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COMPARISON TESTING MONITORING FOR AIRBORNE ASBESTOS FIBERS: SHEET VINYL FLOOR COVERING WET VERSUS DRY SCRAPING

PLAINTIFF'S EXHIBIT

CON-26

Final Report

November 1979

By: Richard Walcott, Industrial Hygienist
James Warrick, Industrial Hygienist

Prepared for:

Resilient Floor Covering Institute
1030 15th St. N.W.
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Washington, D.C. 20005

SRI Project 7988

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SRI International

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SRI International

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STATEMENT OF OBJECTIVE

The principal objective of this study was to monitor for airborne asbestos fibers, if any, that were generated during the complete removal of sheet vinyl floor covering when different methods of removal (wet versus dry scraping) were used. The effect of using different length handles on the scraping instrument was also measured.

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I. INTRODUCTION

Sheet vinyl floor coverings are widely used in many residential, institutional, and commercial locations. Asbestos is used as a constituent in the felt backing of many sheet vinyl floor coverings, but there is no asbestos in the various types of top or wear layers. Attention has recently been centered on the health effects resulting from certain exposures to asbestos. SRI was retained to measure whether or not airborne asbestos fibers were produced under certain conditions of sheet vinyl floor covering removal.

RFCI recommends that the felt backing of the sheet vinyl be removed from the subflooring by a method known as "wet scraping" (See Attachment "A"). Wet scraping is essentially a wetting of the felt remaining after the wear layer has been removed and a careful scraping of the moistened felt by a suitable instrument (wide-bladed putty knife). In the past, dry scraping, that is the scraping of the felt without prior wetting, has been done. In this test both methods were used and the asbestos fibers collected and counted. RFCI Recommended Work Practices strongly advise against sanding an existing floor or sweeping, dry-scraping or sanding residual felt.

II. TEST SITE LOCATION

The site for these evaluations was a six-year-old home located in a suburban Maryland community. The attic insulation material in this home was, according to the occupant, a pink fiber-glass material. This could not be confirmed since access to the attic was not feasible. The heating system in this house was forced-air ventilation, and the air was filtered by the furnace unit. This operation was performed in the kitchen of the home. The total floor surface area was approximately 350 square feet. The tests were done in the Spring (March 15 and 16) of 1979. A diagram of the test site is included as Figure 1, page 3.

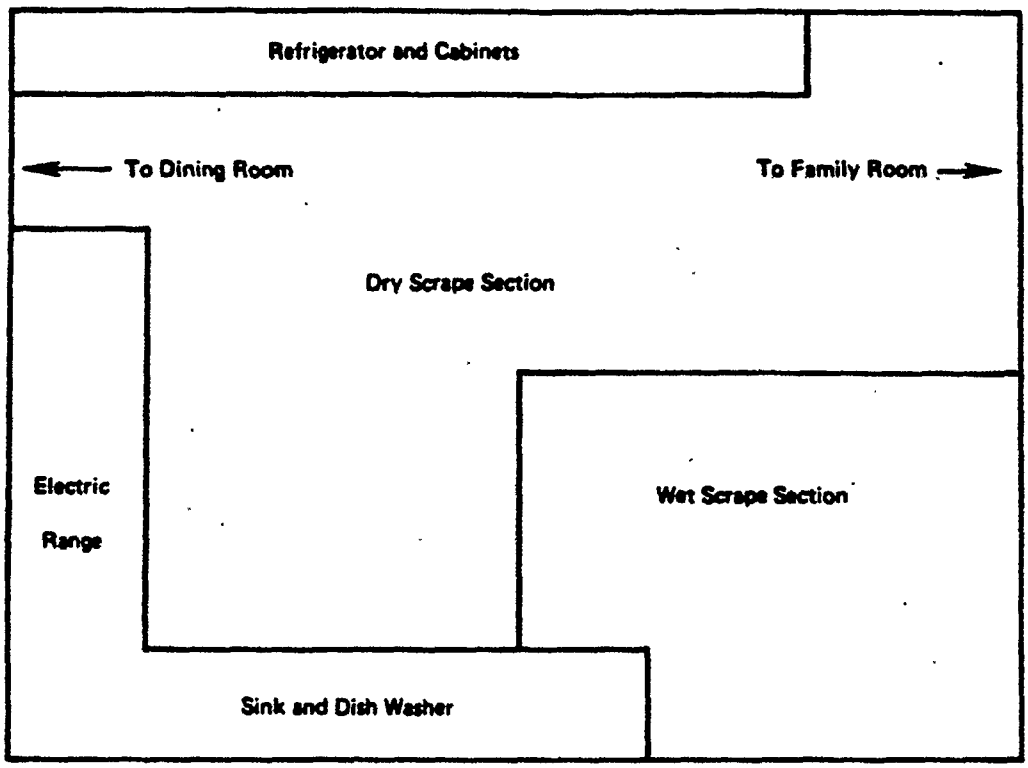

Figure 1 SITE PLAN

III. METHODOLOGY

1. Complete Removal

The operations were not done according to RFCI Recommended Work Practices (see Attachment "A") in that dry scraping was also done.

2. Determination of Airborne Asbestos Fibers

The NIOSH method for determining asbestos fibers in the air was employed (See Attachment "B", NIOSH Method No. P&CAM 239, "Asbestos Fibers in Air").

IV. SUMMARY OF RESULTS

The following Table lists the TWA concentrations of airborne asbestos fibers measured at the test site for the specified operations. TWA concentrations are stated assuming a full-day exposure to the conditions that existed during the test period.

NOTE: The OSHA Standard for a safe workplace allows a concentration of 2 fibers per cc of air on an 8-hour time-weighted average (TWA).

Table No. 1

Operation	8 Hr. TWA (Asbestos Fibers/cc)	
	Mechanic 1	Mechanic 2
Wear Layer Removal	0.1637	0.0844
Wet Scrape	0.4093	NA
Dry Scrape	2.0248	1.1207
Dry Scrape	0.8279	1.0583

V. CONCLUSIONS

Deviation from the recommended RFCI work practice (wet scraping) resulted in a two to five-fold increase in asbestos exposure. These data reinforce the need to follow the recommended practice of wetting the felt backing prior to scraping. Dry scraping should never be done.

VI. COMPLETE REMOVAL

Discussion

An existing sheet vinyl floor covering was removed by using both wet and dry scraping. First the wear layer was removed according to standard practice and part of the floor was dry scraped and the rest was wet scraped. A water-detergent solution was used for wetting the felt. Two different length handles were also used in the scraping: Mechanic 1 used a regular handle on a stiff bladed putty knife while Mechanic 2 used a handle of 3-4 feet.

Sampling Procedure:

The sampling protocol was designed to:

1. Evaluate the background asbestos levels in the home and outside ambient air. This was accomplished using area samples taken several days before the test sampling.

2. Determine any increase above background concentrations of asbestos fibers. Personal samples were taken for each worker during the operation. Separate filters were used for each phase of the operation. Dry scraping was done in two phases so there are two samples for each worker for dry scraping.

See Figure 1, page 3, for a diagram of the sampling area.

Sampling Results:

The results of the individual-filter analyses are shown below in Table 2.

Table 2

Description	Filter No.	Air Vol. (liters)	Time (min)	Fibers/ sq. mm*	Total Fibers/cc	Asbestos** Fibers/cc	8-Hr. TWA
Background Samples							
Outside	AB-9	760	380	0	0	0	
Outside	C-1089	766	383	0	0	0	
Kitchen	XX009	748	374	0	0	0	
Wear Layer Removal							
Mechanic 1	AB-12	150	75	39	0.218	0.1637	0.1637
Mechanic 2	AB-2	140	70	14	0.0844	0.0844	0.0844
Wet Scrape							
Mechanic 1	AB-14	110	55	96	0.4837	0.4093	0.4093
Dry Scrape							
Mechanic 1	AB-13	126	63	327	2.168	2.0248	2.0248
Mechanic 1	AB-11	80	40	96	1.0035	0.8279	0.8279
Mechanic 2	AB-10	126	63	191	1.2669	1.1207	1.1207
Mechanic 2	AB-15	90	45	121	1.1259	1.0583	1.0583

*Fibers/sq mm of total filter surface area.
**Analyst estimated that about 90% of the fibers were asbestos.

Evaluation

The background samples obtained prior to and on the day of the test showed no asbestos fibers. Asbestos fiber concentrations found during the wear-layer removal were very low (0.1637 and 0.0844 fibers/cc). As sometimes happens when the wear layer is removed, a good deal of the felt was separated from the subfloor and removed with the wear layer. The strips of wear layer were rolled and placed in trash bags for disposal. The higher concentration was from the worker who bagged the material.

Wet scraping, which took 55 minutes, resulted in a concentration of 0.4093 fibers/cc. Dry scraping samples, however, showed concentrations ranging from 0.8279 to 2.0248 fibers/cc. Dry scraping was done with two different-length handles. The results from the worker using the longer handle (1.1207 and 1.0583) are, on the average, a good deal lower than the results from the worker using the short handle (2.0248 and 0.8279). The longer handle does provide, as would be expected, some protection from the asbestos concentration.

Conclusion

The contrast between the asbestos fiber concentration values found following wet versus dry scraping clearly indicates the need and desirability of following the recommended RFCI work practice of wet scraping. The comparison between long and short handles, while not showing as great a difference as that between wet and dry scraping, shows that longer handles are also more desirable if they can be practically used.

ATTACHMENT A

RECOMMENDED WORK PRACTICES

FOR RESILIENT FLOOR COVERINGS

REVISED 10/31/79

Pre-Publication Copy

RECOMMENDED
WORK PRACTICES
FOR
RESILIENT FLOOR COVERINGS

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IMPORTANT INFORMATION FOR INSTALLERS OF RESILIENT FLOOR COVERINGS

Introduction

The member companies of the RESILIENT FLOOR COVERING INSTITUTE are manufacturers of the following forms of resilient floor coverings which may contain some asbestos:

1. Sheet Vinyl
2. Vinyl Asbestos Tile
3. Asphalt Tile

Why Asbestos in Resilient Floor Coverings?

Asbestos fibers have been used in the manufacture of resilient floor covering products for more than 50 years. Asbestos fibers are used to provide durability to tile products. In addition, asbestos fibers in sheet vinyl backings permit these products to be installed on all grade levels. The presence of "locked-in" asbestos fibers in resilient floor coverings provide the versatility and economy for which they have been noted throughout the years.

What about Asbestos?

It has been determined that inhalation of free airborne asbestos fibers may be injurious to health. However, the asbestos fibers contained in the above types of resilient floor coverings are not free, but firmly encapsulated or locked-in the product during the manufacturing process. Asbestos contained therein will not become airborne during the lifetime of the product when these products are used and maintained as recommended by the manufacturer*.

*See "Monitoring for Airborne Asbestos Fibers: Vinyl Asbestos Floor Tile" and "Monitoring for Airborne Asbestos Fibers: Sheet Vinyl Floor Covering," report prepared by SRI International, 1978-79. (Available on request from the Resilient Floor Covering Institute, 1030 15th Street, NW - Suite 350, Washington, DC 20005).

It is essential that certain precautions be observed, however, when installing a resilient floor covering or when preparing or removing an existing resilient floor covering. It is the purpose of this Work Practices Manual to provide those precautionary steps necessary to assure the safest way to accomplish the work involved.

PREPARATION OF FLOORS WITH EXISTING RESILIENT FLOOR COVERINGS TO RECEIVE NEW RESILIENT FLOOR COVERINGS

Follow the installation instructions published by the manufacturer of the new floor covering when a new resilient sheet or tile floor covering is to be installed on a surface presently covered with a resilient floor covering. These instructions will tell you what must be done to the existing surface before the new resilient floor covering can be installed.

Of the four general procedures listed below, Items 1 and 2 are covered by manufacturers' instructions; Item 3 and 4 are covered specifically in this Work Practices Manual*:

Resilient Floor Covering Installed Over .....

1. The Existing Surface. Follow the manufacturer's instructions for removing wax, filling in low spots, etc. Use wet scrubbing. Never sand an existing resilient floor covering.
2. New Underlayment. Nail panels on top of the existing surface (wood subfloors only) and apply new floor covering directly over this. Follow the manufacturer's instructions.

*In case of minor variations, the manufacturer's instructions should be followed.

(SKETCHES - one for item 1 & 2 above)

3. Partially Removed Existing Adhered Sheet Vinyl Flooring Covering. See instructions below under heading "Partial Removal of Existing Adhered Sheet Vinyl Floor Covering," page 6.

4. Completely Removed Existing Resilient Floor Covering

   (a) Sheet Vinyl -- See instructions below:

      1. "Complete Removal of an Unadhered (Loose-Lay) or Peripherally Adhered Sheet Vinyl Floor Covering," page 5.

      2. "Complete Removal of an Existing Adhered Sheet Vinyl Floor Covering," page 8.

   (b) Tile -- See instructions under heading "Complete Removal of an Existing Resilient Tile Floor Covering," page 11.

SHEET VINYL FLOOR COVERING

Preparation of Floors with Existing Sheet Vinyl Floor Covering To Receive A New Resilient Floor Covering.

Sheet vinyl floor covering is installed in several ways:

1. Un-adhered or Loose-Lay.
2. Adhered or Cemented.
3. Peripherally adhered.

Some resilient floor covering can be installed over existing resilient sheet vinyl floor covering under certain conditions. Be sure to follow the floor covering manufacturer's instructions, regarding the conditions and floor preparation required.

If partial or complete removal of the existing sheet vinyl floor covering is required, the following instructions are to be followed:

SUPPLIES AND TOOLS

1. Broad, stiff-bladed wall scraper, or floor scraper.
2. Utility or hook knife.
3. Tank type vacuum cleaner with disposable dust bag and metal floor tool (no brush).

4. Large size heavy duty trash bags with ties, tapes, or string to tie shut, and tags for labeling.

5. Hand sprayer or sprinkling can.

6. Liquid dishwashing detergent or liquid wallpaper remover mixed with water to make a dilute solution (1 oz. liquid in one gallon of water).

SPECIAL PRECAUTIONS

1. Never sweep.

2. Never dry scrape adhered areas of floor covering.

3. Never sand an existing floor covering.

4. Never sand or dry scrape residual felt.

Complete Removal of an Un-adhered (Loose-Lay) or Peripherally Adhered Sheet Vinyl Floor Covering.

a. Remove any binding strips or other restrictive moldings from doorways, walls, etc.

b. Cut a strip the length of the floor and about 18" wide along one wall. Remove this strip, gently turn it over and roll face out into a tight roll. Tie or tape securely so it will not unroll. Place it in a heavy duty plastic bag, big enough to accomodate several rolls, for disposition.

c. Clean the exposed floor with a vacuum cleaner positioned so that exhaust air does not blow over the unclean area. DO NOT SWEEP.

d. Repeat the above, cutting, removing, rolling, disposing of one strip at a time and cleaning the newly exposed area immediately until the whole floor covering has been removed and the whole floor vacuumed clean.

e. If seams or door openings have been adhered with double faced tape, remove the tape and place in the plastic trash bag.

(SKETCHES-(1) after item 6, depicting all supplies. (2) Under "b", roll face out in a tight roll. (3) Under "c", show vacuum cleaner exhaust and (4) under "Special Precautions," illustrate each item).

f. If any floor covering areas have been adhered with adhesive and remain stuck to the floor, they should be removed by the wet scraping method explained on page 7-f. DO NOT DRY SCRAPE OR SAND.

g. Carefully remove the dust bag from the cleaner and place it in the trash bag.

h. Close and seal the trash bags tightly for disposal. Identify contents with a label stating - "Caution - Contains Asbestos - Dispose in an approved land fill only."

i. Wash hands immediately before eating and at the end of the work day.

j. Install the new resilient floor covering according to the manufacturer's instructions.

Partial Removal of Existing Adhered Sheet Vinyl Floor Covering.

Most felt backed sheet floor coverings can be separated in the backing or felt layer. The felt left on the floor presents a smooth surface on which some new sheet floor coverings can be directly installed. Be sure to follow the manufacturer's instructions. Use the following procedure to partially remove the existing adhered floor covering.

REMINDER: NEVER SAND AN EXISTING FLOOR COVERING.

a. Remove any binding strips or other restrictive moldings from doorways walls, etc.

b. Make a series of parallel cuts 4 to 8 inches apart through the top layers and about halfway through the backing, parallel to the wall.

c. Start at the end of the room farthest from the entrance door and pry up the corner of a strip, separating the backing layer. Pull the top layer back upon itself slowly and evenly at the angle that permits the best separation, and half the backing and the top layers will pull free.

(SKETCHES: (1) Under "f", show wet scraping method. (2) Under "h", show bag sealing. (3) Under "c", show top layer pulled back.)

After it is removed, roll up the strip face out into a tight roll. Tie or tape securely and place in the heavy duty trash bag for disposal.

d. Each succeeding strip should be removed in the above manner. Avoid walking on the exposed felt as much as possible. Roll up each strip as it is is removed and place it in the trash bag. Close full bags tightly and seal securely for disposal. Identify with a label stating "Caution - contains asbestos. Dispose in an approved land fill only."

e. Occasionally, parts of the top layers will stick to the backing. This can often be eliminated by peeling from the opposite direction. The stiff bladed scraper will help in stubborn areas.

f. Any high spots of felt on the floor can be levelled by wet scraping.

REMINDER: NEVER SAND OR DRY SCRAPE RESIDUAL FELT

Wet scraping is done as follows:

1. Pour the detergent solution into the sprayer or sprinkling can.
2. Thoroughly wet the high felt spot with this solution. Wait a few minutes to allow the solution to soak into the felt.
3. Use the stiff bladed scraper to remove the excess felt. If felt dries out, or dry felt is exposed during scraping, re-wet with more solution.
4. Pick up the larger pieces by hand and place in the trash bag immediately. Wash your hands.

g. Non-adhered felt left on the floor can be cut open and re-adhered to the floor with adhesive.

h. If small areas of backing pull free from the floor, the depression should be filled with latex patching compound, as recommended by the floor covering manufacturer.

(SKETCHES: (1) Top of page, show tight roll tied. (2) Under "f-3, show wetted felt being scraped and (3) Under "h", show filling of depression).

i. Clean the floor with the vacuum cleaner using the metal floor tool. DO NOT SWEEP WITH A BROOM.

Position the vacuum cleaner so that discharge air does not blow on the felt. Carefully remove the dust bag from the cleaner immediately and place in the plastic trash bag.

j. Close and seal trash bags tightly for disposal. Identify contents with a label: "Caution -- contains asbestos. Dispose in an approved land fill only."

k. Do not walk over the felt unnecessarily, as this might scuff the felt and raise dust.

l. Install the new resilient floor covering immediately, following the manufacturer's instructions.

Complete Removal of an Existing Adhered Sheet Vinyl Floor Covering.

If complete removal is required, follow these instructions:

REMINDER: NEVER SAND AN EXISTING FLOOR COVERING

a. Remove any binding strips or other restrictive moldings from doorways, walls, etc.

b. Make a series of parallel cuts 4 to 8 inches apart and almost through the backing, parallel to a wall.

c. Start at the end of the room farthest from the entrance door, and pry up the corner of the first strip, separating the backing layer. Pull the top layer back upon itself slowly and evenly at an angle that permits the best separation and most of the backing and top layers will pull free.

Remove this strip, gently turn it over and roll face out into a tight roll. Tie or tape securely and place in the heavy duty trash bag for disposal.

(SKETCHES: Under "c", show separation of backing & top layers pulling free.)

d. Repeat the above on the next two strips but do not remove anymore than a total of three strips at this time.

e. Remove the felt remaining on the floor in the stripped area by wet scraping.

REMINDER: NEVER SAND OR DRY SCRAPE RESIDUAL FELT

Wet scraping is done as follows:

1. Pour the detergent solution into the sprayer or sprinkling can.
2. Thoroughly wet the residual felt with this solution. Wait a few minutes to allow the solution to soak into the felt.
3. Stand on the remaining floor covering (not the felt) and use the stiff bladed scraper to scrape up the wet felt.

REMINDER: DO NOT SCRAPE DRY FELT

Re-wet the felt if it dries out or if dry felt is exposed during scraping. Pick up the scrapings as they are removed from the floor and place in the plastic trash bag. Scrape all felt from this floor area before proceeding further.

4. Repeat the above on the next series of strips. Do only one three-strip area at a time. Stand on the remaining floor covering or clean floor (do not stand on the felt) to scrape up the felt.
5. Repeat this operation until the felt has been removed from the whole floor. Close full bags tightly, and seal securely for disposal. Identify with a label stating "Caution - Contains Asbestos. Dispose in an approved land fill only."

f. Wash your hands immediately before eating and at the end of the work day.

g. When the whole floor has been cleaned free of felt, let it dry and vacuum up any dirt using the vacuum cleaner with the metal floor tool.

REMINDER: DO NOT SWEEP.

(SKETCHES: Under "e-3", show standing on floor covering not felt to scrape.)

Position the vacuum cleaner so that the discharge air does not blow on the floor being cleaned.

h. Carefully remove the dust bag from the cleaner and place in the plastic trash bag for later disposal.

i. When the floor is dry, it is ready to have a new resilient floor covering installed. Follow the floor covering manufacturer's instructions.

RESILIENT TILE FLOOR COVERING

Preparation of Floors with Existing Resilient Tiles to Receive New Resilient Floor Covering.

Some resilient floor coverings can be installed over existing resilient tile installations. Follow the installation instructions published by the manufacturer of the new floor covering when a new resilient floor covering is to be installed on a surface presently covered with a resilient floor covering. These instructions will tell you what must be done to the existing surface before the new resilient floor covering can be installed.

CAUTION: Never Sand an Existing Tile Installation.

Complete Removal of Existing Resilient Tile Floor Covering.

SUPPLIES AND TOOLS

1. Heavy duty wall scraper with approximately 4" blade and 6" to 8" handle.
2. Hammer
3. Commercial type hand held hot air blower.
4. Heavy duty plastic trash bag(s), ties and labels.

a. Those areas normally exposed to heavy foot traffic patterns usually have tiles adhered the tightest. As a matter of good practice in starting the tile removal, those sections which receive least traffic should be the locations selected for starting the removal of the tile. Since tiles are normally in a 9" X 9" or 12" X 12" dimension, it should be the goal to remove individual tiles as a complete unit.

b. Start the removal by carefully wedging the wall scraper in the seam of two adjoining tiles and gradually forcing the edge of one of the tiles up and away from the floor. Do not break off pieces of the tile but continue to force the balance of the tile up by working the scraper beneath the tile and exerting both a forward pressure and a twisting action on the blade to promote release of the tile from the adhesive and the floor.

c. When the first tile is removed place it, without breaking it into smaller pieces, in the plastic bag which will be used for disposal.

(SKETCHES: After #4 under Supplies & Tools, show supply items. And under "b", show how tile is to be forced up.)

d. With the removal of the first tile accessibility of other tiles is improved. Force the wall scraper under the exposed edge of another tile and continue to exert a prying twisting force to the scraper as it is moved under the tile until the tile releases from the floor. Again, dispose of the tile, and succeeding tiles by placing in the plastic bag without additional breaking.

e. Some tiles will release quite easily while others require varying degrees of force. Where the adhesive is spread heavy or is quite hard, it may prove easier to force the scraper through the tightly adhered areas by striking the scraper handle with a hammer using blows of moderate force while maintaining the scraper at a 25° -30° angle to the floor.

f. If some areas are encountered where even the technique detailed in the previous paragraph proves to be inadequate, the removal procedure can be simplified by thoroughly heating the tile(s) with a hot air blower until the heat penetrates through the tile and softens the adhesive. NOTE: Handle the hot air blower carefully to avoid personal burns.

g. As small areas of subfloor are cleared of tile the adhesive remaining on the floor must be scraped up with the 4" hand scraper until only a thin, smooth film remains. In those areas where deposits are heavy or difficult to scrape the removal can be expedited by heating with the hot air blower prior to scraping. Deposit scrapings in a plastic trash bag.

h. Where the existing floor consists of a tile over tile installation it is recommended that removal be accomplished layer by layer in small areas instead of attempting to remove both layers simultaneously. Less tile breakage is encountered with single layer removal.

(SKETCHES: Under "e", "f", "g" and "h", use appropriate illustrations.)

i. As indicated in previous paragraphs, tiles should be placed immediately in a plastic trash bag. Do not attempt to break tiles after they are in the bag.

j. When all tiles have been removed from the floor and placed in plastic bags, seal the bags by any convenient means and mark: "Caution - Contains Asbestos - Dispose in an approved land fill only."

WARNING

DO NOT SAND EXISTING RESILIENT FLOORING, BACKING, OR LINING FELT. THESE PRODUCTS MAY CONTAIN ASBESTOS FIBERS THAT ARE NOT READILY IDENTIFIABLE. SANDING OF ASBESTOS CONTAINING MATERIAL CAN PLACE FINE PARTICLES OF ASBESTOS IN THE AIR. THESE ASBESTOS PARTICLES IF INHALED MAY CAUSE SERIOUS BODILY HARM.

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ATTACHMENT B

ASBESTOS FIBERS IN AIR

ASBESTOS FIBERS IN AIR

National Institute for Occupational Safety and Health

Analytical Method

Analyte:	Asbestos fibers	**Method No.:**	P&CAM 239
Matrix:	Air	**Range:**	0.1-60 fibers/cm^3
Procedure:	Filter collection, microscopic count	**Precision (CV_T):**	0.24 to 0.38
Date Issued:	3/30/77	**Classification:**	D (Operational)
Date Revised:			

1. Principle of the Method

1.1 This method describes the equipment and procedures for collecting, mounting, and counting asbestos fibers on cellulose ester membrane filters in the evaluation of personal samples of airborne asbestos fibers. The purpose of the method is to determine an employee's index of exposure to airborne asbestos fibers. The method is primarily a personal monitoring technique, but can be used for area monitoring.

1.2 The sample is collected by drawing air through a membrane filter by means of a battery powered personal sampling pump. The filter is transformed from an opaque solid membrane to a transparent optically homogeneous gel. The fibers are sized and counted using a phase-contrast microscope at 400-450X magnification.

1.3 Definitions. Asbestos fiber, for counting purposes, means a particulate which has a physical dimension longer than 5 micrometers and with a length to diameter ratio of 3 to 1 or greater. Asbestos includes chrysotile, cummingtonite-grunerite (amosite), crocidolite, fibrous tremolite, fibrous anthophyllite, and fibrous actinolite.

1.4 Any laboratory attempting to use this procedure should have at least one counter attend a training course conducted by an experienced, proficient laboratory. Novice, untutored counters, using only published instructions, can easily obtain counts of half those performed by experienced, proficient counters. Large differences between laboratories can be caused by: 1) differences in technique and observing ability among counters and 2) small, but significant, differences between microscopes meeting the basic specifications of Section 6.2. The following procedures are recommended:

1.4.1 All microscopists who perform asbestos counting should meet together for an "asbestos counting workshop" at least quarterly. This is best accomplished with counters from several laboratories using their own microscopes.

1.4.2 Each microscopist should count the same series of slides and with the results being compared.

1.4.3 Differences between counters should be resolved with side-by-side counting of the fields by the different counters.

1.4.4 Individuals who are found to be persistent outliers over several sessions should be encouraged to seek other tasks in their respective laboratories.

2. Range and Sensitivity

2.1 The usable range is primarily a function of sample volume, microscope count field area, and background airborne particulates. The influence of these variables is discussed in 8.1.3. For a microscope count field area of 0.003 mm^2 (see Figure 1) and a pump flow rate of 1.7 lpm, the optimal fiber densities would be produced over the range of 0.4 fiber/cm^3 (8-hour sample) to about 60 fibers/cm^3 (15-minute sample). For a field area of 0.006 mm^2 (see Figure 2) and a pump flow rate of 1.7 lpm, the optimal range is 0.2 fiber/cm^3 (8-hour sample) to about 30 fibers/cm^3 (15-minute sample). In each case, the optimal detection limits are inversely proportional to pump flow rate.

The upper detection limit can be extended by using sample times less than 15 minutes or using lower flow rates. The lower detection limit can be extended by increasing the flow rate up to about 2.5 lpm. Filter surface fiber densities less than optimal (less than about 0.5 to 1.0 fiber per count field) are still adequate, but will lead to decreased precision for the method (increased coefficient of variation, see Section 4).

The minimum total fiber count in 100 fields considered adequate for reliable quantitation is 10 fibers. Thus, the lower limit of reliable quantitation is 0.1 fiber/cm^3 (100,000 fibers/m^3). For this level, a flow rate of about 2.5 lpm is recommended. For a field area of 0.003 mm^2, the minimum sample time would be about 2 hours. For a field area of 0.006 mm^2, the minimum sample time would be about 1 hour.

2.2 This method considers only fibers with a length to diameter ratio of 3 to 1 or greater and a length greater than 5 micrometers.

3. Interferences

In an atmosphere known to contain asbestos, all particulates with a length to diameter ratio of 3 to 1 or greater, and a length greater than 5 micrometers should, in the absence of other information, be considered to be asbestos fibers and counted as such.

4. Precision and Accuracy

4.1 In the past decade, there have appeared a number of articles examining sources of variation in the asbestos sampling and counting procedure. These include: Lynch et al. (11.1), Weidner and Ayer (11.2), Conway and Holland (11.3), Leidel and Busch (11.4), Beckett and Attfield (11.5), and Rajhans and Bragg (11.6). The sources of variation will be discussed by stages in the membrane filter evaluation procedure.

4.2 **Sources of Variation in the Sampling Process.** These include variations in pump flow rate, proximity of the filter to the employee's body, and filter location (left to right) in the employee's breathing zone.

4.2.1 Section 9.1 requires that the personal sampling pump be calibrated with sufficient accuracy such that the 95% confidence limits on the flow rate are ± 10%. This is equivalent to a coefficient of variation (CV) of about 5%. However, this CV makes a negligible contribution to the total CV for the method due to the relatively large CV of the counting procedure.

4.2.2 Conway and Holland (11.3) concluded that positioning of the filter cassette on the wearer (regarding the angular portions of the filter and their proximity to the wearer) is not a significant factor in determining the fiber distribution on filters.

4.2.3 Weidner and Ayer (11.2) concluded that there is no appreciable difference between samples collected on either the right or left sides of a breathing zone or between samples collected side-by-side, especially for samples with concentrations less than 2.5 fibers/cm^3.

4.3 Sources of Variation in the Counting Procedure

4.3.1 Random variations exist in the fiber distribution on a filter wedge (intra-wedge variability). The industrial hygiene literature has seen considerable debate in the last 20 years concerning whether or not the distribution of mineral dust or asbestos fibers on a filter surface is adequately described by a Poisson distribution probability density function. Leidel and Busch (11.4) found excellent agreement between empirical error variance and theoretical variance calculated from the assumption of Poisson distributed true counts. They concluded that there was not excessive variation among count fields for a filter wedge and that clumping of fibers (non-random coalescence) did not occur.

4.3.2 Variations exist in the fiber distribution on the total filter surface (inter-wedge variability) due to the random or non-random distribution of fibers across the total surface of the filter. This type of variation is easily confused with intra-wedge variations. The count procedure does not require counting of multiple sectors of the filter. There may be significant differences between average counts for different wedges, or the fiber distribution variations for the total filter surface may be greater than the variations of the Poisson distribution. If either of these occur experimentally, one must use the experimental variations to estimate the minimum precision of the count procedure. The minimum precision is governed by the variations of the fiber distribution on the total surface of the filter.

Conway and Holland (11.3) concluded the distribution of fibers on filters is not uniform and the distribution of fiber counts is more disperse than Poisson. For their filters which had significant variations in fiber concentrations between sectors (as much as 50-60% of the total filter mean), they described the following relation for the standard deviation of the total number of fibers counted on a wedge (N)

$$\text{empirical } s(N) = 1.6\ (N)^{1/2}$$

where N is about 100. The Poisson standard deviation would be:

$$\text{Poisson } \sigma(N) = (N)^{1/2}$$

Rajhans and Bragg (11.6) in Series I of their study found significant variation between filter segments and rejected the Poisson distribution for the total filter surface. However, in Series II of their study, utilizing various experimental modifications, they found no significant variation between filter segments and no reason to reject the assumption of Poisson distributed fiber counts.

4.3.3 Systematic variations due to differences between microscopes were studied by Leidel and Busch (11.4). In their study using five different brands of microscopes, they found no significant differences among four, but the fifth gave counts approximately 45% higher on the average than the other four.

4.3.4 Variations due to differences between counters should be examined at three levels: experienced counters occasionally counting, experienced counters routinely counting, and inexperienced (new or untutored) counters. Leidel and Busch (11.4) studied five experienced counters, with one counting only occasionally. There were no significant differences among three of the counters, but a fourth was 16% lower than the first three. The fifth, who occasionally counted, averaged 27% higher than the first three. Conway and Holland (11.3) studied three experienced counters and three inexperienced counters. They found statistically significant differences between the means of both the experienced and inexperienced counters that typically were in the range plus or minus 5 to 15%. They concluded that experience as a fiber counter is not a significant parameter affecting intercounter variations.

Rajhans and Bragg (11.6) found no significant differences among means of five experienced counters in Series I of their study. But in their carefully controlled Series II, an analysis of variance showed significant variations between counters that were plus or minus 1 to 15%.

4.3.5 Variations between laboratories are most likely due to systematic biases and are not a significant additional source of random variations. Any additional variations are most likely due to differences in counting technique. Beckett and Attfield (11.5) observed that standard counters improved greatly after personal instruction; also new counters, after instruction, tended to overcompensate and get exceedingly high counts. Additionally, they found that counts from an experienced laboratory that had not had contact with other laboratories performing the same analysis were as far from the standard values as were the counts by new counters.

4.4 Sources of variations between samples taken at different times on one employee during one work shift can affect the exposure estimate for that employee. These are primarily due to a) differences in exposure concentrations during the day, b) differences in location of the employee within the plant, and c) differences in work operation performed by the employee during the day. These sources of variation can be controlled by proper choice of sampling strategy. Refer to Leidel and Busch (11.7) and Leidel, Busch, and Lynch (11.8) for an extended discussion of sampling strategies. Interday temporal variations can affect the exposure estimates obtained on different days. Refer to Leidel, Busch, and Crouse (11.9) for a discussion of this type of variation.

4.5 Until recently, the total coefficient of variation (CV_T) for the sampling and counting procedure was best estimated from the work of Conway and Holland (11.3). The conclusions of their study included:

4.5.1 The precision of their procedure for filters not containing an abundance of fine fibers can be estimated by a coefficient of variation of 16.2%. This value includes variation among counters and observed interaction effects.

4.5.2 The accuracy of the procedure for similar filters may be estimated for a 100-fiber count by a coefficient of variation of 21.4%. This assumes that the contribution of the overall variance from the nonuniform fiber distribution is additive.

4.5.3 A high percentage of very fine fibers on the filter can significantly affect the standard deviation and confidence limits for counts by different counters. After combining variations in fiber concentrations over the entire filter with those for different counters, it was concluded:

a. For filters with a low concentration of fine fibers, the coefficient of variation is estimated at 21% and the 95% confidence interval is ± 43%.

b. For filters with a high concentration of fine fibers, the coefficient of variation is estimated at 25% and the 95% confidence interval is ± 50%.

Lynch, Kronoveter, and Leidel (11.1) have also reported on variations of the method. Their intralaboratory study utilized the data from a large number of dust counts made by different methods by experienced counters over a period of years in an epidemiologic study of the asbestos products industry. They concluded that the standard deviation of counts of fibers longer than 5 micrometers on membrane filters could be estimated from the relation $\sigma = (N)^{0.491}$. Thus for counts of about 100 fibers, the coefficient of variation could be estimated at about 15.2% and the 95% confidence limits at ± 30.4%. These values are lower than the values reported by Conway and Holland (11.3).

Recently, the Johns-Manville Corporation conducted an in-house investigation of the asbestos count method (11.10). The study data contained total fiber counts for over

100 filters with each filter counted by two to five counters. From the Johns-Manville data, NIOSH calculated over 100 estimates of the count CV for the method (11.11). The NIOSH CV estimates included random intrafilter variations and intercounter variations, but did not include random pump flow rate variations. It was found that the count coefficient of variation (all random variations except for pump variations) was a function of the total fiber count. NIOSH then included a CV of 0.05 for random pump variations (see Section 9.1) in the CV-estimator equation to obtain a CV_T-estimator. The CV_T-estimator line is plotted on Figure 3 for total fiber counts in the range 10 to 100 fibers. Or the following equation can be used:

$$CV_T = [\text{antilog}_{10}(-0.215 - 0.203(\log_{10}FB)) + 0.0025]^2$$

where FB is total fiber count as discussed in Section 10.

Figure 3 demonstrates that for a total fiber count of 100, the best CV_T is attainable with the appropriate sampling times given in 8.1.3 and the count rules in 8.3.9. When making decisions regarding compliance with the OSHA asbestos exposure standards in 29 CFR 1910.1001, the statistical procedures given in Leidel et al. (11.11) should be followed. The procedures are based on statistical theory and assumptions given in References 11.12, 11.13.

Because of the possibility of systematic biases due to differences between microscopes, counters, and laboratories as discussed above, it is strongly recommended that any laboratory counting asbestos should participate in an interlaboratory quality control program that includes the counting of standard reference filters. These standard filters are available from NIOSH through the Proficiency Analytical Testing (PAT) Program. The PAT Program is used by the American Industrial Hygiene Association (AIHA) as part of its Laboratory Accreditation Program. Each laboratory's quality control program must include protocols for routinely adjusting and calibrating sampling and counting equipment plus training and evaluation programs for counters.

5. Advantages and Disadvantages of the Method

5.1 The method is intended to give an index of employee exposure to airborne asbestos fibers of specified dimensional characteristics.

5.2 It is not meant to count all asbestos fibers in all size ranges or to differentiate asbestos from other fibrous particulates.

6. Apparatus

6.1 Sampling Equipment

The personal sampling equipment train consists of 1) personal sampling pump, 2) tubing, 3) clothing spring clip, 4) tubing-to-field monitor metal adaptor, and 5) field monitor (filter and holder).

6.1.1 Personal Sampling Pump. The pump must be capable of sampling at 1.0 to 2.5 liters per minute (lpm) against a flow resistance of 7.5 inches of water (1.4 cm Hg) for 8 continuous hours on a fully charged battery.

6.1.2 Tubing. Laboratory tubing such as rubber or plastic with 6-mm bore and about 100 cm length.

6.1.3 Clothing Spring Clip. The clip attaches the rubber tubing to the lapel or shirt of the individual being monitored.

6.1.4 Tubing-to-field Monitor Adaptor. A short metal adaptor with ridges on one end to grip the inside of the tubing. The other end is designed for a pressure fit into the field monitor.

6.1.5 Field Monitor (Filter and Holder). The only field monitor currently considered acceptable by NIOSH is manufactured by the Millipore Corporation. The unit con-

sists of 1) a three section styrene plastic case designated Millipore Aerosol Monitor Case, 2) a 37-mm diameter plain white cellulose ester membrane filter designated Millipore AA (pore size of 0.8 micrometer), 3) a support pad, and 4) two plastic sealing caps. If a large number of samples are to be taken, it may be less expensive to reuse the plastic cases. Great care must be taken in the cleaning and reassembly process. The outside mating surfaces of the field monitors may be covered with a "shrink-fit" band to provide proper sealing and a writing surface for filter identification.

6.2 Optical Equipment and Microscope Features

6.2.1 Microscope body with binocular head.

6.2.2 10X Huygenian eyepieces are recommended. Other eyepieces can be substituted if necessary. Wide field eyepieces can be used; however, wide field eyepieces may yield a count field area less than 0.003 mm^2 with the Porton reticle. This is not always desirable from the standpoint of obtaining optimum sampling times (see Section 8.1.3). If wide field eyepieces are used, it is preferable to use the Patterson Globe and Circle reticle to obtain a larger count field area.

6.2.3 Koehler illumination (preferably built-in with provisions for adjusting light intensity).

6.2.4 A Porton reticle is recommended. Others such as the Patterson Globe and Circle can be substituted.

6.2.5 Mechanical stage.

6.2.6 Phase-Contrast condenser with a numerical aperture (N.A.) equal to or greater than the N.A. of the objective.

6.2.7 40-45X phase contrast achromatic objective (N.A. 0.65 to 0.75).

6.2.8 Phase-ring centering telescope or Bertrand lens.

6.2.9 Green or blue filter, if recommended by microscope manufacturer.

6.2.10 Stage micrometer with 0.01 mm subdivisions.

6.2.11 For general guidance on phase contrast microscopy, consult Needham (11.12), Clark (11.15) and McCrone (11.14).

6.3 Filter Mounting Equipment. Experience has shown that certain equipment is useful for efficient sample mounting. The following items are recommended for extracting and mounting a portion of the filter for counting.

6.3.1 Microscope slides. 2.5 by 7.5 cm glass slides are most commonly used. Sample number, data, initials, etc., can be conveniently written on a frosted end slide.

6.3.2 Cover Slips. Cover slips are a necessary part of the slide mount and optical system. The shape should be appropriate for the size of the filter wedge. The appropriate cover slip depends upon the objective to be used. Ordinarily, objectives are optically corrected for a #1½ (0.17 millimeter) thickness cover slip. Improper cover glass thickness will detract from the final image quality.

6.3.3 Scalpel. A scalpel is needed to cut out a portion of the filter to be examined. A number-ten curved blade scalpel is recommended.

6.3.4 Tweezers. A pair of fine-tipped tweezers is used to remove the membrane filter slice from the field monitor and place it upon the slide.

6.3.5 Lens Tissue. To insure cleanliness, a lint-free tissue is recommended. This tissue should also be used for wiping mounting tools and for cleaning slides and cover slips.

6.3.6 Glass Rod. A fire-polished glass rod may be used to spread the mounting solution on the slide.

6.3.7 Wheaton Balsam Bottle. This special glass container has a glass top which prevents contamination of the mounting solution. A glass rod is included for dispensing the solution.

7. Reagents

Chemicals should be reagent grade, free from particles and color, conforming to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available.

7.1 Dimethyl phthalate

7.2 Diethyl oxalate

Avoid getting the mounting solution on the skin. Wash skin promptly with soap and water if skin contact occurs.

8. Procedure

8.1 Sampling

8.1.1 General Information

Guidelines for the monitoring of employee exposures to industrial atmospheres are given in Reference 11.8. The Federal requirements for monitoring employee exposure to airborne asbestos are found in 29 CFR 1910.1001.

8.1.2 Mounting the Sampling Pump on the Worker

Fasten the sampling pump to the worker's belt and fasten the field monitor to the lapel or shirt front (as close to the breathing zone as is practical). Remove the top cover of the plastic monitor, then invert the monitor making certain the exposed filter is facing downward. Turn the pump on and adjust to the calibrated flow rate (1.0 to 2.5 lpm). Record the following information in a logbook.

1. Filter number
2. Pump start time and date
3. Flow rate
4. Subject's name and job title
5. Type of operation or process
6. Ventilation controls and is the worker wearing a respirator approved for asbestos?

The pump should be checked periodically during the sampling period for proper operation and flow rate.

8.1.3 Optimum Sampling Times

The requirement for the minimum count of 100 fibers or 20 fields in 8.3.9 was determined to be the best compromise to achieve adequate precision for the airborne fiber estimate and reasonable counting times. An optimum fiber density of about 1 to 5 fibers per microscope count field is recommended. To estimate appropriate sampling times for feasible counting and optimal counting, one must consider the following constraints:

1. microscope count field area (generally 0.003 to 0.006 mm^2)
2. pump flow rate (typically 2.5 lpm maximum)
3. average airborne fiber concentrations
4. counting rule range of 20 to 100 fields
5. adequate fiber density to obtain a minimum count of 10 fibers in 100 fields, which is the least total fiber count that yields an acceptable count precision
6. background airborne particulate levels that can reduce the count precision due to an obscuring of fibers on the filter surface

The preceding constraints were considered in drawing Figures 1 and 2. These figures were developed from the following relationship:

$$\text{sampling time} = \frac{(FB/FL)\,(ECA/MFA)}{(FR)\,(AC)\,(1000)} \text{ minutes}$$

where:

- FB/FL = 1 to 5 fibers/field
- ECA = effective collecting area of filters (855 mm² for 37-mm filter with effective diameter of 33 mm)
- MFA = microscope field area (generally 0.003 to 0.006 mm²)
- FR = Pump flow rate (generally 1.0 to 2.5 lpm)
- AC = Air concentration of fibers in fibers/cm³.

Figure 1 (microscope field area = 0.003 mm²) and Figure 2 (microscope field area = 0.006 mm²) show optimum and feasible sampling times for a pump flow rate of 1.7 lpm. Each individual responsible for sampling asbestos should prepare a similar chart for his particular pump flow rate and microscope field area before sampling is performed to aid in estimating proper sampling times. On Figures 1 and 2, the areas with solid shading lines are generally the optimum conditions for counting. The broken shading lines are for conditions very close to optimal.

However, feasible counting conditions may extend down to about 0.1 fiber/field and and above 5 fibers/field. Recommended sampling times are most strongly influenced by background airborne particulate levels, once all the other constraints have been estimated. For heavy particulate levels, it may be necessary to limit each filter to about 60 to 180 minutes sampling duration. Each individual responsible for sampling should work closely with the microscopist to attain as high as possible filter surface fiber densities (up to about 5 fibers/field), while avoiding filter surface background particulate levels that create very difficult or impossible counting conditions. If one has very little idea of airborne fiber and particulate levels, the best procedure is to take several long samples (as one 8-hour or two consecutive 4-hour samples) in conjunction with several short samples (as four consecutive 2-hour or eight consecutive 1-hour samples). If the longer samples prove very difficult to count, the microscopist will have the shorter samples to fall back on.

From Figures 1 and 2, it can be seen that there are certain sampling times which will yield optimum fiber densities on the filter for almost all airborne fiber concentrations from 1 to 10 fibers/cm³. These optimum times have been calculated and are presented in Figure 4. Note that the optimum times given by Figure 4 are approximate and can be varied by as much as ± 25%. The nomogram is intended as a guide to be used where no prior knowledge of the air concentration is available.

8.1.4 End of Sampling Period

Remove the field monitor, replace the plastic top cover and the small end caps, and store the monitor. Always shut off the pump when changing monitors to avoid contaminating or damaging the pump. Record the pump shutoff time and flow rate in the logbook.

8.1.5 Blanks

With each batch (25 to 50 filters) of samples sent for analysis, submit two unopened field monitors which have been subjected to the same treatment as the samples except that they were not exposed to the sampling environment. Label these as blanks. If the blanks yield fiber counts greater than 5 fibers/100 fields, then the entire sampling procedure should be examined carefully for the cause of contamination. The

mounting solution of Section 8.2.1 should also be examined for contamination and/or crystal growth.

8.1.6 Shipping

The field monitors in which the samples are collected should be shipped in a rigid container with sufficient packing material to prevent crushing.

8.1.7 Numbers of Samples

When sampling for the Federal ceiling standard of 10 fibers (>5μm)/cm³, [29 CFR 1910.1001(b) (3), effective July 7, 1972], only one sample (15 minutes maximum duration) is necessary, theoretically. However, several samples should be taken during expected periods of peak air concentrations to allow for detection of gross sampling or counting errors.

When sampling for determination of noncompliance with the Federal 8-hour TWA standard of 2 fibers (>5μm)/cm³, [29 CFR 1910.1001(b) (2)], one should continuously sample as large a portion of the work day as is feasible for airborne concentrations of about 2 to 10 fibers/cm³. However, for a lower airborne concentration such as 0.5 fiber/cm³, one sample might require 4 to 8 hours sampling time in order to get the proper filter fiber density (Section 8.1.3). For this situation, the 8-hour TWA exposure would be determined from one 8-hour or two 4-hour samples as appropriate.

8.2 Sample Preparation

8.2.1 Preparation of Mounting Solution

A very important part of the sample evaluation is the mounting process. This process involves a special mounting medium of prescribed viscosity. The proper viscosity is important in order to expedite filter dissolving and still minimize particle migration. After the sample has been mounted, an elapsed time of approximately sixty minutes is needed before the sample is ready for evaluation.

Combine the dimethyl phthalate and diethyl oxalate in a one to one ratio by volume and pour into a Wheaton balsam bottle. Add approximately 0.05 (± 0.005) grams of new membrane filter per milliliter of solution to reach the necessary viscosity. The mixture must be stirred periodically until the filters have dissolved and a homogeneous mixture is formed. The normal shelf life of the mounting solution is about three months. Twenty milliliters of mounting solution will prepare approximately 300 samples.

8.2.2 Sample Mounting

Cleanliness is important! A dirty working area may result in sample contamination and erroneous counts. The following steps should be followed when mounting a sample.

1. Clean the slides and cover slips with lens tissue. Lay each slide down on a clean surface with the frosted end up. It is a good practice to rest one edge of the cover slip on the slide and the other edge on the working surface. By doing this, you keep the bottom surface (the one which contacts the filter) from becoming contaminated.
2. Wipe all the mounting tools clean with lens tissue and place them on a clean surface (such as lens tissue). All tools should be wiped clean prior to mounting each sample.
3. Using the glass rod supplied with the Wheaton balsam bottle, apply a drop of mounting solution onto the center of the slide. It may be necessary to adjust the quantity of solution so that after the cover slip has been placed on top, the solution extends only slightly beyond the filter boundary. If the quantity is greater than this, particle migration may occur.

4. Using another glass rod, spread the mounting media into a triangular shape. The size of this triangle should coincide with the dimension of the filter wedge.
5. Separate the middle and bottom sections of the field monitor case to expose the filter. Cut a triangular wedge from the center to the edge of the filter using the scalpel. The size of the wedge should approximate one-eighth of the filter surface. The filter can be very carefully removed from the cassette for cutting, but this should only be done with great care. .
6. Grasp the filter wedge with the tweezers on the perimeter of the filter which was clamped between the monitor case sections. Do not touch the filter with your fingers. Place the wedge, sample side up, upon the mounting medium.
7. Pick up a clean cover slip with tweezers and carefully place it on the filter wedge. Once this contact has been made, do not reposition the cover slip.
8. Label the slide with the sample number and current date before proceeding to the next filter. On the bottom (backside) of the slide, trace the perimeter of the filter wedge with a felt tip marking pen. This will enable the counter, after the filter has become transparent, to stay within the filter perimeter when counting.
9. The sample should become transparent within fifteen minutes. If the filter appears cloudy, it may be necessary to press very lightly on the cover slip. This is rarely necessary; however, counting should not be started until an hour after the mounting. This allows the microscopic texture of the filter to become invisible to microscope viewing.
10. Discard the sample mount after two days if it has not been counted. Crystals appearing similar to asbestos fibers may begin to grow at the mounting media/air interfaces. They seldom present any problems if the slide is examined before two days. In any case, stay away from the filter's edges when counting and sizing.

8.3 Counting of Fibers

8.3.1 Place the slide on the mechanical stage of the microscope and position the center of the wedge under the objective lens and focus upon the sample. Start counting from one end of the wedge and progress along a radial line to the other end (count in either direction from perimeter to wedge tip). Random fields are selected, without looking into the eyepieces, by slightly advancing the slide in one direction with the mechanical stage control.

8.3.2 It is essential to continually scan over a range of focal planes (generally the upper 10 to 15 micrometers of the filter surface) with the fine focus control during each field count. This is especially necessary for asbestos fibers due to their impaction into the filter matrix.

8.3.3 On most airborne samples, asbestos fibers will generally have fiber diameters less than one micrometer. Therefore, it is necessary to look carefully for faint fiber images.

8.3.4 Regularly check phase ring alignment.

8.3.5 When an agglomerate (mass of material) covers a significant portion of the field of view (approx 1/6 or greater) reject the field and select another. (Do not include it in the number of fields counted.) However, report the fact as it may have meaning on other data collection.

8.3.6 Bundles of fibers are counted as one fiber unless both ends of the fiber can be clearly resolved.

8.3.7 Count only fibers with a length to width ratio greater than or equal to 3:1.

8.3.8 Count only fibers greater than 5 micrometers in length. (Be as accurate as possible in accepting fibers near this length.) Measure curved fibers along the curve to estimate the total length.

8.3.9 Count as many fields as necessary to yield a total count of at least 100 fibers. Exceptions: a) count at least 20 fields even if you count more than 100 fibers, and b) stop at 100 fields even if you haven't reached 100 fibers.

8.3.10 For fibers that cross either one or two sides of the counting field, the following procedure is used to obtain a representative count.

COUNT any fiber greater than 5 micrometers in length, that lies entirely within the counting area. COUNT as "½ fiber" any fiber with only one end lying within the counting area. DO NOT COUNT any fiber crossing any two sides.

Reject and do not count all other fibers. Refer to Figures 5 through 10. Note that the fibers in Figures 5 through 10 are not representative of the appearance of most asbestos fibers. Most fibers have a very faint image.

9. Calibration and Standards

9.1 Sampling Train Calibration

The accurate calibration of the sampling pump is essential to the correct calculation of the air volume sampled. The frequency of calibration is dependent on the use, care, and handling to which the pump is subjected. Pumps must be recalibrated if they have just been repaired, misused, or received from the manufacturer. If the pump receives hard usage, 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 upon the type of instrument used as a reference. The choice of a calibration instrument will depend largely on where the calibration is performed. For laboratory testing, a 1-liter buret used as a soap bubble flow meter or wet-test meter is recommended. Other standard calibrating instruments, such as a spirometer, Marriott's bottle, or dry gas meter can be used. The calibration should be of sufficient precision that the 95% confidence limits on the flow rate are ± 10% (95% of the flow rates will fall within ± 10% of the calibrated value).

Instructions for calibration with the soap bubble flow meter follow. The sampling train used (pump, hose, filter cassette) in the pump calibration should be the same as the one used in the field.

9.1.1 Check the voltage of the pump battery with a voltmeter both with the pump off and while it is operating to assure adequate voltage for calibration. If necessary, charge the battery to manufacturer's specifications.

9.1.2 Fill a beaker with 10 ml of soap solution.

9.1.3 Connect the filter cassette inlet to the top of the buret with a length of hose.

9.1.4 Turn the pump on and moisten the inside of the soap bubble meter by immersing the open end of the buret into the soap solution and drawing bubbles up the inside of the buret. Perform this task until the bubbles are able to travel the entire length of the buret without breaking.

9.1.5 Adjust the pump rotameter to provide a flow between 1.5 to 2.5 lpm.

9.1.6 With a water manometer, check that the pressure drop across the filter is less than 13 inches of water (about 1 inch of mercury).

9.1.7 Start a soap bubble up the buret and measure the time it takes for the bubble to travel a minimum volume of 1 liter.

9.1.8 Repeat the procedure in 9.1.7 at least three times, average the results, and calculate the calibrated flow rate by dividing the volume traveled by the soap bubble by the elapsed time. If the range between the highest and lowest of the three flow rates is greater than about 0.33 lpm, then the calibration should be repeated since it is likely that the precision is not adequate.

9.1.9 Data required for the calibration include the volume measured, elapsed time, pressure drop, air temperature, atmospheric pressure (or elevation), pump serial number, date, and name of person performing the calibration.

9.1.10 Corrections to the flow rate for pumps with rotameters may be necessary if the pressure (elevation) or temperature where the samples are collected (actual flow rate) differs significantly from that where the calibration was performed (indicated flow rate). Actual flow rates at time of sampling may be calculated for a linear scale rotameter by using the following correction formula:

$$Q_{actual} = Q_{indicated} \sqrt{\frac{P_{cal}}{P_{actual}} \cdot \frac{T_{actual}}{T_{cal}}}$$

where both pressure (P) and temperature (T) are in absolute units such as:

psia = psig + 14.7
deg Rankin = deg Fahrenheit + 460
deg Kelvin = deg Celsius + 273

9.2 Microscope Setup

9.2.1 Porton Reticle and the Counting Field

The asbestos fiber count procedure consists of comparing fiber length to the diameters of calibrated circles of a Porton reticle, and counting all fibers greater than 5 micrometers in length lying within a given counting field area. The Porton reticle is a glass plate inscribed with a series of circles and rectangles. The left half of the reticle is divided into six rectangles constituting the counting field. The counting field is illustrated in Figures 5 through 10.

9.2.2 Placement in Eyepiece

The Porton reticle is placed inside the Huygenian eyepiece where it rests on the field-limiting diaphragm. If other types of eyepieces are used, it may be necessary to insert a counting collar for retaining the reticle. The reticle should always be kept clean, since dirt on the reticle is in focus and could complicate the counting and sizing process.

9.2.3 Stage Micrometer

The Porton reticle cannot be used for counting until it has been properly calibrated with a stage micrometer. Most stage micrometer scales are approximately two millimeters long and are divided into units of one-hundredth of a millimeter (ten micrometers).

9.2.4 Microscope Adjustment

When adjusting the microscope, follow the manufacturer's instructions while observing the following guidelines.

1. The light source image must be in focus and centered on the condenser iris or annular diaphragm.
2. The particulate material to be examined must be in focus.
3. The illuminator field iris must be in focus, centered on the sample, and opened only to the point where the field of view is illuminated.
4. The phase rings (annular diaphragm and phase-shifting elements) must be concentric.

9.2.5 Porton Reticle Calibration Procedure

Each eyepiece-objective-reticle combination on the microscope must be calibrated. Should any of the three be changed (disassembly, replacement, zoom adjustment, etc.), the combination must be recalibrated. Calibration may change if interpupillary dis-

tance is changed. For proper calibration, the following procedure should be followed closely.

With a 10X objective in place, place the stage micrometer on the mechanical stage, focus the millimeter scale, and center the image. Change to the 40-45X objective and adjust the first millimeter scale division to coincide with the left boundary of the Porton rectangle. Measure the distance between the left and extreme right boundaries of the Porton rectangle, estimating any portion of the final division. This measurement represents 200 L units. The rectangle is 100 L units on the short vertical dimension. The calculated "L" is inserted into the formula $D = L(2^N)^{1/2}$ where "N" is the circle number (indicated on the reticle) and "D" is the circle diameter. Since the circle diameters vary logarithmically, every other circle doubles in diameter. For example, circle number three is twice the diameter of number one; number four is twice the diameter of number two. When the circle sizes have been determined, the counting field area which consists of the left six smaller rectangles can be calculated from the relation 10,000 L^2. This completes the reticle calibration for this specific objective-eyepiece-reticle combination.

Example for Porton Reticle

The following calibration was obtained for a pair of 10X Huygenian eyepieces and a 43X objective:

200 L = 0.148 mm = 148 micrometers
100 L = 0.074 mm = 74 micrometers
One L-unit = 0.74 micrometers

Thus Circle #1 has a diameter $D = L(2^N)^{1/2} = 0.74(2^1)^{1/2} = 0.74 \quad (1.414) = 1.05$ micrometers.
Then our circle diameter calibration table looks like:

Diameter of Circle #1 = 1.05 micrometers
#2 = 1.48
#3 = 2.09
#4 = 2.96
#5 = 4.19
#6 = 5.92

Field area = (10,000) (L^2) = (100 L) (100 L) = (0.074) (0.074) = 0.0055 mm^2

Thus fibers with a length greater than a distance halfway between the diameters of the #5 and #6 circles would be counted.

If a Patterson Globe and Circle reticle is used, a different calculation procedure is required. The circle diameters are related as follows. The #25 circle diameter is (0.1) (reticle length).

The circle diameters are proportional to the ratio of their numbers. Thus the #20 circle diameter is (20/25) or 0.8 times the #25 circle diameter.

10. Calculations

10.1 The average airborne asbestos fiber concentration estimated by the filter sample may be calculated from the following formula:

$$AC = \frac{[(FB/FL) - (BFB/BFL)]\ (ECA)}{(1000)\ (FR)\ (T)\ (MFA)}$$

where:

AC = Airborne fiber concentration in (fibers > 5 μm)/cm^2.
BFB = Total number of fibers counted in the BFL fields of the blank or control filters in fibers > 5 μm.
BFL = Total number of fields counted on the blank or control filters.
ECA = Effective collecting area of filter (855 mm^2 for a 37-mm filter with effective diameter of 33 mm).
FR = Pump flow rate in liters/min (lpm).
FB = Total number of fibers counted in the FL fields in fibers > 5 μm.
FL = Total number of fields counted on the filter.
MFA = Microscope count field area in mm^2 (generally 0.003 to 0.006).
T = Sample collection time in minutes.

10.2 Recount criteria. It is very desirable for a counter to conduct a "blind recount" for about 1 in every 10 filter wedges (slides) counted. Alternatively, a second counter could perform the blind recount. In training sessions for novice counters, the trainee should conduct a blind recount for filter wedges counted by an experienced, proficient counter. In all cases, we will observe differences between the first and second counts of the same filter wedge. Most of these differences will be due to chance alone, that is, due to the random variability (precision) of the count method. Statistical recount criteria enable us to decide whether observed differences can reasonably be explained due to chance alone or are probably due to systematic differences between counters or microscopes or due to some other biasing factor.
The following recount criterion is for a pair of counts that estimate some airborne fiber concentration (AC) in fibers/cm^3. The criterion is given at the type-I error level. That is, there is a 5% maximum risk that we will reject a pair of counts for the reason that one might be biased, when the large observed difference is really due to chance.
Reject a pair of counts because one might be biased if:

$$(AC_2 - AC_1) \text{ exceeds } 2.77(\overline{AC})(CV_{FB})$$

where:

AC_1 = lower estimated airborne fiber concentration
AC_2 = higher estimated airborne fiber concentration
$\overline{AC}$ = average of the two airborne concentration estimates
CV_{FB} = average CV for the two concentration estimates which are a function of the total fiber count (FB) in each case. Use the relation in Section 4 or Figure 3.

For a pair of counts on the same filter, reject the pair because one might be biased if:

$$(FB_2 - FB_1) \text{ exceeds } 2.77(\overline{FB})(CV_{\overline{FB}})$$

where:

FB_1 = lower fiber count on the filter (total fibers)
FB_2 = higher fiber count on the filter (total fibers)
$\overline{FB}$ = average of the two total fiber counts
$CV_{\overline{FB}}$ = CV_T for the value FB. Use the relation in Section 4 or Figure 3.

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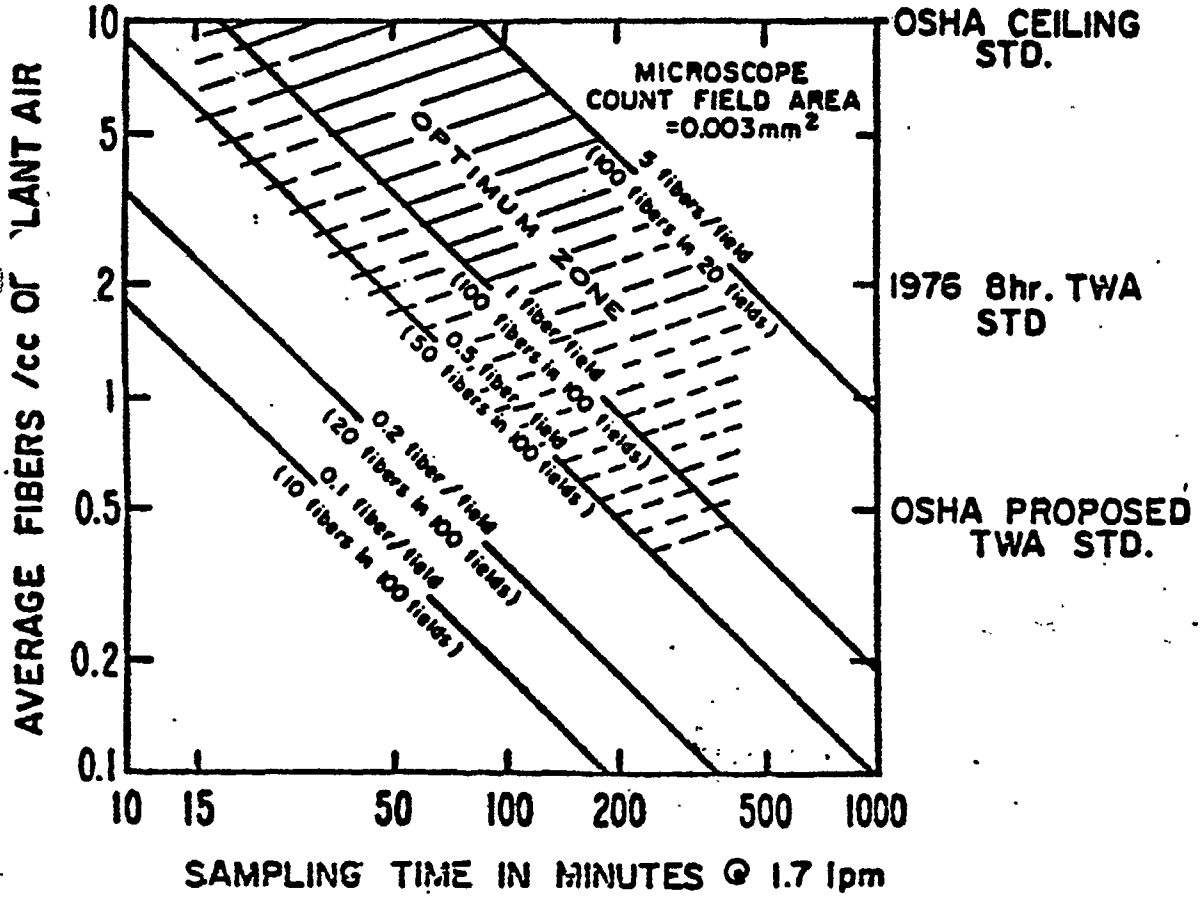

FIGURE 1. Optimum Sampling Times for airborne asbestos where microscopic field area = 0.003 mm²

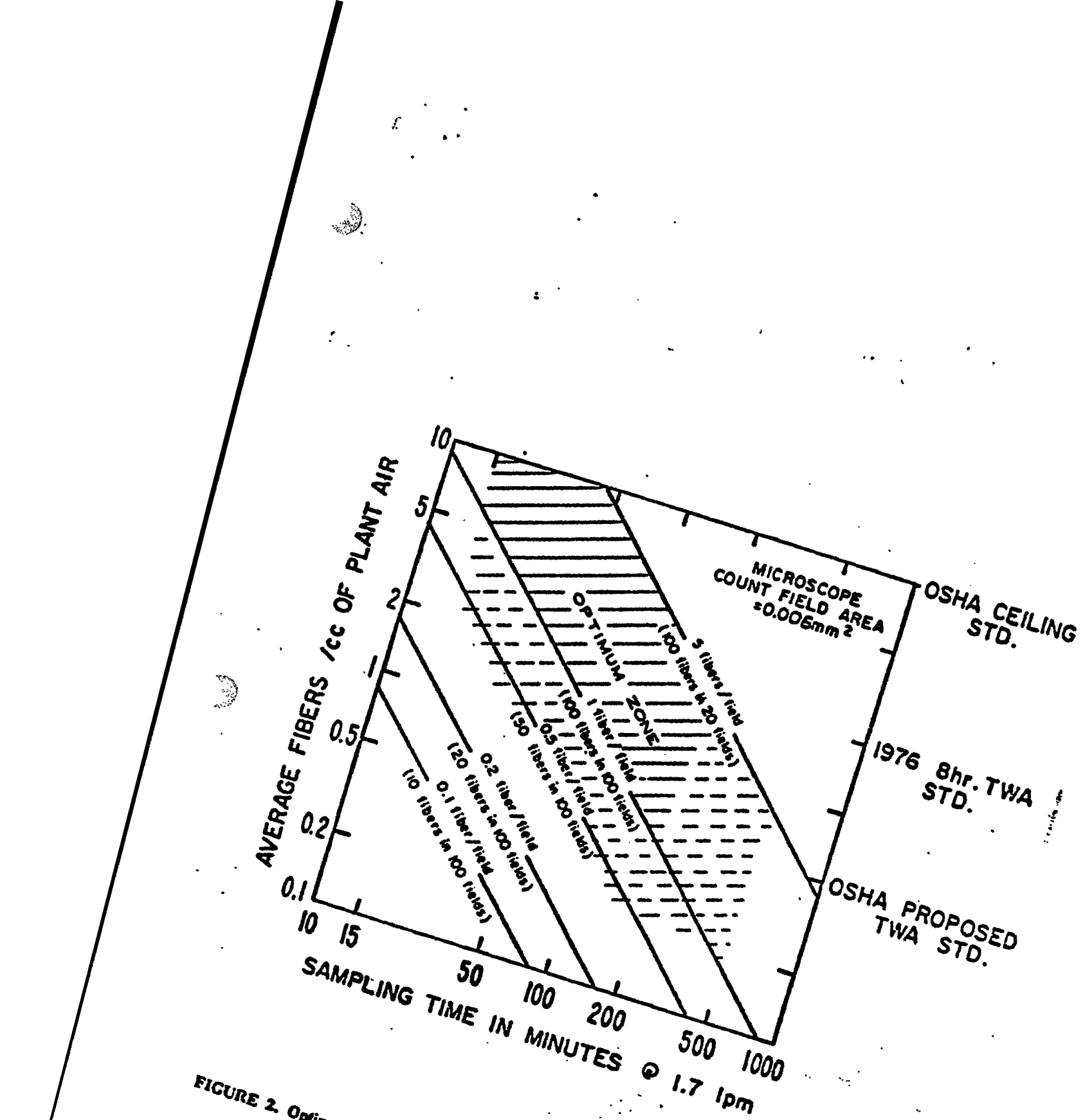

FIGURE 2. Optimum sampling times for airborne asbestos where microscopic field area = 0.006 mm²

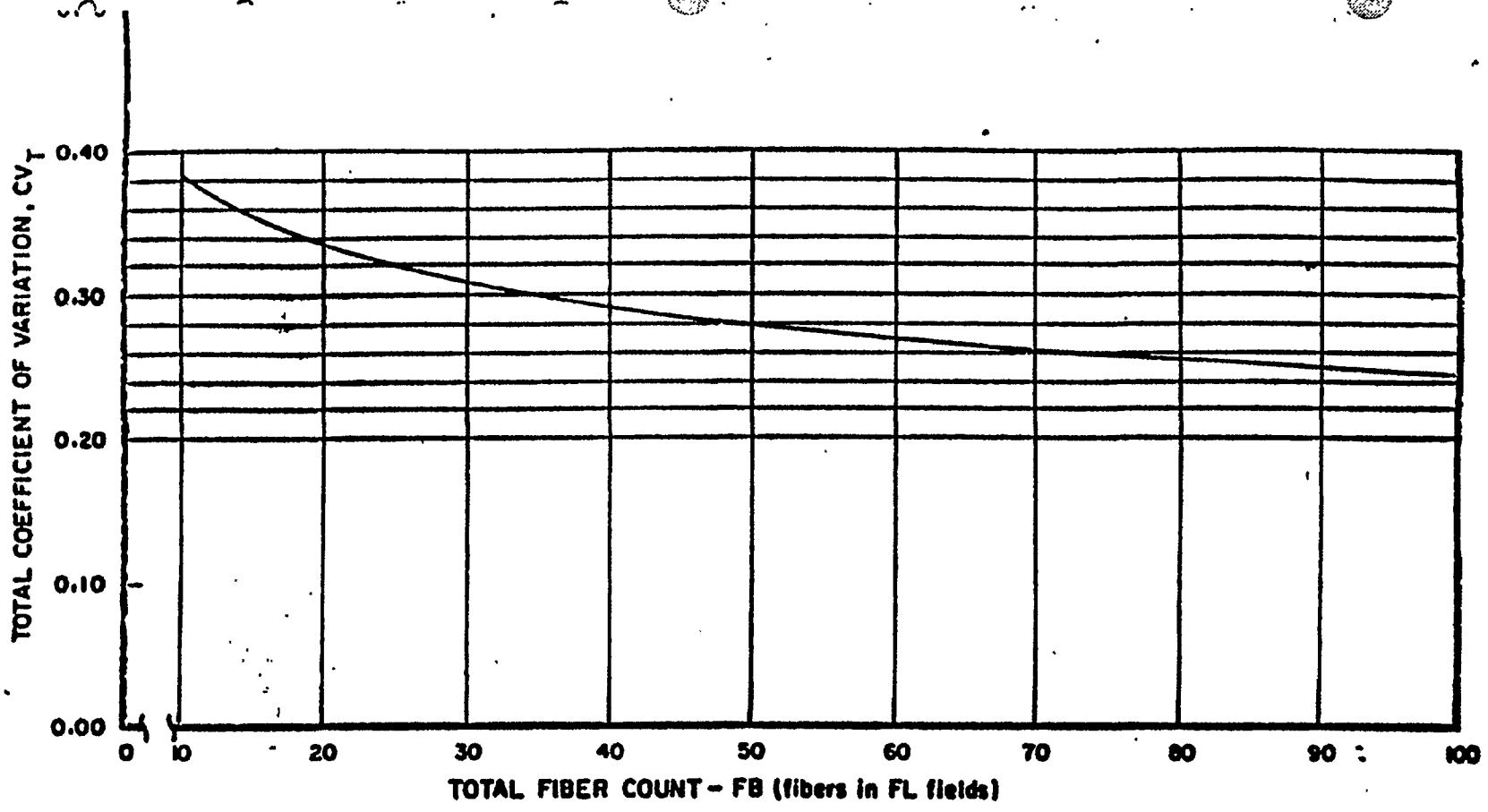

FIGURE 3. Total coefficient of variation as a function of total fiber count

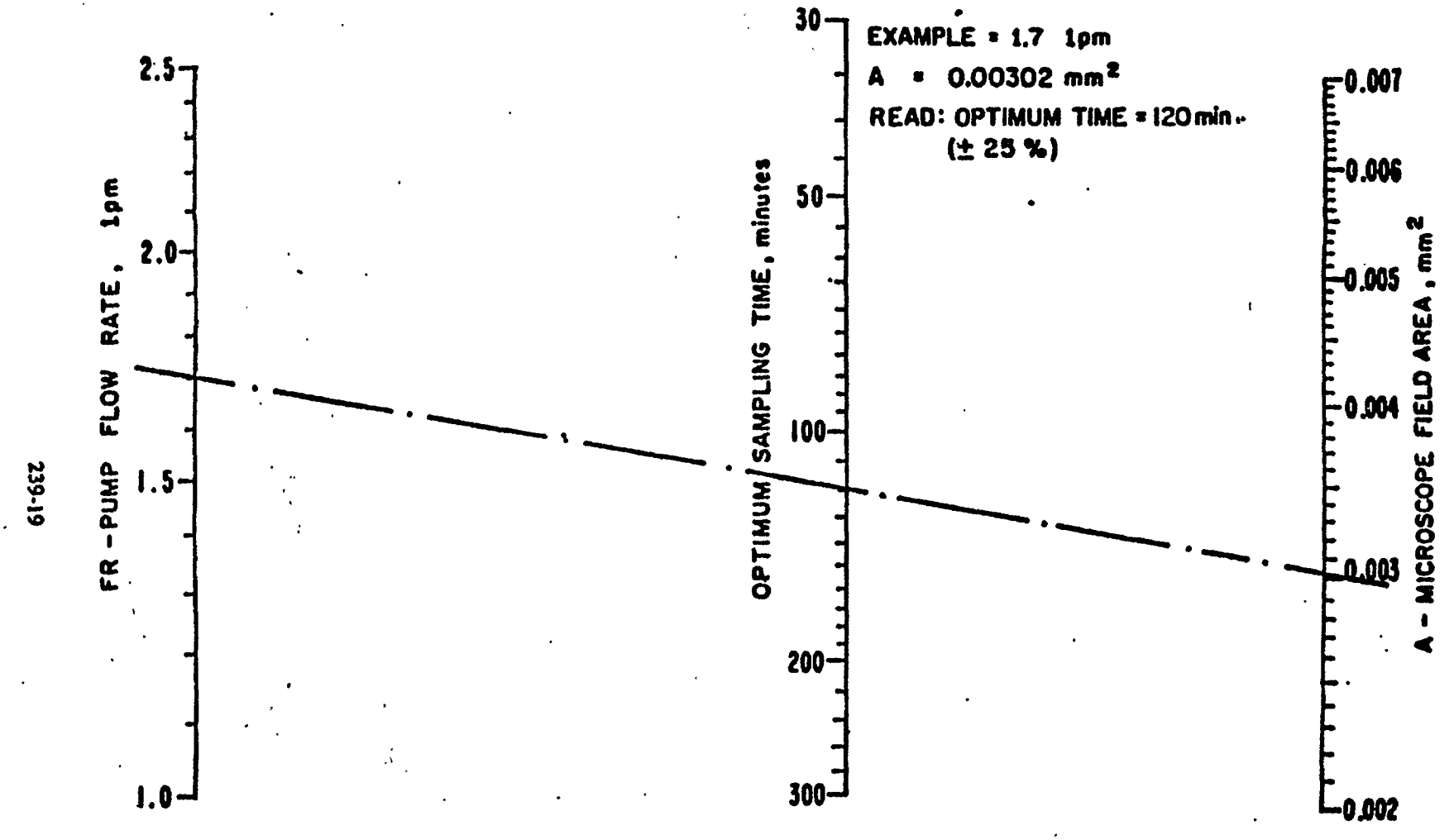

FIGURE 4. Nomogram of optimum sampling times for airborne asbestos fibers in concentrations of 1 to 10 fibers/cm³

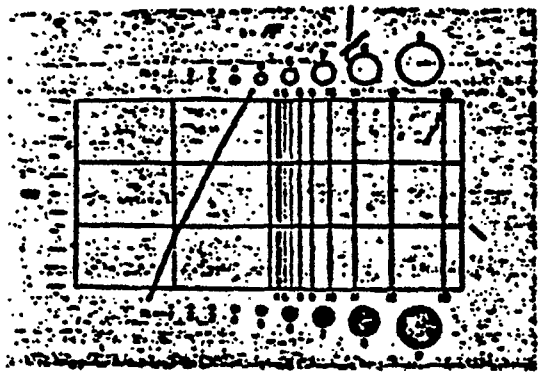

FIGURE 5

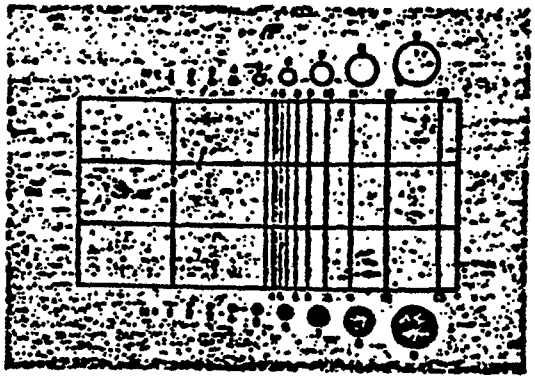

FIGURE 6

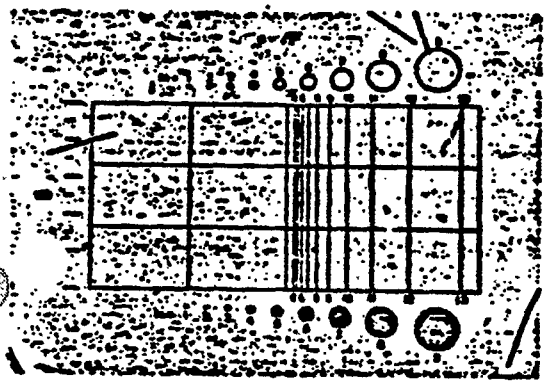

FIGURE 7

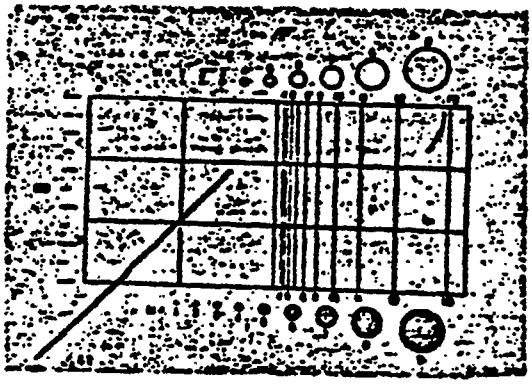

FIGURE 8

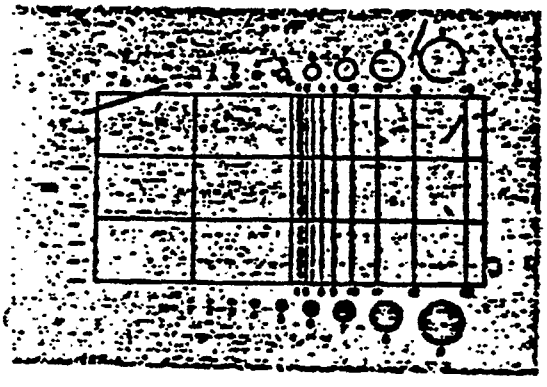

FIGURE 9

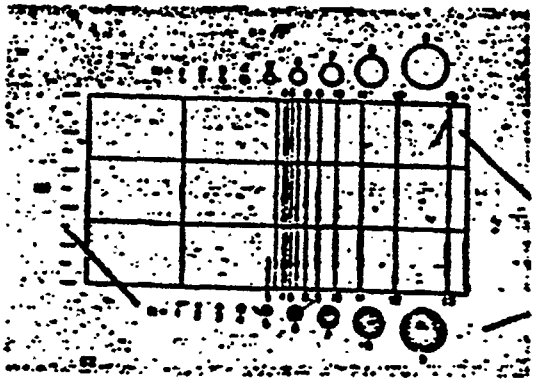

FIGURE 10

LIST OF FIGURES

(5 through 10)

FIGURE 5. DO NOT COUNT. Fiber crosses top and bottom sides.

FIGURE 6. COUNT. One fiber.

FIGURE 7. COUNT. One-half fiber. Fiber crosses left side and one end lies within count area.

FIGURE 8. COUNT. One-half fiber. Fiber crosses bottom side and one end lies within count area.

FIGURE 9. DO NOT COUNT. Fiber crosses two sides.

FIGURE 10. DO NOT COUNT. Fiber crosses two sides (bottom left corner).
COUNT. One-half fiber. Fiber crosses bottom side and one end lies within count area.
COUNT. One fiber (top right corner).

ATTACHMENT C

REPRESENTATIVE AMBIENT-AIR ASBESTOS CONCENTRATIONS

Representative Ambient-Air Asbestos Concentrations

Location	Fibers/cc
New York	0
Washington	0.0022
Miami	0.0027
Cleveland	0.0067
Denver	0.0041
San Francisco	0.0038
Spokane	0.0154