals may be exposed. Currently, these measurements are accomplished with the Membrane Filter Method (MFM) prescribed by the National Institute for Occupational Safety and Health (NIOSH) Method 7400. However, the accuracy of the NIOSH Method 7400 may be affected by a number of variables. One variable is the build-up of static electricity on the sides of the extension cowls of the filter cassette holders. These forces may divert the fibers travelling through the open-faced extension cowls and cause them to adhere to the sides of the cowls rather than be collected on the membrane filter. If a significant number of fibers are collected on the sides of the cowls, the evaluation of the membrane filter may indicate a lower concentration of airborne asbestos fibers than is actually present. Additionally, these forces may cause a nonuniform distribution of fibers across the collection filter, which would lead to an inaccurate analysis.

Research has suggested that this problem may be reduced by two methods: grounding the cowls and using extension cowls made of conductive plastic; or increasing the sampling flow rate to reduce the loss of fibers to the sides of the cowl by decreasing the resident time of the fibers within the cowl.

To effectively evaluate the airborne asbestos concentration to which an individual may be exposed, it is imperative that this sampling variable be fully evaluated and eliminated if possible.

PURPOSE OF THE STUDY

The purpose of this study is to evaluate the effects of varying the electrostatic conductivity of the plastic extension cowls used during airborne asbestos monitoring. By using conductive and nonconductive plastic extension cowls that are grounded and ungrounded, it is projected that there will be a statistically significant difference in the number of fibers collected on the inside of the cowls between the four configurations: grounded conductive (GC); grounded nonconductive (GN); ungrounded conductive (UG); ungrounded nonconductive (UN). Additionally, by increasing the sampling flow rate, it is projected that the airborne asbestos fibers would spend less time travelling through the cowls and therefore be less affected by the electrostatic forces. This leads to the hypothesis that the samples collected at the high flow rate using the grounded nonconductive plastic extension cowls will have significantly fewer fibers collected on the inside of the cowls. This in turn will provide a more accurate determination of the ambient airborne asbestos concentration.

HISTORY OF THE MEMBRANE FILTER METHOD

A review of the literature indicated that since 1924 it has been recognized that inhalation of asbestos fibers can produce severe respiratory disease (Timbrell, 1970). However, determining the level of exposure that causes disease has not been an easy task. One of the first attempts to monitor and quantify the concentrations of airborne asbestos fibers in industries within the United States was initiated in 1935. Collection procedures consisted of using a konimeter or an impinger containing 90% ethyl alcohol solution in which to trap the fibers. A portion of the sample solution was then diluted to one part sample per ten parts dilution liquid; placed on a glass microscope slide; and then manually viewed with a phase-contrast microscope to determine the number of fibers. This method became widely accepted and was used for more than twenty years before being challenged (Walton, 1982).

One possible alternative was a method outlined by Schmidt and Heidermann (1959) in which dusts were collected from the air using a membrane filter. A phase-contrast microscope was then used to analyze the number of particles on the membrane filter (Walton, 1982).

The membrane filter method (MFM) had two important advantages: it provided flexibility to vary the sampling times and flow rates (Asbestos Research Council, 1963); and the equipment was small enough to use for personal monitoring (Hunt and Ellison, 1963). As research continued, attempts were made to standardize the procedures. Standardization included not only the sampling equipment and strategies, but also the method used for mounting, clearing and counting the loaded filter.

The United States Public Health Service (USPHS) conducted numerous studies in the 1960s to evaluate both the impinger method and the use of membrane filters to detect airborne asbestos. During these years of research, the USPHS developed a methodology for employing the membrane filters (Walton, 1982). This method was later revised and published by Edwards and Lynch (1968).

One of the first standardized methodologies for effective use of the membrane filter was published by Holmes (1965). His recommendations included sampling with a 0.45μ m pore size (Millipore type HA) membrane filter in a Gelman aluminum sampling head for five minutes at 200 ml/min. A 0.05% polymethyl methacrylate in chloroform solution was suggested as the fixative for the loaded filter. Following the placement of a few drops of triacetin on a clean glass slide, the membrane filter was placed on the slide and covered with a 25mm coverslip. Once the filter became transparent, the slide was viewed with a phase-contrast microscope at 500x magnification. Random fields were viewed and the number of fibers counted in each field was recorded. This procedure continued until enough fields had been viewed to yield a count of 200 fibers, 5-100μm long, with a length to width ratio greater than 3:1. Determination of size was accomplished through the use of a Patterson-Globe eyepiece graticule.

The Joint American Industrial Hygiene Association-American Conference of Governmental Industrial Hygienists (AIHA-ACGIH) Aerosol Hazards Evalution Committee published

guidelines for using the MFM and incorporated the use of a specially designed filter holder. This holder allowed for complete open-faced sampling so that the fibers could be uniformly collected across the filter. The holder also provided protection against contamination (Joint AIHA-ACGIH Aerosol Hazards Evaluation Committee, 1975).

With the increased concern for quantifying airborne asbestos concentrations, the need for standardization of procedures became more evident. This standardization, in the United States, was enforced by the Occupational Safety and Health Act of 1970 and the Code of Federal Regulations (CFR). The procedures outlined in the 29 CFR 1910.1001 require the use of a constant flow rate sampling pump to draw air into an open faced three piece 25mm cassette and through a 0.8 - 1.2μ m pore size mixed cellulose ester filter and backup pad (figure 1). It was also suggested in the 29 CFR that a conductive plastic 50mm extension cowl be used to provide added protection from contamination from large non-respirable particles. A copy of this regulation is provided as Appendix A.

Studies conducted by the Asbestos International Association (1979), Lui et al. (1980), and Peck et al. (1985) indicated that the use of these extension cowls could adversely affect the collection of the asbestos fibers onto the filter. These studies caused NIOSH to reevaluate the MFM. In 1987 NIOSH recommended that the cowls be washed down following sample collection or that they not be used at all (Appendix B).

Once the air sample has been taken, the filter cassette is sealed with the top cover and end caps to prevent contamination or disruption of the filter during transit to the laboratory. There the filter will be carefully removed from the cassette. A pie-shaped wedge is cut from the filter (approximately 20% of the filter) and placed on a clean glass microscope slide. The filter is then chemically treated to make it transparent and then covered with a coverslip.

Upon completion of these preparations, the sample is ready to be counted using a phase-contrast microscope. The first steps in counting entail checking, adjusting and calibrating the microscope to meet stringent specifications. The slide is then placed on the microscope stage and the analyst counts the number of fibers in the viewing field and records the number.

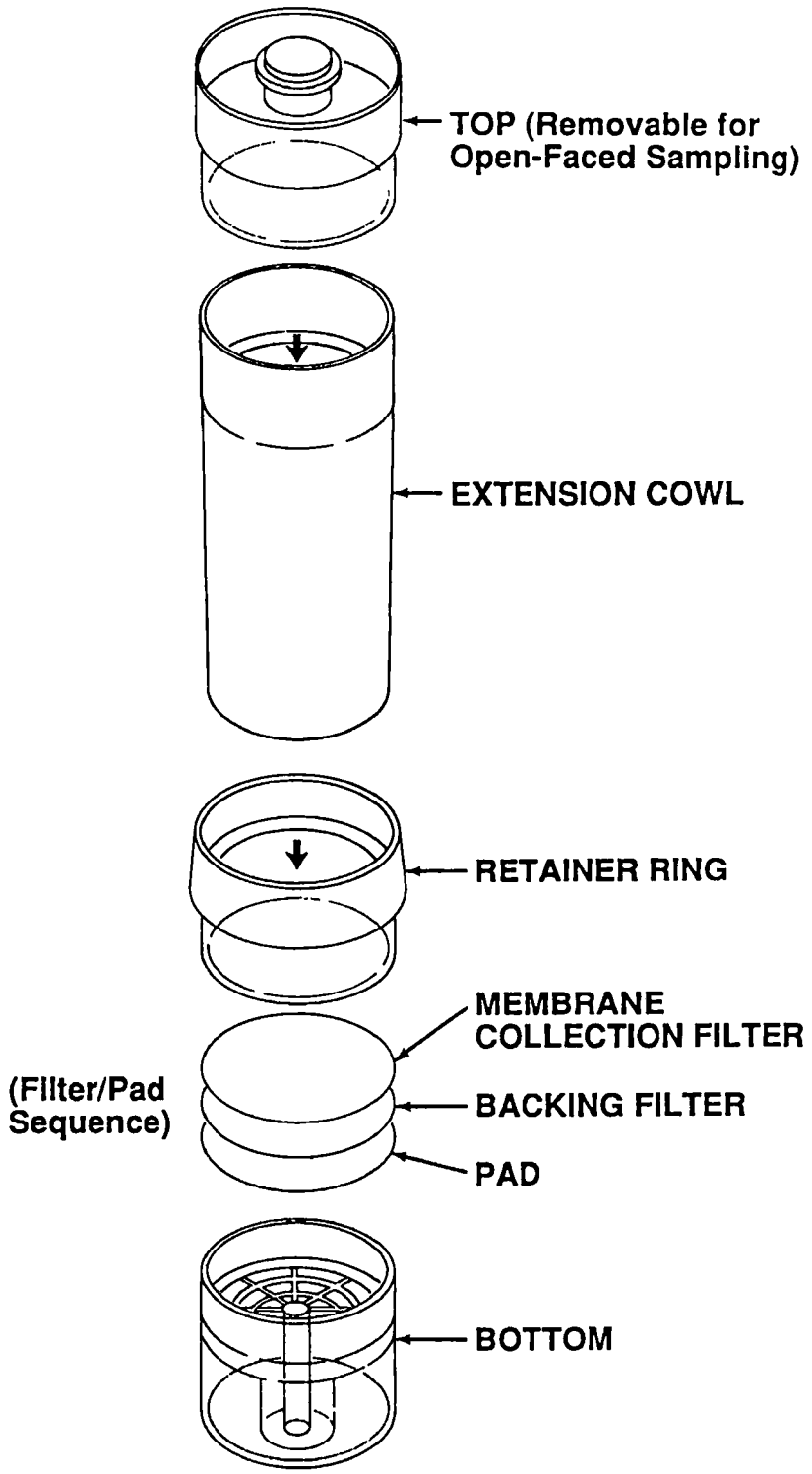


Figure 1. Membrane Filter Cassette with Extension Cowl

The slide is moved radially from the tip to the outer edge of the filter with each field being counted and the results recorded. It is then shifted up or down and advanced radially in the opposite direction until enough fields, at least twenty, have been counted to yield a total fiber count of at least 100 fibers. Regardless of the total fiber count, counting stops when 100 fields have been counted. For more specific information concerning the MFM and the subsequest phase-contrast microscopic analysis, refer to Appendix B.

The basic underlying assumption of the MFM is that there is a uniform distribution of fibers in the ambient air which will in turn allow for the collection of a uniform distribution of fibers across the filter. However, no studies were found to substantiate this assumption. Studies conducted by Johnson et al. (1980), Beckett (1980) and Cherrie et al. (1982) suggested that this assumption of a uniform distribution of fibers across the filter may not always hold true. Their studies indicated that there are a number of variables: sampling flow rate, fiber density on the filter, proficiency of the counters, and electrostatic charge effects, which can affect the distribution of fibers. Since these variables may act independently or synergistically, it is often difficult to determine their individual impact upon the collection and analysis of airborne asbestos samples.

REVIEW OF RELATED STUDIES

Several studies conducted around 1980 indicated that an increase sampling flow rate could greatly increase the concentration of airborne asbestos fibers collected on the filter membrane. One study found that the concentration of fibers was two times higher if collection was accomplished at 10 l/min than if collection was accomplished at 0.5 l/min (Rendall et al., 1980). A similar study conducted by Teichert in 1980 seemed to substantiate Rendall's finding (Teichert, 1980). However, as was later pointed out, these previous studies had failed to adjust the sampling time for the different flow rates (Beckett, 1980). This resulted in a larger volume of air being sampled at the high flow rates therefore producing a greater number of fibers on the

collection filter. When Beckett conducted his study and adjusted the sampling time to sample the same volume of air at both the high and low sampling flow rates, he found no significant difference in the quantity of fibers collected at the different flow rates (Beckett, 1980). Although some variance was noted in Beckett's first experiment, it was not statistically significant and was probably due to a counting variance, as was later suggested by Johnston et al. (1982).

In their study, Johnston et al. also pointed out that the studies conducted by Rendall and Teichert failed to reduce the sampling time when they increased the sampling flow rate.

To resolve the question as to the effect of sampling flow rates as well as another suggestion that aerodynamic factors also influenced the distribution of fibers across the filter, Johnston et al. designed a study to assess the affects of both sampling flow rates and external wind velocity. It was their belief that aerodynamic factors would not affect small respirable particles such as asbestos fibers targeted for collection. The experiment was conducted in a test chamber where fibrous particles were generated. Since no other particles were intermixed, the analysis of the filters was accomplished by weighing the filters before and after sampling. Using sampling flow rates between 0.2-0.4l/min and 4.0-8.0l/min and adjusting the sampling time to ensure the same volume of air was sampled at the different flow rates, they found no significant difference in the amount of fibers collected at the different sampling flow rates. Using the same sampling flow rates, they added an external wind velocity of 1.0 l/min and 4.0 l/min. The results of the experiment indicated that there was no significant effect caused by external wind velocities or sampling flow rates. Based on studies conducted around 1980, Johnston et al. suggested that most variance in sampling for airborne asbestos fibers could probably be attributed to variance in the density of fibers on the filter and the counting proficiency of the analysts (Johnston et al., 1982).

Three separate studies conducted in 1980 by Beckett, Beckett et al., and Pickford suggested that the fiber density on the filter would greatly affect the counting proficiency of the analysts. In all studies, they found that the analysts tended to under-count the number of fibers on filters containing a high density of fibers yet they tended to over-count the number of fibers on

filters containing a low density of fibers. In general, the conclusion was that when the analysts had an over-abundance of fibers to count, fatigue would cause significant variances between counts. The variances seen between analysts tasked with counting the number of fibers on filters containing a low density of fibers was most probably due to what Beckett described as a "psychophysical effect." In other words, the analysts tended to look harder and find more fibers on filters containing a low density of fibers (Beckett, 1980).

Numerous studies were conducted to investigate this counting variance. One of the most interesting ones was conducted by Cherrie et al. (1986). Their study compared the variances of counters at the same laboratory, counters at different laboratories and counts done by a computerized counter known as the Magiscan Image-Analyzer (Kenny, 1984). The results of their study indicated that the least amount of variance occurred when the fiber density on the filter was between 100-1000 fibers/mm2 of filter. An interesting fact uncovered in their study was that the Magiscan tended to over-count the number of fibers on filters containing a low density of fibers just as the human analysts did. Cherrie et al. suggested that when the sample filters are chemically treated to render them invisible, some artifacts of the filters which look like fibers may remain visible and may be counted as fibers. Based on their findings, they suggested that the lower and upper limits of fiber densities on the collection filters be set at 100-1000 fibers/mm2 of filter area (Cherrie et al., 1986). Their study and others cited here substantiated the guidelines set by NIOSH in 1986 in which both a lower and an upper limit of fiber densities on the filter of 100-1300 fibers/mm2 filter area were incorporated.

Sometimes it seems that the most obvious problems go unrecognized for long periods of time. This seems to be true in the case of the effects of static electricity upon airborne asbestos monitoring. Over the course of improving the MFM, some of the original suggestions were overlooked. As far back as 1951 (Woodland and Zeigler, 1951) the electrostatic accumulation of dusts on the sides of plastic chambers was publicized. Although it was suggested in 1979 that a metallic cowl be used to reduce the possible loss of fibers to the sides of the filter cassette (Asbestos International Association, 1979), this recommendation was overlooked during the

publication of a standardized methodology. In the past decade, researchers have realized the need to further investigate the significance of static electricity upon airborne asbestos monitoring.

At a special 1984 Annual Conference of the British Occupational Hygiene Society, a number of studies were presented and discussed. Lui et al. (1984) revealed that a significant electrostatic charge accumulated on the filters used for collection of aerosols. They compared the Millipore 0.8 μm pore diameter mixed cellulose ester membrane filter; the Ghia Corp. 2.0 μm Zefluor membrane filter; the Nucleopore Corp. 0.6 μm nucleopore polycarbonate membrane filter; and the Gelman A/E glass fiber filter. Using an electrostatic field mill, they measured the charge carried by each filter. They found that the Millipore filter carried a -10 V/cm field strength when gently removed from the container but when rubbed on the separator paper the field strength rose to approximately -40 V/cm. The nucleopore filter carried a field strength of +60 V/cm but, when rubbed on the separator paper, the field strength rose to +80 V/cm. The Zefluor filter carried a +70 V/cm field strength and the A/E glass fiber filter carried less than a +0.5 V/cm field strength, which was basically neutral (Lui et al.,1984).

Another possible source of electrostatic forces may also be found in the fibers themselves. Chrysotile is listed as carrying a positive charge and amosite and the other amphiboles are listed as carrying a negative (Rajharas and Sullivan, 1981). Although no studies were found to have investigated this possibility, it seems as though this factor would also affect the path of the asbestos fibers as they enter the filter cassettes. If, as previously suggested, the mixed cellulose membrane filter carries a negative charge and the amphibole fibers also carry a negative charge, the amphibole fibers would be repelled as they approached the membrane filter. This could also account for an accumulation of fibers on the filter cassette cowls.

In a study conducted by Speight and Marsh (1984) airborne amosite asbestos insulation fibers were collected using both cowled and uncowled cassettes. Their findings indicated that there was a significant decrease in the number of fibers collected on the filters of the cowled cassettes. Other studies conducted by Peck et al. (1985) and Knight et al. (1985), also investigated this problem but their findings indicated that there was not a significant difference in the

number of fibers collected on the filters of the cowled and the uncowled cassettes. One possible reason for the different results of the aforementioned experiments in that Speight and Marsh conducted their study using amosite asbestos fibers while Peck et al and Knight et al., collected chrysotile asbestos fibers.

In a recent study conducted by Seixas et al. (1987) samples were collected utilizing conductive (graphite-impregnated) extension cowls. The cowls and cassettes were wrapped with aluminum foil to further reduce the build-up of static electricity during sampling. The results of the experiment indicated that, even with the foil and the use of the conductive cowls, there was still a significant number of fibers collected on the inside of the cowls. Seixas et al. noted that although some fibers may be attracted to the inside of the uncowled cassette, the extension cowl creates a larger surface area and thereby decreases the number of fibers collected on the filter surface.

Indications from earlier research suggests that the electrostatic effect may also be enhanced by decreased humidity (Stein, 1972). Upon researching the factors associated with electrostatic accumulation of fibers on the sides of the filter cassettes and cowls, it appears that there are still many unanswered questions. If the MFM is to be a viable measurement tool, research must continue to identify and reduce or eliminate these variables.

BACKGROUND OF THE STUDY

EXPERIMENTAL DESIGN

The experiment was designed as a two factor analysis of variance problem. The proportions of the numbers of fibers found on the extension cowls per the number of fibers found on the membrane filters would be tabulated as described in Appendix C. Factor A would be the two sampling flow rates. Factor B would be the four cowl configurations: Grounded Conductive (GC), Grounded Nonconductive (GN), Ungrounded Conductive (UC), and Ungrounded Noncon-

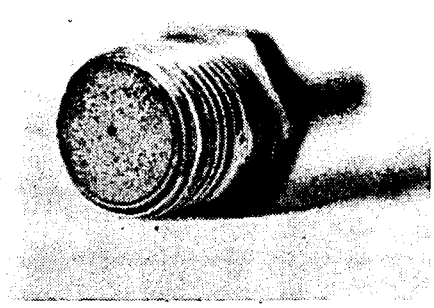
ductive (UN). All procedures used before, during and after the collection of the samples would be within the guidelines of the NIOSH Method 7400 (Appendix B) with the exception of varying the electroconductivity of the filter cassette extension cowls and the sampling flow rates. The samples would be collected within the same five-hour (300 minutes) period to eliminate possible variables caused by changes in the ambient temperature, humidity, air flow, or increased work activity. Additionally, all samples would be analyzed by the same individual to reduce any errors introduced by different analysts.

STUDY AREA

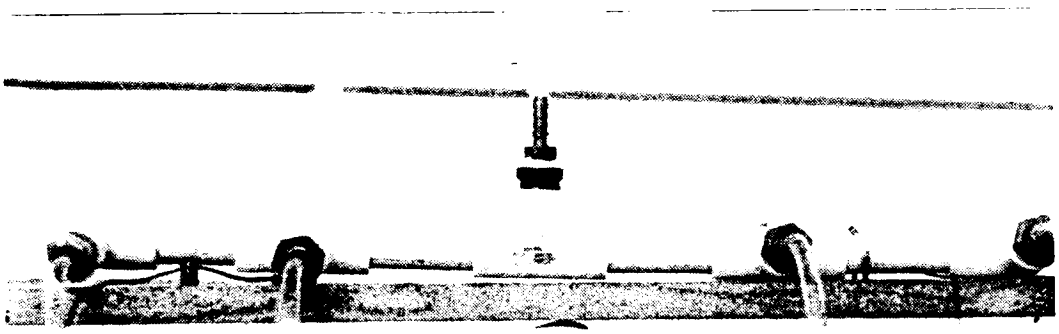
The study area was a room approximately 30 feet square with 15 foot ceilings covered with a thick layer of blown-on insulation composed primarily of chrysotile asbestos. A previously conducted survey of the building identified the components of the insulation and recommended it be removed when building renovations were initiated. At the time the samples were collected, removal of the asbestos-laden insulation had been initiated and debris was scattered throughout the room. However, no actual work was being conducted during the time in which the samples were being collected. Since the room was an internal room with no windows or doors leading to the outside, the temperature and humidity remained fairly constant at approximately 20 °C with 47% relative humidity.

EXPERIMENTAL EQUIPMENT

Due to the limited availability of necessary equipment, it was necessary to construct specially designed manifolds and critical orifices. The low flow critical orifices were constructed by drilling a minute hole, approximately 1/32 inch or 22µm, into a thin brass disk approxi-



Photograph 1. Specially Designed Low Flow Critical Orifice

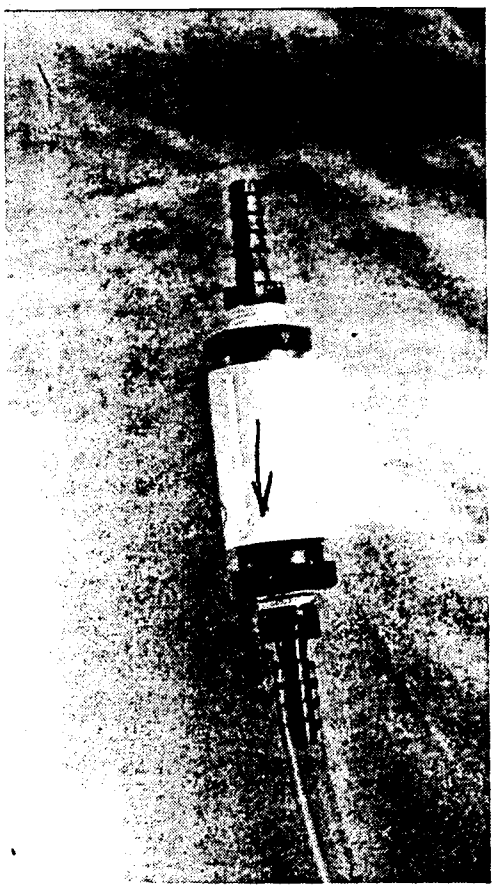


Photograph 2. Specially Designed Sampling Manifold

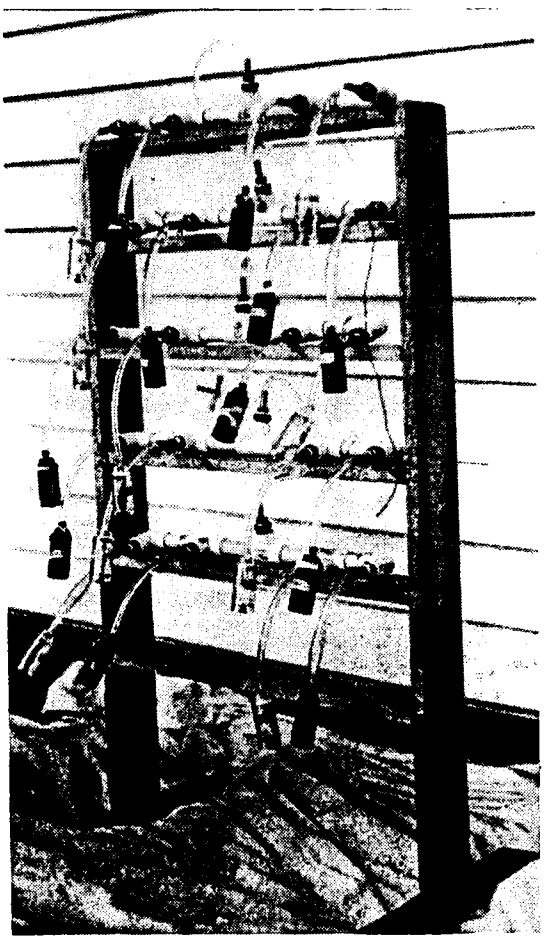
mately one-half-inch in diameter. These disks were then glued to the ends of one-half to one-quarter-inch reducers. One-quarter-inch hose barbs were then screwed into the reducers. Twenty of these critical orifices (Photograph 1) were constructed and then screwed into threaded one-half-inch PVC tees and elbows. Using approximately two inches of straight one-half-inch PVC pipe, the critical orifices were connected in groups of four (Photograph 2). An open one-half to one-quarter-inch reducer and one-quarter-inch hose barb were placed in the center of the manifold as the connection port to the pump. The critical orifices were then calibrated using a Gilibrater bubble meter, which electronically measured the speed of a soap bubble in liters per minute. Ten repetitive measurements were taken on each orifice and then averaged to determine the flow rate before and after the samples were collected. The high flow critical orifaces were constructed in the same manner except that the holes in the center of the brass disks were approximately 1/64 inch or 1220 µm. These critical orifices were screwed into one-half-inch threaded PVC pipe approximately one and one-half inches in length (Photograph 3). A reducer and hose barb were then screwed into the opposite ends to serve as the connection port to the pump. Calibration was completed in the same manner as the others.

EXPERIMENTAL PROCEDURES

The five low-volume sampling manifolds were placed on racks about ten inches appart



Photograph 3. Specially Designed High-Flow Critical Orifice



Photograph 4. Sampling Manifolds Mounted on Rack

starting eighteen inches from the floor (Photograph 4). Since there were a limited number of sampling pumps available, three manifolds were connected to one high-volume sampling pump and the remaining two manifolds were connected to a second high-volume sampling pump. Utilizing a random numbers table, each of the twenty monitors were assigned to positions on the manifolds.

Utilizing both nonconductive and conductive plastic monitors, eight sets of samples were collected. One set was collected with nonconductive plastic monitors. A second set was collected with grounded nonconductive (GN) plastic monitors. Grounding of the monitors was accomplished by wrapping an electrostatic wrist strap around the monitor and attaching the lead to a strand of wire attached to the grounding lead of the pump. A third set was collected with conductive plastic monitors and a forth set was collected with grounded conductive plastic monitors. These four sets were collected simultaneously at a low-volume sampling flow rate of approximately 1.3 l/min for 300 minutes. Another four sets of samples were collected with the same monitor configurations but at a high-volume sampling flow rate of approximately 8.9l/min at 45 minute intervals within the same 300 minutes. Each set contained five repetitions yielding a total of forty samples.

Upon donning the proper respiratory equipment, the sampling manifolds were taken into the study area and connected to the high-volume sampling pumps. Due to limited access to the sampling area, a baseline sample could not be obtained prior to the start of the experiment. Therefore, following the collection of the first set of high-volume samples, one sample was taken to the laboratory and analyzed to ensure that the estimated sampling time would produce viable results. The analysis of that sample indicated that the ambient airborne asbestos concentration was 0.14 fibers/cc. and sampling continued as planned.

Upon completion of each high-volume sampling period, each monitor was sealed with the end caps and top covers, removed from the collection area and placed in sectional cartons for transport to the laboratory.

At the end of the 300 minutes, all low-volume sampling was stopped and the monitors

were sealed and placed in the cartons. Since samples collected in the field are usually packed and shipped to the laboratory for evaluation, it was felt that no special care should be taken with the experimental samples if a true field evaluation was to be conducted.

Prior to analyzing the samples, the cowls from each cassette were labeled and then removed and placed over clean filters. Using a sample from another source, the cowl was washed onto a clean filter with water. Following the first washdown, the sample cowl was placed over a second clean filter and washed a second time. The two resulting filters were analyzed and since fibers were found on both, additional washings were conducted. Following the fourth washing, no fibers were found on the filter and it was determined that each sample cowl should be rinsed at least four times.

While the extension cowl samples were being prepared, portions of the original filters were cut and mounted on microscope slides as prescribed by the NIOSH Mehtod 7400. To reduce the variance introduced by different counters, Mr. Ray Collins, an experienced PAT round certified counter, analyzed all the samples. Due to the number of samples to be counted, each sample was only counted one time.

Following the washdown of the extension cowls, the resulting filters were dried and then portions were cut and mounted for analysis. Table 1 lists the results of the analyses and provides information concerning each sample.

ANALYSIS OF THE DATA

Utilizing the data from table 1, the information was retabulated and grouped to determine the totals, mean averages, and standard deviations for each group. These data are listed in table 2.

The data were analyzed using the statistical model outlined in chapter 7 of Biostatistics: A Foundation For Analysis In The Health Sciences (Daniel, 1983). The results of the two factor analysis of variance (ANOVA) are listed in table 3. As can be seen, the variance ratio (VR) of

Sample Number	Cowl Config	Time (min)	Flow Rate l/min	Fibers/cc of Air on the Filter	Fibers/cc of Air on the Cowl
1	UC	300	1.367	0.1264	0.0079
2	UC	300	1.276	0..0762	0.0085
3	UN	300	1.347	0.0641	0.0073
4	UN	300	1.279	0.0436	0.0110
5	UC	300	1.363	0.0713	0.0200
6	GC	300	1.354	0.0890	0.0080
7	GN	300	1.441	0.0790	0.0076
8	GN	300	1.367	0.0590	0.0072
9	GC	300	1.364	0.1200	0.0130
10	GC	300	1.432	0.0830	0.0150
11	GN	300	1.296	0.0790	0.0076
12	GN	300	1.437	0.088	0.0069
13	GC	300	1.274	0.0970	0.0210
14	UC	300	1.379	0.1384	0.0078
15	UN	300	1.290	0.1339	0.0084
16	GC	300	1.265	0.1200	0.0085
17	UC	300	1.332	0.1257	0.0190
18	GN	300	1.335	0.0710	0.0074
19	UN	300	1.356	0.0420	0.0073
20	UN	300	1.436	0.0610	0.0069

UC = Ungrounded Conductive GC = Grounded Conductive

UN = Ungrounded Nonconductive GN = Grounded Nonconductive

Results of Airborne Asbestos Monitoring Using Four Different Extension Cowl Configurations

Table 1

Sample Number	Cowl Config	Time (min)	Flow Rate l/min	Fibers/cc of Air on the Filter	Fibers/cc of Air on the Cowl
21	UC	45	8.9	0.15	0.0078
22	GC	45	8.68	0.20	0.0077
23	UN	45	8.87	0.096	0.0075
24	GN	45	8.82	0.094	0.0076
25	UC	45	8.9	0.19	0.0078
26	GC	45	8.68	0.15	0.0098
27	UN	45	8.87	0.088	0.0075
28	GN	45	8.82	0.10	0.0076
29	UC	45	8.9	0.099	0.0170
30	GC	45	8.68	0.093	0.0084
31	UN	45	8.87	0.080	0.0075
32	GN	45	8.82	0.085	0.0076
33	UC	45	8.9	0.13	0.0078
34	GC	45	8.68	0.13	0.0077
35	UN	45	8.87	0.073	0.0075
36	GN	45	8.82	0.095	0.0076
37	UC	45	8.9	0.13	0.14
38	GC	45	8.68	0.12	0.0077
39	UN	45	8.87	0.090	0.0075
40	GN	45	8.82	0.13	0.0076

UC = Ungrounded Conductive GC = Grounded Conductive

UN = Ungrounded Nonconductive GN = Grounded Nonconductive

Results of Airborne Asbestos Monitoring Using Four Different Extension Cowl Configurations

Table 1 continued

Flow Rate	Cowl Configuration FF = Fibers on the Filter FC = Fibers on the Cowl FC/FF = Fibers on the Cowl per Fibers on the Filter											
	Ungrounded Conductive			Ungrounded Nonconductive			Grounded Conductive			Grounded Nonconductive		
	FF	FC	FC/FF	FF	FC	FC/FF	FF	FC	FC/FF	FF	FC	FC/FF
Low Flow	.1264 .0762 .0713 .1384 .1257	.0079 .0085 .0200 .0078 .0190	.0625 .1116 .2805 .0564 .1512	.0641 .0436 .1339 .0425 .0614	.0073 .0110 .0084 .0073 .0069	.1138 .2521 .0627 .1719 .1123	.0891 .1188 .0830 .0975 .1181	.0080 .0130 .0150 .0210 .0085	.0898 .1095 .1808 .2154 .0720	.0637 .0593 .0792 .0877 .0715	.0069 .0072 .0076 .0069 .0074	.1083 .1316 .0956 .0787 .1035
Total	.5380	.0632	.6621	.3455	.0409	.7128	.5065	.0655	.6675	.3614	.0360	.5182
Mean	.1076	.0126	.1324	.0691	.0082	.1426	.1013	.0131	.1335	.0723	.0072	.1036
Std. Dev.	.0313	.0582	.0914	.0376	.0017	.0724	.0165	.0053	.0617	.0115	.0003	.0193
High Flow	.1468 .1892 .0988 .1299 .1327	.0078 .0078 .0170 .0078 .0140	.0531 .0412 .1720 .0601 .1055	.0960 .0878 .0796 .0727 .0906	.0075 .0075 .0075 .0075 .0075	.0781 .0854 .0942 .1031 .0828	.2028 .1521 .0930 .1268 .1197	.0077 .0098 .0084 .0077 .0077	.0380 .0644 .0904 .0607 .0643	.0937 .1033 .0854 .0951 .1323	.0076 .0076 .0076 .0076 .0076	.0811 .0735 .0890 .0799 .0575
Total	.6974	.0544	.4320	.4267	.0375	.4437	.6944	.0413	.3178	.5098	.0380	.3811
Mean	.1395	.0109	.0864	.0853	.0075	.0887	.1389	.0083	.0636	.1020	.0076	.0762
Std. Dev.	.0386	.0043	.0537	.0092	.0000	.0099	.0415	.0009	.0186	.0181	.0000	.0118

Mathematical Evaluation of Group Samples
Table 2

Source	Sum of Squares	Degrees of Freedom	Mean Sum of Square	Variance Ratio
A (Flow Rate)	.0243	1	MSA = .0243	9.1601
B (Cowl Config)	.0039	3	MSB = .0013	0.4910
AB (Flow Rate X (Cowl Config.)	.0023	3	MSAB = .0008	0.2933
Treatments	0306	7		
Residual	.0849	32	MSE =.0026	

Analysis of Variance for Airborne Asbestos Samples Collected at Two Different Flow Rates and Four Different Conditions of Electroconductivity

Table 3

factor A is 9.16. Using the 95% confidence level for the F values, the VR for Factor A exceeds the tabulated F value of 4.17, indicating that the null hypothesis should be rejected. In other words, the analysis indicates that there is a difference between the means of samples collected at different flow rates. Using Tukey's HSD (honestly significant difference) Test to further analyze Factor A, it was discovered that 75% of the sample groups collected at 45 l/min had equal means. However, 75% of the sample groups collected at 300 l/min had unequal means.

The analysis of Factor B, the cowl configurations, yielded a variance ratio of 0.491, which does not exceed the tabulated F value of 2.92. This tends to support the argument that there is no difference between samples collected with grounded, ungrounded, conductive, or non-conductive extension cowls. Likewise, the interaction of Factors A and B also indicated that there is no difference between the means of samples collected with different cowl configurations at different flow rates.

FINDINGS AND CONCLUSIONS

The results of this experiment indicated that regardless of the cowl electroconductivity (grounded, ungrounded, conductive, or nonconductive), some incoming asbestos fibers adhered to the sides of all the cowls. When analyzed to determine if any significant difference was noted between cowls with different electroconductive configurations, the findings failed to substantiate the hypothesis that the grounded conductive cowls would attract fewer fibers. In fact, as indicated in Table 3, no significant difference was noted between any of the cowl configurations. The only substantiated finding was that there was an accumulation of fibers on the extension cowls. This finding is supported by the latest NIOSH experiment in which a comparison was made between samples collected with filter cassettes with extension cowls and filter cassettes without extension cowls. They also noted the accumulation of fibers on the inside of the cowls (NIOSH, 1987). Although some fibers may accumulate on the inside of the uncowled cassettes, the large surface area created by the extension cowls increases the probability of reducing the number of

fibers collected on the filters. This in turn causes an underestimation of the total ambient asbestos concentration. The NIOSH recommendation was to eliminate the use of extension cowls or wash down the cowls to determine the total fiber count. The data obtained from this experiment tends to support this recommendation.

The second half of the hypothesis was that an increased flow rate would reduce the resident time of the fibers travelling through the cowl and thereby reduce the number of fibers collected on the walls of the cassette. The findings indicated that this would be a true assumption. However, when further analyzed using Tukey's HSD test, this assumption was not substantiated. Using the findings for Factor A (time), the probability of falsely rejecting the null hypothesis lies between .01 and .005%. Although this seems to support the idea that there is a difference between samples collected at different flow rates, the data revealed by Tukey's HSD test indicated that the difference actually may be attributed to the differences within the low-flow rate sample groups. One conclusion that can be drawn from this finding is samples collected at the low-flow rates may have a greater opportunity to be affected by a build-up of electrostatic charges on the cowls, or by air currents within the area being sampled. There are so many factors that can affect this sampling process it seems logical to assume that an increased sampling time would enhance the probability of these factors interfering with the process.

Although there was no conclusive evidence as to the severity of electrostatic forces during the collection of airborne asbestos samples, there was evidence indicating that it does exist and that it can have an effect on the total number of fibers collected on the membrane filters. Washing the cowls prior to analysis of the filters or not using the extension cowls at all were the solutions offered by NIOSH and other researchers. At the present time they are the best solutions for obtaining a reasonable estimate of ambient airborne asbestos concentrations.

Since there are currently no other alternatives to the membrane filter method, it is imperative to remember that this method is and always has been only an index of possible levels of exposure. If, as medical research has suggested, there is no safe level of exposure to asbestos fibers, the membrane filter method can be an effective tool to alert personnel to the presence of asbestos so that control measures can be implemented, but it cannot be used for precise quantitative analysis.

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Appendix A

Appendix A to CFR 1910.1001- Osha Reference Method - Mandatory

duration of employment plus thirty (30) years, in accordance with 29 CFR 1910.20.

(4) *Training.* The employer shall maintain all employee training records for one (1) year beyond the last date of employment of that employee.

(5) *Availability.* (i) The employer, upon written request, shall make all records required to be maintained by this section available to the Assistant Secretary and the Director for examination and copying.

(ii) The employer, upon request shall make any exposure records required by paragraph (m)(1) of this section available for examination and copying to affected employees, former employees, designated representatives and the Assistant Secretary, in accordance with 29 CFR 1910.20 (a)–(e) and (g)–(i).

(iii) The employer, upon request, shall make employee medical records required by paragraph (m)(2) of this section available for examination and copying to the subject employee, to anyone having the specific written consent of the subject employee, and the Assistant Secretary, in accordance with 29 CFR 1910.20.

(6) *Transfer of records.* (i) The employer shall comply with the requirements concerning transfer of records set forth in 29 CFR 1910.20(h).

(ii) Whenever the employer ceases to do business and there is no successor employer to receive and retain the records for the prescribed period, the employer shall notify the Director at least 90 days prior to disposal of records and, upon request, transmit them to the Director.

(n) *Observation of monitoring*—(1) *Employee observation.* The employer shall provide affected employees or their designated representatives an opportunity to observe any monitoring of employee exposure to asbestos, tremolite, anthophyllite, or actinolite conducted in accordance with paragraph (d) of this section.

(2) *Observation procedures.* When observation of the monitoring of employee exposure to asbestos, tremolite, anthophyllite, or actinolite requires entry into an area where the use of protective clothing or equipment is required, the observer shall be provided with and be required to use such clothing and equipment and shall comply with all other applicable safety and health procedures.

(o) *Dates*—(1) *Effective date.* This standard shall become effective July 21, 1986. The requirements of the asbestos standard issued in June 1972 (37 FR 11318), as amended, and published in 29 CFR 1910.1001 (1985) remain in effect until compliance is achieved with the parallel provisions of this standard.

(2) *Start-up dates.* All obligations of this standard commence on the effective date except as follows:

(i) *Exposure monitoring.* Initial monitoring required by paragraph (d)(2) of this section shall be completed as soon as possible but no later than October 20, 1986.

(ii) *Regulated areas.* Regulated areas required to be established by paragraph (e) of this section as a result of initial monitoring shall be set up as soon as possible after the results of that monitoring are known and not later than November 17, 1986.

(iii) *Respiratory protection.* Respiratory protection required by paragraph (g) of this section shall be provided as soon as possible but no later than the following schedule:

(A) Employees whose 8-hour TWA exposure exceeds 2 fibers/cc—July 21, 1986.

(B) Employees whose 8-hour TWA exposure exceeds the PEL but is less than 2 fibers/cc—November 17, 1986.

(C) Powered air-purifying respirators provided under paragraph (g)(2)(ii)—January 16, 1987.

(iv) *Hygiene and lunchroom facilities.* Construction plans for changerooms, showers, lavatories, and lunchroom facilities shall be completed no later than January 16, 1987; and these facilities shall be constructed and in use no later than July 20, 1987. However, if as part of the compliance plan it is predicted by an independent engineering firm that engineering controls and work practices will reduce exposures below the permissible exposure limit by July 20, 1988, for affected employees, then such facilities need not be completed until 1 year after the engineering controls are completed, if such controls have not in fact succeeded in reducing exposure to below the permissible exposure limit.

(v) *Employee information and training.* Employee information and training required by paragraph (j)(5) of this section shall be provided as soon as possible but no later than October 20, 1986.

(vi) *Medical surveillance.* Medical examinations required by paragraph (1) of this section shall be provided as soon as possible but no later than November 17, 1986.

(vii) *Compliance program.* Written compliance programs required by paragraph (f)(2) of this section as a result of initial monitoring shall be completed and available for inspection and copying as soon as possible but no later than July 20, 1987.

(viii) *Methods of compliance.* The engineering and work practice controls as required by paragraph (f)(1) shall be implemented as soon as possible but no later than July 20, 1988.

(p) *Appendices.* (1) Appendices A, C, D, and E to this section are incorporated as part of this section and the contents of these Appendices are mandatory

(2) Appendices B, F, G and H to this section are informational and are not intended to create any additional obligations not otherwise imposed or to detract from any existing obligations.

Appendix A to § 1910.1001—Osha Reference Method—Mandatory

This mandatory appendix specifies the procedure for analyzing air samples for asbestos, tremolite, anthophyllite, and actinolite and specifies quality control procedures that must be implemented by laboratories performing the analysis. The sampling and analytical methods described below represent the elements of the available monitoring methods (such as the NIOSH 7400 method) which OSHA considers to be essential to achieve adequate employee exposure monitoring while allowing employers to use methods that are already established within their organizations. All employers who are required to conduct air monitoring under paragraph (f) of the standard are required to utilize analytical laboratories that use this procedure, or an equivalent method, for collecting and analyzing samples.

Sampling and Analytical Procedure

1. The sampling medium for air samples shall be mixed cellulose ester filter membranes. These shall be designated by the manufacturer as suitable for asbestos, tremolite, anthophyllite, and actinolite counting. See below for rejection of blanks.

2. The preferred collection device shall be the 25-mm diameter cassette with an open-faced 50-mm extension cowl. The 37-mm cassette may be used if necessary but only if written justification for the need to use the 37-mm filter cassette accompanies the sample results in the employee's exposure monitoring record.

3. An air flow rate between 0.5 liter/min and 2.5 liters/min shall be selected for the 25-mm cassette. If the 37-mm cassette is used, an air flow rate between 1 liter/min and 2.5 liters/min shall be selected.

4. Where possible, a sufficient air volume for each air sample shall be collected to yield between 100 and 1,300 fibers per square millimeter on the membrane filter. If a filter darkens in appearance or if loose dust is seen on the filter, a second sample shall be started.

5. Ship the samples in a rigid container with sufficient packing material to prevent dislodging the collected fibers. Packing material that has a high electrostatic charge on its surface (e.g., expanded polystyrene) cannot be used because such material can cause loss of fibers to the sides of the cassette.

6. Calibrate each personal sampling pump before and after use with a representative filter cassette installed between the pump and the calibration devices.

7. Personal samples shall be taken in the "breathing zone" of the employee (i.e., attached to or near the collar or lapel near the worker's face).

8. Fiber counts shall be made by positive phase contrast using a microscope with an 8 to 10 X eyepiece and a 40 to 45 X objective for a total magnification of approximately 400 X and a numerical aperture of 0.65 to 0.75. The microscope shall also be fitted with a green or blue filter.

9. The microscope shall be fitted with a Walton-Beckett eyepiece graticule calibrated for a field diameter of 100 micrometers (+/−2 micrometers).

10. The phase-shift detection limit of the microscope shall be about 3 degrees measured using the HSE phase shift test slide as outlined below.

a. Place the test slide on the microscope stage and center it under the phase objective.

b. Bring the blocks of grooved lines into focus.

Note.—The slide consists of seven sets of grooved lines (ca. 20 grooves to each block) in descending order of visibility from sets 1 to 7, seven being the least visible. The requirements for asbestos, tremolite, anthophyllite, and actinolite counting are that the microscope optics must resolve the grooved lines in set 3 completely, although they may appear somewhat faint, and that the grooved lines in sets 6 and 7 must be invisible. Sets 4 and 5 must be at least partially visible but may vary slightly in visibility between microscopes. A microscope that fails to meet these requirements has either too low or too high a resolution to be used for asbestos, tremolite, anthophyllite, and actinolite counting.

c. If the image deteriorates, clean and adjust the microscope optics. If the problem persists, consult the microscope manufacturer.

11. Each set of samples taken will include 10 percent blanks or a minimum of 2 blanks. The blank results shall be averaged and subtracted from the analytical results before reporting. Any samples represented by a blank having a fiber count in excess of 7 fibers/100 fields shall be rejected.

12. The samples shall be mounted by the acetone/triacetin method or a method with an equivalent index of refraction and similar clarity.

13. Observe the following counting rules.

a. Count only fibers equal to or longer than 5 micrometers. Measure the length of curved fibers along the curve.

b. Count all particles as asbestos, tremolite, anthophyllite, and actinolite that have a length-to-width ratio (aspect ratio) of 3:1 or greater.

c. Fibers lying entirely within the boundary of the Walton-Beckett graticule field shall receive a count of 1. Fibers crossing the boundary once, having one end within the circle, shall receive the count of one half (½). Do not count any fiber that crosses the graticule boundary more than once. Reject and do not count any other fibers even though they may be visible outside the graticule area.

d. Count bundles of fibers as one fiber unless individual fibers can be identified by observing both ends of an individual fiber.

e. Count enough graticule fields to yield 100 fibers. Count a minmum of 20 fields; stop counting at 100 fields regardless of fiber count.

14. Blind recounts shall be conducted at the rate of 10 percent.

Quality Control Procedures

1. Intralaboratory program. Each laboratory and/or each company with more than one microscopist counting slides shall establish a statistically designed quality assurance program involving blind recounts and comparisons between microscopists to monitor the variability of counting by each microscopist and between microscopists. In a company with more than one laboratory, the program shall include all laboratories and shall also evaluate the laboratory-to-laboratory variability.

2. Interlaboratory program. Each laboratory analyzing asbestos, tremolite, anthophyllite, and actinolite samples for compliance determination shall implement an interlaboratory quality assurance program that as a minimum includes participation of at least two other independent laboratories. Each laboratory shall participate in round robin testing at least once every 6 months with at least all the other laboratories in its interlaboratory quality assurance group. Each laboratory shall submit slides typical of its own work load for use in this program. The round robin shall be designed and results analyzed using appropriate statistical methodology.

3. All individuals performing asbestos, tremolite, anthophyllite, and actinolite analysis must have taken the NIOSH course for sampling and evaluating airborne asbestos, tremolite, anthophyllite, and actinolite dust or an equalivalent course.

4. When the use of different microscopes contributes to differences between counters and laboratories, the effect of the different microscope shall be evaluated and the microscope shall be replaced, as necessary.

5. Current results of these quality assurance programs shall be posted in each laboratory to keep the microscopists informed.

Appendix B to § 1910.1001—Detailed Procedure for Asbestos Tremolite, Anthophyllite, and Actinolite Sampling and Analysis—Non-Mandatory

This appendix contains a detailed procedure for sampling and analysis and includes those critical elements specified in Appendix A. Employers are not required to use this procedure, but they are required to use Appendix A. The purpose of Appendix B is to provide a detailed step-by-step sampling and analysis procedure that conforms to the elements specified in Appendix A. Since this procedure may also standardize the analysis and reduce variability, OSHA encourages employers to use this appendix.

Asbestos, Tremolite, Anthophyllite, and Actinolite Sampling and Analysis Method

Technique: Microscopy, Phase Contrast
Analyte: Fibers (manual count)
Sample Preparation: Acetone/triacetin method
Calibration: Phase-shift detection limit about 3 degrees
Range: 100 to 1300 fibers/mm ^{2} filter area
Estimated limit of detection: 7 fibers/mm ^{2} filter area
Sampler: Filter (0.8–1.2 um mixed cellulose ester membrane, 25-mm diameter)
Flow rate: 0.5 1/min to 2.5 1/min (25-mm cassette) 1.0 1/min to 2.5 1/min (37-mm cassette)

Appendix B

NIOSH Method 7400

FORMULA: various

M.W.: various

FIBERS

METHOD: 7400
ISSUED: 2/15/84
REVISION #2: 8/15/87

OSHA: 0.2 asbestos fibers (> 5 μm long)/mL [1]
NIOSH: 0.1 asbestos f/mL [1]; 3 glass fibers (>10 μm x <3.5 μm)/mL [3]
ACGIH: 0.2 crocidolite; 0.5 amosite; 2 chrysotile and other asbestos, f/mL

PROPERTIES: solid, fibrous

SYNONYMS: actinolite asbestos [CAS #13768-00-8], grunerite asbestos (amosite) [CAS #12172-73-5], anthophyllite asbestos [CAS #17068-78-9], chrysotile asbestos [CAS #12001-29-5], crocidolite asbestos [CAS #12001-28-4], tremolite asbestos [CAS #14567-73-8]; fibrous glass.

SAMPLING

SAMPLER: FILTER
(0.8- to 1.2- μm cellulose ester membrane, 25-mm diameter; conductive cowl on cassette)

FLOW RATE*: 0.5 to 16 L/min (see step 4)

VOL-MIN*: 400 L @ 0.1 fiber/mL (see step 4)
-MAX*: (see step 4)
*Adjust for 100 to 1300 fibers/mm² (step 4)

SHIPMENT: routine (securely packed to reduce shock)

SAMPLE STABILITY: stable

FIELD BLANKS: 10% (≥2) of samples

ACCURACY

RANGE STUDIED: 80 to 100 fibers counted

BIAS: see EVALUATION OF METHOD

OVERALL PRECISION (s_r): 0.115 to 0.13 (A Rules) [3]

MEASUREMENT

TECHNIQUE: LIGHT MICROSCOPY, PHASE CONTRAST

ANALYTE: fibers (manual count)

SAMPLE PREPARATION: acetone/triacetin "hot block" method [5]

COUNTING RULES: Set A (required by OSHA; [1,4]) or Set B (modified CRS [6])

EQUIPMENT: 1. positive phase-contrast microscope
2. Walton-Beckett graticule (100-μm field of view): A Rules use Type G-22; B Rules use Type G-24
3. phase-shift test slide (HSE/NPL)

CALIBRATION: HSE/NPL test slide

RANGE: 100 to 1300 fibers/mm² filter area

ESTIMATED LOD: 7 fibers/mm² filter area

PRECISION: 0.10 to 0.12 (A Rules) [3]
(see Evaluation of Method:B)

APPLICABILITY: The method gives an index of airborne fibers in workplace atmospheres. Phase contrast microscopy will not differentiate between asbestos and other fibers; use this method in conjunction with electron microscopy (e.g., Method 7402) for positive identification. Fibers < ca. 0.25 μm diameter will not be detected by this method [7].

INTERFERENCES: Any other airborne fiber may interfere since all particles meeting the counting criteria are counted. Chain-like particles may appear fibrous. High levels of non-fibrous dust particles may obscure fibers in the field of view and increase the detection limit.

OTHER METHODS: This method introduces changes for improved sensitivity and reproducibility. It replaces P&CAM 239 [4,8] and Method 7400, Revision #1 (dated 5/15/85).

REAGENTS:

1. Acetone.*
2. Triacetin (glycerol triacetate), reagent grade.

*See SPECIAL PRECAUTIONS.

EQUIPMENT:

1. Sampler: field monitor, 25-mm, three-piece cassette with ca. 50-mm electrically-conductive extension cowl and cellulose ester filter, 0.8- to 1.2-µm pore size, and backup pad.
   NOTE 1: Analyze representative filters for fiber background before use. Discard the filter lot if mean is ≥ 5 fibers per 100 graticule fields. These are defined as laboratory blanks.
   NOTE 2: Use an electrically-conductive extension cowl to reduce electrostatic effects. Ground the cowl when possible during sampling.
2. Personal sampling pump, 0.5 to 16 L/min (see step 4 for flow rate), with flexible connecting tubing.
3. Microscope, positive phase contrast, with green or blue filter, 8 to 10X eyepiece, and 40 to 45X phase objective (total magnification ca. 400X); numerical aperture = 0.65 to 0.75.
4. Slides, glass, frosted-end, pre-cleaned, 25 x 75 mm.
5. Cover slips, 22 x 22 mm, No. 1-1/2, unless otherwise specified by microscope manufacturer.
6. Lacquer or nail polish.
7. Knife, #10 surgical steel, curved blade.
8. Tweezers.
9. Heated aluminum block for clearing filters on glass slides (see ref. [5] for instructions on manufacture).
10. Micropipets, 5-µL and 100- to 500-µL.
11. Graticule, Walton-Beckett type with 100-µm diameter circular field (area = 0.00785 mm^2)at the specimen plane (Type G-22 for A Rules; Type G-24 for B Rules). Available from PTR Optics Ltd., 145 Newton Street, Waltham, MA 02154 [phone (617) 891-6000] and McCrone Accessories and Components, 850 Pasquinelli Drive, Westmont, IL 60559 [phone (312) 887-7100].
    NOTE: The graticule is custom-made for each microscope. Specify disc diameter needed to fit exactly the ocular of the microscope and the diameter (mm) of the circular counting area (see APPENDIX A).
12. HSE/NPL phase contrast test slide, Mark II. Available from PTR Optics Ltd. (address above).
13. Telescope, ocular phase-ring centering.
14. Stage micrometer (0.01-mm divisions).
15. Wire, multi-stranded, 22-gauge.

SPECIAL PRECAUTIONS: Acetone is extremely flammable. Take precautions not to ignite it. Heating of acetone in volumes greater than 1 mL must be done in a ventilated laboratory fume hood using a flameless, spark-free heat source.

SAMPLING:

1. Calibrate each personal sampling pump with a representative sampler in line.

2. For personal sampling, fasten sampler to the worker's lapel near the worker's mouth. Remove top cover from cowl extension (open face) and orient face down. Wrap joint between cowl and monitor body with shrink tape to prevent air leaks.
   NOTE: If possible, ground the cassette to remove any surface charge, using a wire held in contact (e.g., with a hose clamp) with the conductive cowl and a non-electrical metal fixture, or a cold-water pipe.
3. Submit at least two field blanks (or 10% of the total samples, whichever is greater) for each set of samples. Remove top covers from the field blank cassettes and store top covers and cassettes in a clean area (bag or box) with the top covers from the sampling cassettes during the sampling period. Replace the top covers in the cassettes after sampling.
4. Sample at 0.5 L/min or greater [9]. Adjust sampling flow rate, Q (L/min), and time, t (min), to produce a fiber density, E, of 100 to 1300 fibers/mm^2 ($3.85 \cdot 10^4$ to $5 \cdot 10^5$ fibers per 25-mm filter with effective collection area A_c= 385 mm^2) for optimum accuracy. These variables are related to the action level (one-half the current standard), L (fibers/mL), of the fibrous aerosol being sampled by:

$$t = \frac{(A_c)(E)}{(Q)(L)10^3}.$$

   NOTE 1: The purpose of adjusting sampling times is to obtain optimum fiber loading on the filter. A sampling rate of 1 to 4 L/min for 8 hrs is appropriate in non-dusty atmospheres containing ca. 0.1 fiber/mL. Dusty atmospheres require smaller sample volumes ($\leq$400 L) to obtain countable samples. In such cases take short, consecutive samples and average the results over the total collection time. For documenting episodic exposures, use high flow rates (7 to 16 L/min) over shorter sampling times. In relatively clean atmospheres, where targeted fiber concentrations are much less than 0.1 fiber/mL, use larger sample volumes (3000 to 10000 L) to achieve quantifiable loadings. Take care, however, not to overload the filter with background dust. If $\geq$ 50% of the filter surface is covered with particles, the filter may be too overloaded to count and will bias the measured fiber concentration.
   NOTE 2: OSHA regulations specify a maximum sampling rate of 2.5 L/min [1].
5. At the end of sampling, replace top cover and small end caps.
6. Ship samples with conductive cowl attached in a rigid container with packing material to prevent jostling or damage.
   NOTE: Do not use untreated polystyrene foam in shipping container because electrostatic forces may cause fiber loss from sample filter.

SAMPLE PREPARATION:

NOTE: The object is to produce samples with a smooth (non-grainy) background in a medium with refractive index $\leq$ 1.46. This method collapses the filter for easier focusing and produces permanent mounts which are useful for quality control and interlaboratory comparison. The aluminum "hot block" technique may be used outside the laboratory [5]. Other mounting techniques meeting the above criteria may also be used (e.g., the laboratory fume hood procedure for generating acetone vapor as described in Method 7400 - revision of 5/15/85, or the non-permanent field mounting technique used in P&CAM 239 [2,4,8,22]). A videotape of the mounting procedure is available from the NIOSH Publication Office [20].

7. Ensure that the glass slides and cover slips are free of dust and fibers.
8. Adjust the rheostat to heat the "hot block" to ca. 70 °C [5].
   NOTE: If the "hot block" is not used in a fume hood, it must rest on a ceramic plate and be isolated from any surface susceptible to heat damage.

9. Mount a wedge cut from the sample filter on a clean glass slide.
   a. Cut wedges of ca. 25% of the filter area with a curved-blade steel surgical knife using a rocking motion to prevent tearing. Place wedge, dust side up, on slide.
      NOTE: Static electricity will usually keep the wedge on the slide.
   b. Insert slide with wedge into the receiving slot at base of "hot block". Place tip of a micropipet containing ca. 250 µL acetone into the inlet port of the PTFE cap on top of the "hot block". Inject the acetone into the vaporization chamber with a slow, steady pressure on the plunger button while holding pipet firmly in place. After waiting 3 to 5 sec for the filter to clear, remove pipet and slide from their ports.
      CAUTION: Although the volume of acetone used is small, use safety precautions. Work in a well-ventilated area (e.g., laboratory fume hood). Take care not to ignite the acetone. Continuous, frequent use of this device in an unventilated space may produce explosive acetone vapor concentrations.
   c. Using the 5-µL micropipet, immediately place 3.0 to 3.5 µL triacetin on the wedge. Gently lower a clean cover slip onto the wedge at a slight angle to reduce bubble formation.
      NOTE: If too many bubbles form or the amount of triacetin is insufficient, the cover slip may become detached within a few hours. If excessive triacetin remains at the edge of the filter under the cover slip, fiber migration may occur.
   d. Glue the edges of the cover slip to the slide using lacquer or nail polish [10] Counting may proceed immediately after clearing and mounting are completed.
      NOTE: If clearing is slow, warm the slide on a hotplate (surface temperature 50 °C) for up to 15 min to hasten clearing. Heat carefully to prevent gas bubble formation.

CALIBRATION AND QUALITY CONTROL:

10. Microscope adjustments. Follow the manufacturers instructions. At least once daily use the telescope ocular supplied by the manufacturer to ensure that the phase rings (annular diaphragm and phase-shifting elements) are concentric. With each microscope, keep a logbook in which to record the dates of microscope cleanings, adjustments, and calibrations.
   a. Each time a sample is examined, do the following:
      (1) Adjust the light source for even illumination across the field of view at the condenser iris. With some microscopes, the illumination may have to be set up with bright field optics rather than phase contract optics.
          NOTE: Use Köhler illumination if available.
      (2) Focus on the particulate material to be examined.
      (3) Make sure that the field iris is in focus, centered on the sample, and open only enough to fully illuminate the field of view.
   b. Check the phase-shift detection limit of the microscope periodically for each analyst/microscope combination:
      (1) Center the HSE/NPL phase-contrast test slide under the phase objective.
      (2) Bring the blocks of grooved lines into focus in the graticule area.
          NOTE: The slide contains seven blocks of grooves (ca. 20 grooves per block) in descending order of visibility. For asbestos counting the microscope optics must completely resolve the grooved lines in block 3 although they may appear somewhat faint, and the grooved lines in blocks 6 and 7 must be invisible when observing them in the center of the graticule area. Blocks 4 and 5 must be at least partially visible but may vary slightly in visibility between microscopes. A microscope which fails to meet these requirements has resolution either too low or too high for fiber counting.
      (3) If image quality deteriorates, clean the microscope optics. If the problem persists, consult the microscope manufacturer.

11. Document the laboratory's precision for each counter for replicate fiber counts.
    a. Maintain as part of the laboratory quality assurance program a set of reference slides to be used on a daily basis. These slides should consist of filter preparations including a range of loadings and background dust levels from a variety of sources including both field and PAT samples. The Quality Assurance Officer should maintain custody of the reference slides and should supply each counter with a minimum of one reference slide per workday. Change the labels on the reference slides periodically so that the counter does not become familiar with the samples.
    b. From blind repeat counts on reference slides, estimate the laboratory intra- and intercounter s_r (see step 21). Obtain separate values of relative standard deviation for each sample matrix analyzed in each of the following ranges: 5 to 20 fibers in 100 graticule fields, 21 to 50 fibers in 100 graticule fields, 51 to 100 fibers in 100 graticule fields, and 100 fibers in less than 100 graticule fields. Maintain control charts for each of these data files.
       NOTE 1: Since fiber counting is the measurement of randomly placed fibers which may be described by a Poisson distribution, a square root transformation of the fiber count data will result in approximately normally distributed data.
       NOTE 2: Certain sample matrices (e.g., asbestos cement) have been shown to give poor precision [6]
12. Prepare and count field blanks along with the field samples. Report counts on each field blank.
    NOTE 1: The identity of blank filters should be unknown to the counter until all counts have been completed.
    NOTE 2: If a field blank yields greater than 7 fibers per 100 graticule fields, report possible contamination of the samples.
13. Perform blind recounts by the same counter on 10% of filters counted (slides relabeled by a person other than the counter). Use the following test to determine whether a pair of counts by the same counter on the same filter should be rejected because of possible bias: Discard the sample if the difference between the two counts exceeds $2.77\ (X)s_r$, where X = average of the two fiber counts and s_r = intracounter relative standard deviation from step 11.
    NOTE: If a pair of counts is rejected by this test, recount the remaining samples in the set and test the new counts against the first counts. Discard all rejected paired counts. It is not necessary to use this statistic on blank counts.
14. Enroll each new counter in a training course which compares performance of counters on a variety of samples using this procedure.
    NOTE: All laboratories engaged in asbestos counting should participate in a proficiency testing program such as the AIHA-NIOSH Proficiency Analytical Testing (PAT) Program and routinely exchange field samples with other laboratories to compare performance of counters.

MEASUREMENT:

15. Center the slide on the stage of the calibrated microscope under the objective lens. Focus the microscope on the plane of the filter.
16. Adjust the microscope (Step 10) [7].
    NOTE: Calibration with the HSE/NPL test slide determines the minimum detectable fiber diameter (ca. 0.25 μm).
17. Select one of the following sets of counting rules:
    NOTE: The two sets of rules have produced approximately equivalent mean counts on a variety of asbestos sample types [6]. OSHA regulations require the use of the A rules [1]. In either case, the rules must be strictly followed to obtain valid results. No hybridizing of the two sets of rules is permitted.

a. A Rules (same as P&CAM 239 rules [2,4,8]; see APPENDIX B).
   1. Count only fibers longer than 5 µm. Measure length of curved fibers along the curve.
   2. Count only fibers with a length-to-width ratio equal to or greater than 3:1.
   3. For fibers which cross the boundary of the graticule field:
      a. Count any fiber longer than 5 µm which lies entirely within the graticule area.
      b. Count as 1/2 fiber any fiber with only one end lying within the graticule area, provided that the fiber meets the criteria of rules a.1. and a.2.
      c. Do not count any fiber which crosses the graticule boundary more than once.
      d. Reject and do not count all other fibers.
   4. Count bundles of fibers as one fiber unless individual fibers can be identified by observing both ends of a fiber.
   5. Count enough graticule fields to yield 100 fibers. Count a minimum of 20 fields. Stop at 100 graticule fields regardless of count.

b. B Rules (see APPENDIX B)
   1. Count only ends of fibers. Each fiber must be longer than 5 µm and less than 3 µm diameter.
   2. Count only ends of fibers with a length-to-width ratio equal to or greater than 5:1.
   3. Count each fiber end which falls within the graticule area as one end, provided that the fiber meets rules b.1 and b.2. Add split ends to the count as appropriate if the split fiber segment also meets the criteria of rules b.1 and b.2.
   4. Count visibly free ends which meet rules b.1 and b.2 when the fiber appears to be attached to another particle, regardless of the size of the other particle. Count the end of a fiber obscured by another particle if the particle covering the fiber end is less than 3 µm in diameter.
   5. Count free ends of fibers emanating from large clumps and bundles up to a maximum of 10 ends (5 fibers), provided that each segment meets rules b.1 and b.2.
   6. Count enough graticule fields to yield 200 ends. Count a minimum of 20 graticule fields. Stop at 100 graticule fields, regardless of count.
   7. Divide total end count by 2 to yield fiber count.

18. Start counting from the tip of the filter and progress along a radial line to the outer edge. Shift up or down on the filter, and continue in the reverse direction. Select graticule fields randomly by looking away from the eyepiece briefly while advancing the mechanical stage. Ensure that, as a minimum, each analysis covers one radial line from the filter center to the outer edge of the filter. When an agglomerate covers ca. 1/6 or more of the graticule field, reject the graticule field and select another. Do not report rejected graticule fields in the total number counted.

NOTE 1: When counting a graticule field, continuously scan a range of focal planes by moving the fine focus knob to detect very fine fibers which have become embedded in the filter. The small-diameter fibers will be very faint but are an important contribution to the total count. A minimum counting time of 15 seconds per field is appropriate for accurate counting.

NOTE 2: This method does not allow for differentiation of fibers based on morphology. Although some experienced counters are capable of selectively counting only fibers which appear to be asbestiform, there is presently no accepted method for ensuring uniformity of judgment between laboratories. It is, therefore, incumbent upon all laboratories using this method to report total fiber counts. If serious contamination from non-asbestos fibers occurs in samples, other techniques such as transmission electron microscopy must be used to identify the asbestos fiber fraction present in the sample (see NIOSH Method 7402). In some cases (i.e., for fibers with diameters > 1 µm), polarized light microscopy (e.g., NIOSH Method 7403) may be used to identify and eliminate interfering non-crystalline fibers.

CALCULATIONS AND REPORTING OF RESULTS:

19. Calculate and report fiber density on the filter, E (fibers/mm^2), by dividing the total fiber count per graticule field, F/n_f, minus the mean field blank count per graticule field, B/n_b, by the graticule field area, A_f (0.00785 mm^2 for a properly calibrated Walton-Beckett graticule):

$$E = \frac{(\frac{F}{n_f} - \frac{B}{n_b})}{A_f}, \text{ fibers/mm}^2.$$

NOTE: Fiber counts above 1300 fibers/mm^2 and fiber counts from samples with > 50% of filter area covered with particulate should be reported as "uncountable" or "probably biased."

20. Calculate and report the concentration, C (fibers/mL), of fibers in the air volume sampled, V (L), using the effective collection area of the filter, A_c (385 mm^2 for a 25-mm filter):

$$C = \frac{(E)(A_c)}{V \cdot 10^3}.$$

NOTE: Periodically check and adjust the value of A_c, if necessary.

21. Report intralaboratory and interlaboratory relative standard deviations (from Step 11) with each set of results.

NOTE: Precision depends on the total number of fibers counted [4,11]. Relative standard deviation (also called coefficient of variation) is documented in references [4,11,12,13] for fiber counts up to 100 fibers in 100 graticule fields. Comparability of interlaboratory results is discussed below. As a first approximation, use 213% above and 49% below the count as the upper and lower confidence limits for fiber counts greater than 20 (Fig. 1).

EVALUATION OF METHOD:

A. This method is a revision of P&CAM 239 [2,4,8]. A summary of the revisions is as follows:
   1. Sampling:
      The change from a 37-mm to a 25-mm filter improves sensitivity for similar air volumes. The change in flow rates allows for 2-m^3 full-shift samples to be taken, providing that the filter is not overloaded with non-fibrous particulates. The collection efficiency of the sampler is not a function of flow rate in the range 0.5 to 16 L/min [9].
   2. Sample Preparation Technique:
      The acetone vapor-triacetin preparation technique is a faster, more permanent mounting technique than the dimethyl phthalate/diethyl oxalate method of P&CAM 239 [2,4,5,8,14]. The aluminum "hot block" technique minimizes the amount of acetone needed to prepare each sample.
   3. Measurement:
      a. The Walton-Beckett graticule standardizes the area observed [14,15].
      b. The HSE/NPL test slide standardizes microscope optics for sensitivity to fiber diameter [7,14].

c. An international collaborative study involved 16 laboratories using prepared slides from the asbestos cement, milling, mining, textile, and friction material industries [6]. The modified CRS (NIOSH B) Rules were found to yield equivalent counts but were more precise than the AIA (NIOSH A)* Rules. The relative standard deviations (s_r) varied with sample type and laboratory. The ranges were:

	s_r		
	Intralaboratory	Interlaboratory	Overall
AIA (NIOSH A Rules)*	0.12 to 0.40	0.27 to 0.85	0.46
Modified CRS (NIOSH B Rules)	0.11 to 0.29	0.20 to 0.35	0.25

*Under AIA rules, only fibers having a diameter less than 3 μm are counted and fibers attached to particles larger than 3 μm are not counted. NIOSH A Rules are otherwise similar to the AIA rules.

d. The B Rules have also been favorably received by analysts as less ambiguous and simpler to use; these rules also showed the least bias relative to AIA rules in the collaborative study. An independent NIOSH laboratory study using amosite fibers reported a relative standard deviation, including within- and between-sample variability, of 0.16 for the B Rules [16]. Another NIOSH study was conducted using field samples of asbestos [19]. This study indicated intralaboratory s_r in the range 0.17 to 0.25 and an interlaboratory s_r of 0.45. This agrees well with other recent studies [6,11,13].

e. Because of past inaccuracies associated with low fiber counts, the minimum recommended loading has been increased to 100 fibers/mm^2 filter area (80 fibers total count). This level should yield intracounter s_r in the range of 0.13 to 0.17 [4,8,16,19].

B. Interlaboratory Comparability:

At this time, there is no independent method for assessing the overall accuracy of this method. One measure of reliability is to estimate how well the count for a single sample agrees with the mean count from a large number of laboratories. The following discussion indicates how this estimation can be carried out based on measurements of the interlaboratory variability, as well as showing how the results of this method relate to the theoretically attainable counting precision and to measured intra- and interlaboratory s_r.

Theoretically, the process of counting randomly (Poisson) distributed fibers on a filter surface will give an s_r that depends on the number, N, of fibers counted:

$$s_r = 1/(N)^{1/2} \qquad (1)$$

Thus s_r is 0.1 for 100 fibers and 0.32 for 10 fibers counted. The actual s_r found in a number of studies is greater than these theoretical numbers [6,11,12,13].

An additional component of variability comes primarily from subjective laboratory-to-laboratory differences. In a study of ten counters in a continuing sample exchange program, Ogden [11] found this subjective component of intralaboratory s_r to be approximately 0.2 and estimated the overall s_r by the term:

$$\frac{(N + (0.2 \cdot N)^2)^{1/2}}{N} \qquad (2)$$

Ogden found that the 90% confidence interval of the individual intralaboratory counts in relation to the means were +2 s_r and - 1.5 s_r. In this program, one sample out of ten was a quality control sample. For laboratories not engaged in an intensive quality assurance program, the subjective component of variability can be higher.

In a study of field sample results in 46 laboratories, the Asbestos Information Association [13] also found that the variability had both a constant component and one that depended on the fiber count. These results gave a subjective interlaboratory component of s_r (on the same basis as Ogden's) for field samples of ca. 0.45. A similar value was obtained for 12 laboratories analyzing a set of 24 field samples [19]. This value falls slightly above the range of s_r (0.25 to 0.42 for 1984-85) found for 80 reference laboratories in the NIOSH Proficiency Analytical Testing (PAT) program for laboratory-generated samples [12].

A number of factors influence s_r for a given laboratory, such as that laboratory's actual counting performance and the type of samples being analyzed. In the absence of other information, such as from an interlaboratory quality assurance program using field samples, the value for the subjective component of variability is chosen as 0.45. Note that, though based on at least two studies, this is a somewhat arbitrary choice. It is hoped that by the use of this number in the absence of other information, laboratories will carry out the recommended interlaboratory quality assurance programs to improve their performance and thus reduce the s_r.

The above relative standard deviations apply when the population mean has been determined. It is more useful, however, for laboratories to estimate the 90% confidence interval on the mean count from a single sample fiber count (Figure 1). These curves assume similar shapes of the count distribution for interlaboratory and intralaboratory results [11].

For example, if a sample yields a count of 24 fibers, Figure 1 indicates that the mean interlaboratory count will fall within the range of 227% above and 52% below that value 90% of the time. We can apply these percentages directly to the air concentrations as well. If, for instance, this sample (24 fibers counted) represented a 500-L volume, then the measured concentration is 0.02 fibers/mL (assuming 100 fields counted, 25-mm filter, 0.00785 mm^2 counting field area). If this same sample were counted by a group of laboratories, there is a 90% probability that the mean would fall between 0.01 and 0.08 fiber/mL. These limits should be reported in any comparison of results between laboratories.

Note that the s_r of 0.45 used to derive Figure 1 is used as an estimate for a random group of laboratories. If several laboratories belonging to a quality assurance group can show that their interlaboratory s_r is smaller, then it is more correct to use that smaller s_r. However, the estimated s_r of 0.45 is to be used in the absence of such information. Note also that it has been found that s_r can be higher for certain types of samples, such as asbestos cement.

Quite often the estimated airborne concentration from an asbestos analysis is used to compare to a regulatory standard. For instance, if one is trying to show compliance with an 0.5 fiber/mL standard using a single sample on which 100 fibers have been counted, then Figure 1 indicates that the 0.5 fiber/mL standard must be 213% higher than the measured air concentration. This indicates that if one measures a fiber concentration of 0.16 fiber/mL (100 fibers counted), then the mean fiber count by a group of laboratories (of which the compliance laboratory might be one) has a 95% chance of being less than 0.5 fibers/mL; i.e., 0.16 + 2.13 x 0.16 = 0.5.

It can be seen from Figure 1 that the Poisson component of the variability is not very important unless the number of fibers counted is small. Therefore, a further approximation is to simply use +213% and -49% as the upper and lower confidence values of the mean for a 100-fiber count.

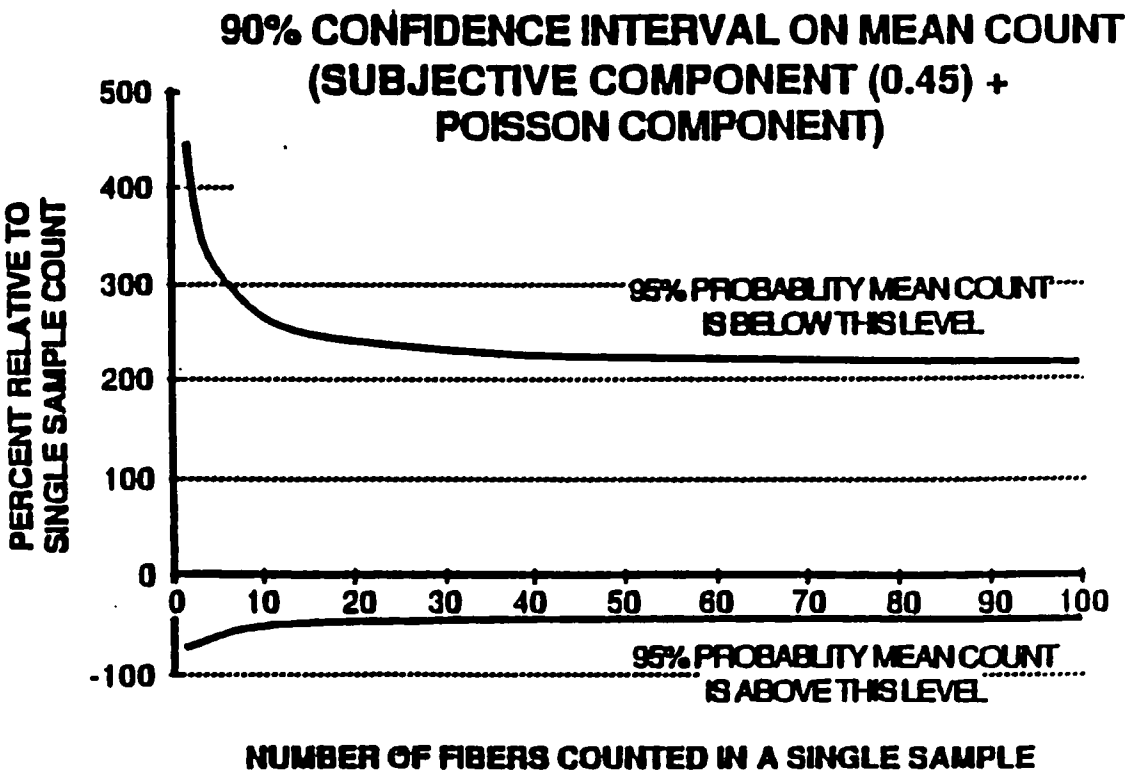

Figure 1. Interlaboratory Precision of Fiber Counts

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APPENDIX A: CALIBRATION OF THE WALTON-BECKETT GRATICULE:

Before ordering the Walton-Beckett graticule, the following calibration must be done to obtain a counting area (D) 100 µm in diameter at the image plane. The diameter, d_c (mm), of the circular counting area and the disc diameter must be specified when ordering the graticule.

1. Insert any available graticule into the eyepiece and focus so that the graticule lines are sharp and clear.
2. Set the appropriate interpupillary distance and, if applicable, reset the binocular head adjustment so that the magnification remains constant.

3. Install the 40 to 45X phase objective.
4. Place a stage micrometer on the microscope object stage and focus the microscope on the graduated lines.
5. Measure the magnified grid length of the graticule, L_o (µm), using the stage micrometer.
6. Remove the graticule from the microscope and measure its actual grid length, L_a (mm). This can best be accomplished by using a stage fitted with verniers.
7. Calculate the circle diameter, d_c (mm), for the Walton-Beckett graticule:

$$d_c = \frac{L_a}{L_o} \times D.$$

Example: If L_o = 112 µm, L_a = 4.5 mm and D = 100 µm, then d_c = 4.02 mm.

8. Check the field diameter, D (acceptable range 100 µm ± 2 µm) with a stage micrometer upon receipt of the graticule from the manufacturer. Determine field area (acceptable range 0.00785 mm² ± 0.00032 mm²).

APPENDIX B: COMPARISON OF COUNTING RULES:

Figure 2 shows a Walton-Beckett graticule as seen through the microscope. Although the graticule incorporates the 3:1 aspect ratio, both the "A" and "B" rules will be discussed as they apply to the labeled fibers in the figure.

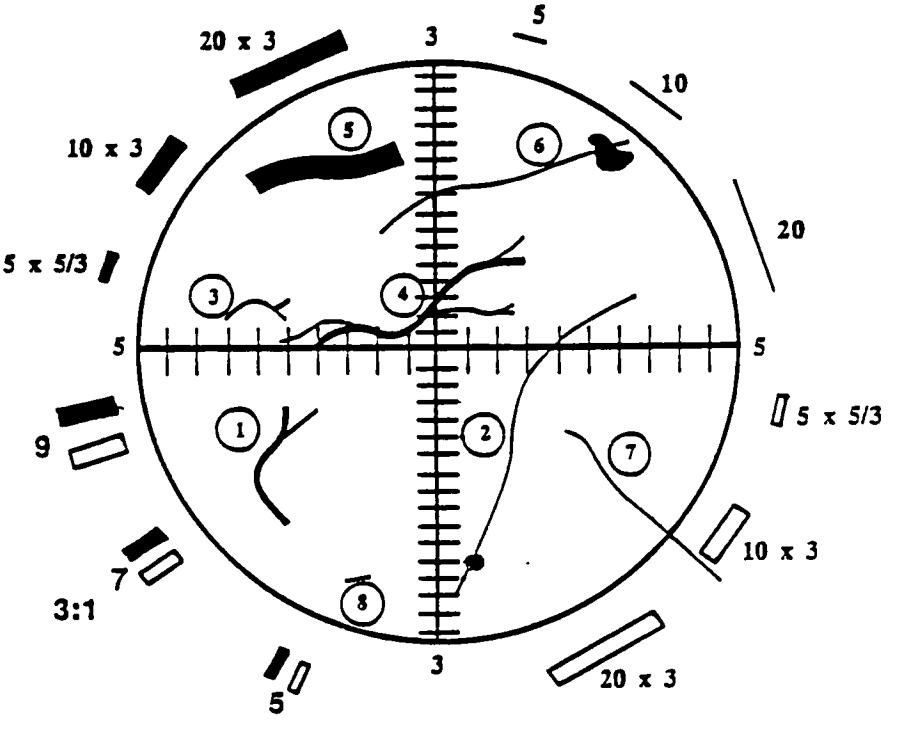

Figure 2. Walton-Beckett graticule with fibers.

Fiber	FIBER COUNT A Rules	FIBER COUNT B Rules	DISCUSSION
1	1 fiber	3 ends	(A)"A" rules do not allow for split ends; therefore, count one fiber. (B) Under 'B' rules, first detemine whether the fiber meets dimensional criteria, (i.e., >5 µm, >5:1 aspect ratio, <3 µm diameter). Next determine and count which two ends are the main trunk of the fiber. Finally, count all split ends >5 µm as one end. Fiber #1 is counted as 3 ends.
2	1 fiber	2 ends	(A) Single fiber with small particle attached. The particle is treated as if it does not exist by the "A" rules. (B) The particle is <3 µm diameter and therefore ignored under "B" rules.
3	1 fiber	2 ends	(A) As with Fiber 1, count one fiber under "A" rules because it meets the >3:1 aspect ratio, >5 µm criteria. (B) The split end is <5 µm long so it is not counted under "B" rules.
4	1 fiber	5 ends	(A) Fiber ends all attached to a central large fiber or bundle; therefore, count one fiber under "A" rules. (B) Count two ends as belonging to the main fiber. Three of the remaining four split ends are >5 µm, giving a total of 5 ends.
5	1 fiber	Do not count	(A) No diameter limit under "A" rules; therefore count this thick fiber because it meets the >3:1, >5 µm counting criteria. (B) The fiber is >3 µm diameter; therefore not counted under "B" rules.
6	1 fiber	1 end	(A) Ignore non-fibrous particulate matter under the "A" rules; count this as a whole fiber. (B) The short end of the fiber is <5 µm long and obscured by a particle >3 µm in diameter; therefore, not counted under "B" rules.
7	1/2 fiber	1 end	(A) Fibers which meet rules a.1. and a.2. and cross the graticule boundary are counted as 1/2 fiber under "A" rules unless the fiber crosses the graticule boundary more than once, in which case the fiber is not counted no matter how many ends lie within the graticule area. (B) Fiber ends lying inside the graticule boundary are counted as one end provided that the entire fiber meets rules b.1. and b.2. and each end is >5 µm. The portion of the fiber lying outside the graticule boundary must be considered in order to make this determination. Under "B" rules, it does not matter how often the fiber crosses the graticule boundary.
8	Do not count	Do not count	The fiber is <5 µm long.