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Evaluation of Two Negative-Air Glove Bag Techniques for Asbestos Removal

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Two "negative pressure," modified glove bag containment techniques were independently evaluated at two separate study sites to assess the effectiveness of these techniques in controlling asbestos exposures to the environment and the worker. The Aero-Pipe Capsule® (APC) is a rigid, reinforced plastic glove box; a large plastic bag, sealed to the lower sides of the APC with an elastic band, closes the open bottom of the APC and provides a replaceable receptacle for debris. The custom fabricated negative-air glove bag (CNAGB) was constructed on site from polyethylene film, gauntlet gloves or prefabricated glove and arm inserts, spray adhesive, and tape. Worker exposures to asbestos, as determined by phase contrast microscopy (PCM), were less than the Occupational Safety and Health Administration permissible exposure limit of 200,000 fibers per cubic meter of air (f/m^3) and the National Institute for Occupational Safety and Health (NIOSH) recommended exposure limit (REL) of 100,000 f/m^3 with both controls. Transmission electron microscopy (TEM) analysis indicated the presence of many asbestos structures with a diameter less than 0.25 μm that are not visible with PCM. TEM analyses of area samples taken before and after asbestos removal using aggressive sampling techniques (a 5- to 10-minute blowdown of all surfaces immediately preceded sampling and the room air was continuously circulated during the sampling period) indicated a threefold increase in the concentrations of fibers in both study areas after asbestos removal using the APC system. Based on Student's *t*-test, the differences of the average concentrations were significant ($p = 0.05$). Where the CNAGB system was used, asbestos concentrations after asbestos removal were significantly higher ($p = 0.05$) in one area; in the other area the concentrations were lower but lacked statistical significance. The "negative pressure" techniques described in this study were effective in controlling worker exposure to below the NIOSH REL. It is prudent, however, to use respiratory protection and disposable coveralls with either of these controls to provide protection against accidental asbestos releases that may occur because of the loss of vacuum, seal failure, or the rupture of a bag. Data from these studies are insufficient to define conditions where "negative pressure" glove bags can be used without back-up containment of the work area; further evaluations should be made to establish these parameters.
Froehlich, P.A.: Evaluation of Two Negative-Air Glove Bag Techniques for Asbestos Removal. Appl. Occup. Environ. Hyg. 8(10):871–882; 1993.

Introduction

Glove bags have been and are being used as source controls to contain the emissions of asbestos fibers that may occur during asbestos abatement and maintenance operations involving asbestos-containing materials (ACM). They were originally developed for removing asbestos-containing insulation (pipe lagging) from horizontal runs of pipe but have been adapted for use in other configurations for industry and facility maintenance activities. They are often used for small jobs without other means of containment, such as enclosure of the removal area with plastic barriers and/or the use of negative pressure. The effectiveness of glove bags to control asbestos emissions is extremely important to ensure the health of workers and to prevent contamination of the adjoining workplaces and the environment.

A previous evaluation of glove bag removal was conducted by researchers at the National Institute for Occupational Safety and Health (NIOSH) to assess the effectiveness of this technique in controlling asbestos exposures to the environment and the worker.[1,2] That study indicated exposures exceeded the Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) and the NIOSH recommended exposure limit (REL) when inexperienced workers performed asbestos abatement operations. Also, it was shown that asbestos contamination was greater after asbestos abatement in five of eight rooms evaluated.

Because that study revealed glove bags alone may not provide adequate control, NIOSH researchers undertook an additional study in which "negative pressure" was used with two modified glove bag containment techniques: an Aero-Pipe Capsule® (APC) (Aerospace America Inc., Bay

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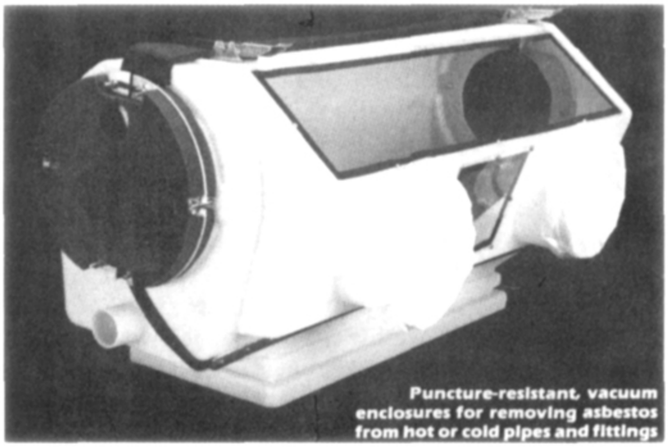

FIGURE 1. Aero-Pipe Capsule.

City, Michigan)[3] and a custom-fabricated negative-air glove bag (CNAGB).[4] Modified abatement site clearance tests were conducted to determine the potential for contamination of the work environment in addition to the occupational exposure levels.

Description of Controls

The APC (Figure 1) is a rigid, reinforced plastic glove box, open at the bottom. A large plastic bag, sealed to the lower sides of the APC with an elastic band, closes off the bottom and provides a receptacle for debris and the water used to wet down the pipe lagging to reduce dustiness. The gloves also are attached to the capsule with elastic bands and may be replaced as needed. The APC is split and hinged so that it can be opened and clamped around a pipe. Removable, split gaskets at each end of the APC are available with various sized openings; these gaskets create a snug fit to the pipe and compensate for differences in diameter between bare and insulated pipe. Gasket materials can be made from various materials; some resist softening at temperatures above 500°F.

The APC is provided with a hose connection for attachment to a 90 cubic feet/min (ft^3/m) high-efficiency particulate air (HEPA) filtered "Back-Pac" (Aerospace America, Inc.) vacuum device. The connecting hose contains an air bypass control to adjust the pressure (vacuum) in the APC. Another hose connection is provided for attachment of a 5-gallon amended water or encapsulant supply system to an internal applicator. This system includes a pump controlled by a foot-operated switch. The APC has a clear plastic observation window and an internal shelf to hold the tools used to remove the lagging. APCs can be fabricated in sizes and shapes to accommodate vertical pipes, elbows, tees, valves, and other configurations.

The CNAGB (Figure 2) was fabricated by the abatement workers at the site from large sheets of polyethylene (poly), gauntlet gloves or prefabricated glove and arm inserts, spray adhesive, tape, and HEPA respirator cartridges. A framework to support the bag and to prevent it from collapsing under negative pressure was constructed around the pipes from which lagging was to be removed. For this study, the frame was fabricated with 1-inch polyvinyl chloride (PVC) pipe and fittings and suspended with wires from various available points of attachment (pipe hangers, brackets, etc.). The CNAGB was constructed to allow the workers ample space to manipulate tools using the gloves within the bag and to enclose the amount of material that could be removed in one day. Several pairs of gloves were installed at intervals to provide access to all portions of the bag. A large, three-blower, HEPA-filtered vacuum cleaner

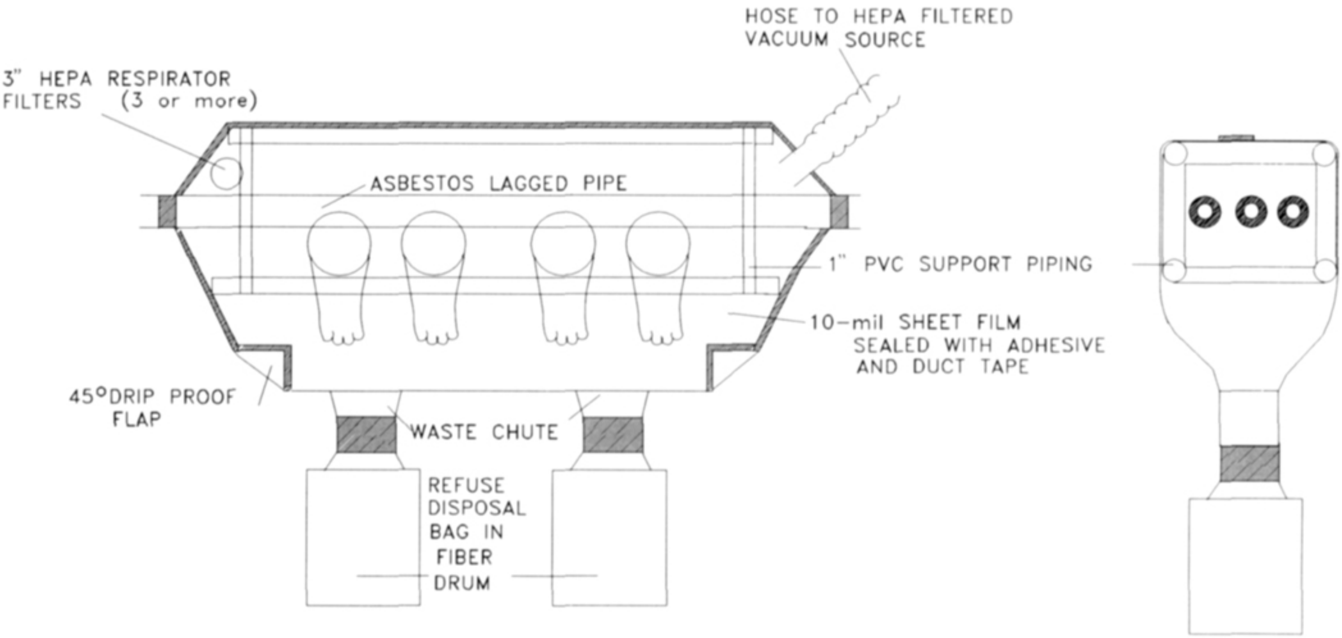

FIGURE 2. Custom negative-air glove bag.

(Type GS-83-7810, Nilfisk of America, Inc., Malvern, Pennsylvania) was used to reduce the pressure in the bag. The air flow necessary to maintain an effective negative pressure depends on the size and tightness of the construction. HEPA-filter respirator cartridges were installed in the walls of the bag away from the vacuum source inlet to provide a restricted flow of replacement air. These filters also prevented the release of asbestos if the pressure in the bag became positive briefly because of work activity or if the vacuum source were to fail.

Work Activities

APC System

For the APC system, asbestos removal was evaluated in a storage area in a multipurpose office building. Approximately 45 feet of 3-inch thick pipe lagging, containing 50 percent chrysotile and 10 to 15 percent crocidolite, were removed from a 6-inch diameter steam pipe that ran through several small rooms.

To determine the efficacy of the APC to prevent the release of asbestos during abatement operations, two contiguous areas (designed "B" and "C") were isolated with poly barriers (Figure 3). Poly was glued or taped to the ceiling, walls, and floors to isolate the study areas from the rest of the building. Shelving and other equipment in these areas also were isolated with poly. The surface of the lagging was dampened with a mist of amended water (water containing agents to enhance the wetting process) to control surface dust. The pipe was then wrapped loosely with poly to restrict additional contamination of the worksite if vibrations and movement of the pipes from the removal operations caused further deterioration of the lagging. Because of lack of space, conventional abatement airlock entries were not used; entries to these areas were closed off by double poly barrier flaps. Shower facilities were not available; however, workers donned disposable coveralls before entry into the work areas.

Using the gloves in the capsule, workers removed the insulation contained within the APC and washed the bare pipe with wet rags. The cleaned pipe and the ends of the lagging were sprayed with an encapsulant. The APC was then moved along the pipe and removal and cleaning proceeded in sequential sections. After the initial section of pipe was cleaned, the gasket at the trailing end of the APC was replaced with one of smaller diameter to seal against the bare pipe. The upper walls of the bag and the interior of the APC were washed thoroughly before it was opened. When sufficient debris had accumulated, the bag was collapsed, sealed by twisting, taped shut, released from the capsule, and double bagged for disposal. Because of the design of the APC, lagging was removed only from horizontal, straight-run pipe sections. When an obstruction in the pipe-run was encountered, lagging was removed as close to the fitting or partition as practical, the end of the lagging was sealed with encapsulant, and then the unit was dismounted and reinstalled on the other side of the obstacle. The exhaust ventilation to the APC was operated continuously throughout these operations.

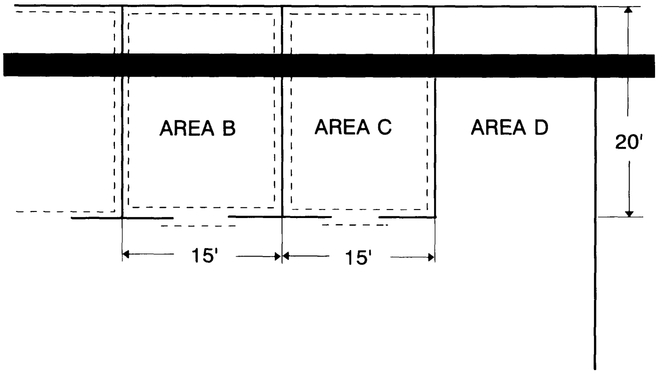

FIGURE 3. Aero-Pipe Capsule system asbestos removal site.

The APC "Junior Enclosure" used in this study was about 3 feet long with a single pair of gloves; only one worker could be accommodated. However, a crew of two, working on a mobile scaffold, was required to move the APC and to remove and replace the filled collection bags. When a new, empty bag was installed, the vacuum bypass was used to reduce the pressure differential until the bag was loaded with enough debris to prevent it from being drawn up into the APC. Because the negative pressure tended to collapse the bag, it was necessary for the second worker to pull the walls apart, squeeze the bag, or otherwise force the debris to the bottom.

Asbestos removal was done at night so that the normal daytime use of the building was not affected. In general, work areas were isolated on one night and asbestos lagging was removed the following night. The workers were experienced in asbestos abatement, but were not entirely familiar with the use of the APC. A foreman gave on-the-job instruction during the removal operations in Area B (30 by 20 feet). Lagging was removed from Area C (30 by 30 feet) on the next night. The lagging from a 15-foot section in an open loft area (Area D) was removed without secondary isolation on the last night.

Workers wore half-face respirators with HEPA filters and Tyvek® hooded coveralls with boots during the removal operations. Work was conducted on very hot summer nights, and the pipe carried high-pressure steam. As a result, the temperature within the unventilated containment areas increased as the lagging was removed. Crew members rotated in and out of the work area every 20 to 30 minutes.

CNAGB System

For the CNAGB system, asbestos-containing lagging was removed from a run of three parallel pipes in a college dormitory recreation room. About 145 feet of Aircel thermal insulation was removed from the 48 foot runs of 1-, 2-, and 3-inch hot water pipes. The Aircel contained 45 to 60 percent chrysotile and the joint cement on 13 pipe fittings contained 10 to 20 percent amosite and 30 to 40 percent chrysotile. The study area (Figure 4) was divided into three test

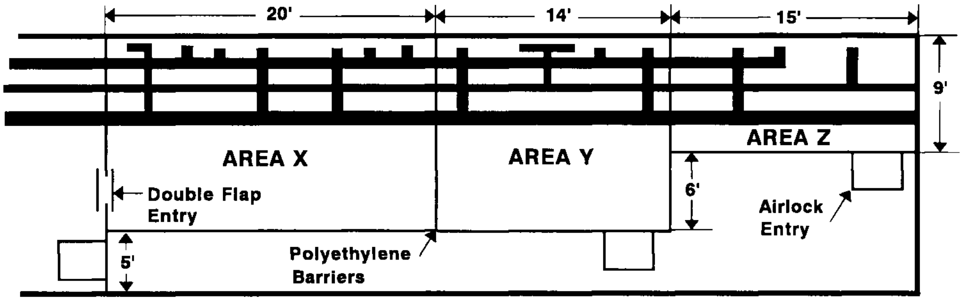

FIGURE 4. Custom negative-air glove bag asbestos removal site.

sections designated "X," "Y," and "Z." Area X (15 by 20 feet) was used for on-site training. The other containments, Area Y (15 by 14 feet) and Area Z (15 by 9 feet) were study areas. Each pipe run was wrapped separately, and the areas were isolated from floor to ceiling (12 feet) by 6-ml poly. Conventional abatement enclosure airlock entries were provided for entry to the study areas; however, shower facilities were not provided in the immediate area. The study areas were not ventilated.

The abatement work crew was experienced in abatement methods and the use of conventional glove bags, but were unfamiliar with CNAGB system. A half day of classroom instruction and a day and a half of on-site training on how to construct and use a CNAGB was provided in Area X. After the containment of Area X was completed, a CNAGB was constructed enclosing all three pipes. The lagging was removed from pipe enclosed in this bag the following day, and the periphery of Areas Y and Z was isolated by poly. The study continued for three days with the construction of a CNAGB and asbestos removal in each of these areas. Workers wore half-face respirators with HEPA filters and Tyvek hooded coveralls with boots during the removal operations.

Smoke tubes were used to test the integrity of the construction, (i.e., to identify major leaks that developed in the course of removal and to determine the effectiveness of capture at small openings and minor leaks). The pressure differential between the inside and outside of the bag was measured occasionally with a magnahelic gauge; the differential ranged from 0 to 0.5 inches water gauge but normally was between 0.02 and 0.07 inches.

When the asbestos removal was completed, the inside of the bag and its support structure was washed thoroughly and the wet bag was collapsed against the frame. The framework was dismantled inside the bag, and the PVC pipe was wiped clean as it was extracted through small slits cut in the bag. The CNAGB was removed from the hot water pipes starting at the end furthest from the vacuum source. A cut was made at the top and continued toward the other end as the portion of the bag released was rolled up beneath the pipes. When completely freed, it was overwrapped and drummed for disposal.

Methodology

Sampling

Personal breathing zone (PBZ) samples were collected and analyzed in accordance with NIOSH Method 7400[5] with the use of 25-mm diameter, mixed cellulose ester filters. Sample volumes of approximately 300 L were collected using personal pumps precalibrated at a flow rate between 2.5 and 3.5 L/min. Carbon-impregnated polypropylene cassettes and cowls minimized possible localized effects of static electricity.

A crew of four workers used the APC system. PBZ samples were taken only during removal operations and other associated activities, including waste collection and disposal, but not while the containment areas were constructed or the pipe was wrapped. As stated earlier, this system could only accommodate two workers at a time, but because of the heat, it was necessary for the workers to be relieved at 20- to 30-minute intervals by the other members of the four-man crew. The PBZ samplers were operated continuously within the containment areas and were placed on the workers as they rotated in and out of the enclosure in order to accumulate sufficient sample volumes. Because the workers performed tasks interchangeably, no attempt was made to restrict the use of one sampler to the worker using the capsule and the other to the assistant; therefore, essentially duplicate personal samples were taken over the sampling periods which lasted 2 to 3 hours. The purpose of the study was to determine the efficacy of the APC system to control asbestos, not compliance with regulations. Short-term samples were obtained by placing second sampling train on a worker for 15 to 20 minutes.

Operations using the CNAGB system were performed during the day shift by a crew of four workers. The PBZ samples were collected on two workers only while they were engaged in bag fabrication and installation, and during asbestos removal operations and other associated activities, including waste collection and disposal. These activities spanned a period of 2 to 3 hours on each shift. The workers performed all tasks interchangeably, therefore the PBZ samples were essentially duplicates. Workers were not sampled during activities associated with isolation of the test areas or while the pipes were wrapped.

Area samples for both systems were collected inside the work containments to determine asbestos concentrations in the work space within the enclosures and also outside the containments to determine the background concentration in the building. Duplicate area samples were taken at approximately the same time the PBZ sampling was performed, with the use of two side-by-side 25-mm diameter cellulose ester filters.

To assess the efficacy of the asbestos removal and preliminary cleanup operations, preremoval and postremoval air samples were obtained by sampling in the aggressive mode for about 6.25 hours to obtain an approximate 3500-L sample. In accordance with the Asbestos Hazard Emergency Response Act (AHERA)[6] procedure for aggressive sampling, dust, and fibers were dislodged from walls, ceiling, floor, and other surfaces during a 5 to 10 minute blowdown with a leaf blower; two 12-inch fans, placed on the floor and pointed upwards at about a 45-degree angle, were then operated during the entire sampling period to keep the dust and fibers suspended. Five samples were collected simultaneously on 25-mm diameter, 0.45-μm pore size, mixed cellulose ester filters. A 5.0-μm pore size, cellulose ester filter was placed between the primary filter and the backup pad in three-piece, open-face cassettes. The cassettes were hung face down approximately 5 feet above the floor. Samples were collected at a flow rate between 8.0 and 9.5 L/min. Five side-by-side outdoor ambient samples were collected through a window, well removed from the asbestos removal activities, using the same filter media and flow rate.

Analytical Methods

PBZ and area samples were analyzed by phase contrast microscopy (PCM) using NIOSH Method 7400.[5] About half of the duplicate samples were subsequently analyzed by transmission electron microscopy (TEM) using the AHERA method, as were preremoval and postremoval and ambient samples.

PCM has been used, historically, for the purpose of analyzing occupational exposures to airborne asbestos. PCM was developed for determining occupational exposure in industrial environments where airborne fibers were known to consist essentially of asbestos. Epidemiological studies have correlated observed health effects to PCM fiber counts. PCM does not, however, differentiate between asbestos and other fibrous matter such as textile or cellulose fibers nor does it detect very thin or short fibers. The OSHA PEL [200,000 fibers per cubic meter (f/m^3)] is based on a method that utilizes PCM to manually count the number of fibers greater than 5 μm in length having an aspect ratio of at least 3:1 (length:width) collected on cellulose ester filter media.[7] The NIOSH REL is 100,000 f/m^3.[8]

A note on the applicability of NIOSH Method 7400[9] states: "The method gives an index of airborne fibers. . . . Fiber [less than about] 0.25 μm diameter will not be detected by this method." The method requires a microscopist to count the number of fibers collected on several very small areas of the filter used to capture these fibers. The deposition of the fibers on the filter is assumed to be uniform. Baron and Deye[10] note, however, that "The charge in particle trajectories caused by [electrostatic] change effects can result in non-uniform deposits on the collecting filter surface and net loss of sample . . . " Therefore, although attempts are made to randomize counting areas, the specific fields counted may not be representative of the entire filter. The interlaboratory coefficient of variation (CV = 0.45) for this method is quite large when compared to the CV of about 0.1 to 0.2 for many chemical analyses. The term "index" is properly applied to the result of microscopic fiber counts, since quantitation of analytical results contains more uncertainty with respect to an absolute concentration than does the analysis of most chemicals. In spite of these limitations, PCM analysis is recognized as an appropriate index of occupational exposure for approximating disease potential. This method does have the capability of producing results rapidly (less than 24 hours) and relatively inexpensively.

As an alternative to PCM, TEM is used for asbestos counting because of both the greatly enhanced resolution and contrast and because of the analytical capability to differentiate between asbestos and nonasbestos structures. Because of the poorer resolving power of the PCM method, the Environmental Protection Agency (EPA) requires the TEM method to be used for quantitating asbestos fibers in clearing buildings for reoccupancy.[6] The greater power of the TEM method becomes important where airborne fibers with diameters less than 0.25 μm (the limit of the resolving power of PCM) are present. For example, in relatively clean buildings and in the surrounding ambient environment, there is a proportionately lower concentration of airborne fibers greater than 0.25 μm in diameter because of the rapid settling of the larger, heavier material.

TEM analyses are reported as "structures" for asbestos abatement clearance; in addition to individual fibers, asbestos structures include bundles (of parallel fibers), clusters (of randomly oriented interlocking fibers), and matrixes (of fiber and other particles). The TEM count of asbestos structures is made from a considerably smaller area of the filter than that used for PCM. This exacerbates the error due to nonuniform deposition on the filter. Other factors also can affect the result of asbestos-counting methods. As was stated above, PCM counts include all fibers observed that are greater than 5 μm in length and 0.25 μm in diameter. TEM provides the opportunity to identify and characterize all airborne fibers present in the work environment. Total fiber counts by TEM are often far higher than counts of the same sample obtained by PCM because fibers less than 0.25 μm can be seen. However, TEM counts of *asbestos fibers* include only fibers with at least a 5:1 aspect ratio, verified by their crystalline structures and elemental compositions, and can be lower than the PCM count, especially for relatively low concentrations of mixed fibers containing a high proportion of nonasbestos fibers.

Widespread use of TEM has been limited by the relative high cost of analysis, the availability of equipment and trained personnel, and the absence of a standardized method of analysis. For instance, NIOSH Method 7402,[11] in place at the time of this study, and the subsequent revision[11] employ the same mixed cellulose ester filter medium as does Method 7400 used for PCM. The EPA has developed a Yamate provisional method for TEM analysis of asbestos, a method that allows the use of either a mixed cellulose ester or a polycarbonate filter medium.[12] This EPA method was further modified for regulatory purposes when the AHERA was promulgated; it differs considerably from the NIOSH Method 7402 and the requirements of the OSHA Standard.

Findings and Observations

PCM

At the time of these studies, the second revision of NIOSH Method 7400[13] was effective. The results reported are based on the "A" rules of this revision that defines a fiber as having an aspect ratio of 3:1 or greater.

Analyses of field and quality control blanks were all within normal limits. No corrections were necessary for blank analysis. The estimated limit of detection (LOD) for Method 7400 is 7 fibers/mm^2 of filter area.[5] This is equivalent to about 3000 fibers per filter for 25-mm-diameter filters; thus, for a 300-L sample, the LOD is 10,000 f/m^3.

For the APC system, the results of samples collected while pipe lagging was being removed are shown in Table I. Concentrations indicated as "less than" are below the LOD calculated from the volume of the sample. Six of eight PBZ samples were below the LOD, and the other two were approximately equal to the LOD (4000 and 8000 f/m^3). Two short-term (15 minute) samples were also below the LOD. Area sampling results were similar; 5 of 16 approximated the LOD (3000 to 8000 f/m^3) and the other 11 were below the LOD.

For the CNAGB system, the results of samples collected while pipe lagging was being removed are shown in Table II. All of the PBZ samples and all but two of the area samples were above the LOD. The PBZ samples ranged from 8000 to 67,000 f/m^3; area samples ranged from 5000 to 67,000 f/m^3. The high concentrations occurred during construction of the containment and not during asbestos removal operations.

TEM

TEM analysis would normally have been made using NIOSH Method 7402. However, the EPA supported the abatement clearance sampling by providing TEM analysis for these and about half of the occupational exposure samples using the AHERA method. There was no established LOD for the AHERA method. The analytical laboratory reported that the filter blanks contained less than about 11 asbestos structures per square millimeter (s/mm^2) present. Assuming 11.5 s/mm^2 as the LOD for counting, then about 4500 structures would be found on a 25-mm diameter filter

TABLE I. Fiber and Asbestos Structure Concentration During Asbestos Removal Using an Aero-Pipe Capsule System

Type and Area Location of Samples	Time	Sample Volume (L)	Concentration By PCM (f/m^3)[A]	Concentration By TEM (s/m^3)[B]
Personal breathing zone samples				
B	Day 1	402	<(8000)	159,000
	Day 1	402	8000	NA
C	Day 2	550	<(6000)	237,000
	Day 2	552	<(6000)	113,000
	Day 2	529	<(5000)	46,000
	Day 2	571	4000	NA
D	Day 3	335	<(9000)	115,000
	Day 3	347	<(9000)	NA
D (short term)[C]	Day 3	45	<(68,000)	185,000
	Day 3	63	<(48,000)	68,000
Area samples				
B (outside)	Day 1	402	<(8000)	76,000
	Day 1	402	8000	NA
	Day 1	1009	<(3000)	48,000
	Day 1	1012	3000	NA
C (Inside)	Day 2	735	7000	NA
	Day 2	745	<(4000)	240,000
	Day 2	363	8000	NA
	Day 2	363	<(8000)	247,000
	Day 2	996	<(3000)	167,000
	Day 2	996	3000	NA
	Day 2	369	<(8000)	56,000
	Day 2	357	<(8000)	NA
D (proximate)	Day 3	426	<(7000)	NA
	Day 3	426	<(7000)	123,000
Ambient	Day 3	1209	<(2000)	NA
	Day 3	1208	<(2000)	<(3000)

[A]Fibers per cubic meter.
[B]Structures per cubic meter.
[C]15-minute sampling period.
NA = Not analyzed;
< = less than the limit of detection for the sample volume.

(NIOSH Method 7400 states that the effective capture area is about 385 mm^2). Thus, for a 300-L sample, an LOD of 15,000 s/m^3 (4500 structures/0.3 m^3) may be calculated.

For the APC system, one of each of the pairs of samples collected during asbestos removal was also analyzed by TEM. These results, shown in Table I, ranged from less than 3000 s/m^3 for one ambient sample to 247,000 s/m^3 for a sample taken within the containment while asbestos removal was being performed in the APC system.

Results of samples collected to determine the preremoval and postremoval concentrations of asbestos structures in Areas B and C are shown in Table III. These data indicate that in Area B the asbestos structure contamination increased from an average of about 27,000 s/m^3 before removal to 74,000 s/m^3 after removal was completed. Average contamination in Area C was about an order-of-magnitude greater than that in Area B; it increased from about 265,000 s/m^3 before removal to 783,000 s/m^3 after removal was completed.

For the CNAGB system, one of each of the pairs of samples collected during asbestos removal was also analyzed

TABLE II. Fiber and Asbestos Structure Concentration During Asbestos Removal Using a Custom Negative-Air Glove Bag System

Type and Area Location of Samples	Time	Sample Volume (L)	Concentration By PCM (f/m³)[A]	Concentration By TEM (s/m³)[B]
Personal breathing zone samples				
X	Day 1	528	12,000	69,200
	Day 1	544	13,000	NA
*	Day 2	706	29,000	115,000
	Day 2	682	67,000	NA
Y	Day 3	386	11,000	187,000
	Day 3	493	12,000	NA
Z	Day 4	501	8000	107,000
	Day 4	486	8000	NA
Area samples				
X (outside)	Day 1	495	<(6000)	109,000
	Day 1	493	14,000	NA
	Day 1	523	10,000	35,000
	Day 1	525	17,000	NA
Y (Inside)	Day 2	672	45,000	40,000
	Day 2	672	45,000	NA
Y (outside)*	Day 2	688	30,000	<(7000)
	Day 2	682	67,000	NA
Y (inside)	Day 3	658	5000	32,000
	Day 3	658	<(5000)	NA
Y (outside)	Day 3	652	14,000	<(7000)
	Day 3	654	14,000	NA
Z (inside)	Day 4	525	6000	53,000
	Day 4	523	6000	NA
Z (outside)	Day 4	535	38,000	8000
	Day 4	535	38,000	NA

*During construction of the custom negative-air glove bag there was no asbestos removal.
See Table I for explanations and abbreviations.

by TEM. These results, shown in Table II, range from less than 7000 (LOD) to 187,000 s/m³.

To save time and resources, the perimeter of the adjacent Areas Y and Z was isolated and preremoval samples were taken in the combined volume. A poly barrier was then constructed to separate the space into the two areas for abatement and postremoval sampling evaluations. Postremoval concentration samples were collected from each area after completing the asbestos removal and the initial cleaning and after the area was dried out (oscillating fans were operated several hours to assist the drying process). Results are shown in Table IV. These data indicate that Area Z postremoval samples are significantly lower than the preremoval samples. The outdoor ambient concentrations were less than 1400 s/m³. As shown, the postremoval values for Area Z (between <1200 and 2600 s/m³) were only slightly above this level, and the average postremoval level in Area Y was 6600 s/m³.

TABLE III. Aero-Pipe Capsule System Preremoval and Postremoval Asbestos Concentrations Determined by TEM Analysis*

Area B		Area C	
Preremoval	Ambient	Preremoval	Ambient
36,700	1200	254,100	1200
40,700	<(1200)	299,300	<(1200)
17,000	<(1100)	300,900	1200
17,900	1200	240,700	<(1300)
23,300	<(1200)	227,500	1200
Average		Average	
27,100		264,500	
Postremoval	Ambient	Postremoval	Ambient
74,400	<(1300)	444,700	<(1300)
67,900	<(1300)	696,600	<(1300)
61,800	<(1200)	687,900	<(1200)
89,100	<(1300)	1,502,000	<(1300)
74,600	<(1300)	582,200	<(1300)
Average		Average	
73,600		782,600	

*Structures/cubic meter.
See Table I for explanations and abbreviations.

TABLE IV. Custom Negative-Air Glove Bag System Preremoval and Postremoval Asbestos Concentrations Determined by TEM Analysis*

Area Y		Area Z	
Preremoval	Ambient	Preremoval	Ambient
14,800	<(700)	14,800	<(700)
5500	<(700)	5500	<(700)
9100	<(700)	9100	<(700)
10,100	<(800)	10,100	<(800)
16,800	<(700)	16,800	<(700)
Average		Average	
11,300		11,300	
Postremoval	Ambient	Postremoval	Ambient
10,300	<(1,100)	1200	<(1400)
1300	<(1,300)	2600	<(1400)
1300	<(1,000)	1300	<(1300)
5700	<(1,200)	1300	<(1300)
14,600	<(1,100)	<(1200)	<(1300)
Average		Average	
6600		<1500	

*Structures/cubic meter.
See Table I for explanations and abbreviations.

Discussion

Worker Exposure

Because of the limited number of observations obtained during asbestos removal operations, statistical analysis has little power in detecting true differences between the sample concentrations. The PCM results (Tables I and II) indicate that both the APC and CNAGB systems, as used in this study, provided worker protection well below the NIOSH REL (100,000 f/m³) and the OSHA PEL (200,000 f/m³). The PBZ exposures measured when the APC system was used were all at or below the LOD for the volume of air sampled (< 10,000 f/m³). PBZ exposures for the CNAGB system were somewhat higher. The maximum measured, 67,000 f/m³, occurred during the construction of the containment and the CNAGB in Area Z. This may have been an anomaly, because fiber concentrations determined in that area the next day were lower (12,000 f/m³).

Results from area samples were similar to those of the PBZs. The concentrations measured using the APC system were at or below the LOD, and those measured for the CNAGB system were somewhat higher. In general, the average concentrations measured inside the poly containment areas were lower than those measured outside. As was shown by the PBZ samples, higher fiber concentrations were measured during the construction of the CNAGB in Area Z.

TEM analyses were not consistent with the PCM results, especially for the CNAGB system. High concentrations in the PBZs were shown by TEM on third and fourth days (187,000 and 107,000 s/m³, respectively) when PCM analyses indicated low levels (12,000 and 8000 f/m³, respectively). Incongruities between PCM and TEM fiber counts were discussed previously in the "Analytical Methods" section.

Environmental Exposure

The results of the preremoval and postremoval sampling indicated that asbestos contamination using the APC system increased about threefold in both areas. Based on Student's *t*-test, the differences of the average concentrations were significant ($p = 0.05$). Contamination levels in Area C were about an order of magnitude greater than those in Area B. A possible explanation for this is that removal operations were performed in Area B first. Vibrations and movement of the pipe created by these removal operations may have been transmitted along the pipe to Area C, thus causing detrition of the lagging in that area.

When the CNAGB system was used, asbestos contamination in Areas Y and Z was less after removal than before. The preremoval concentration in the combined area averaged 11,300 s/m³. The average postremoval concentration in Area Y was 6600 s/m³, in Area Z it was less than the LOD of 1500 s/m³. A *t*-test of the natural logs of the concentrations showed that the preremoval versus postremoval difference is not significant in Area Y but is significant ($p = 0.05$) in Area Z.

The dimensions (length and width) of the asbestos structures counted by TEM were recorded and a distributional analysis of the structures was made. Figure 5 is a plot of the average cumulative concentration, by length of asbestos structure, for asbestos structures counted in the preremoval and postremoval samples collected in Areas B and C when the APC system was used. Figure 6 is a similar presentation for Areas Y and Z when the CNAGB system was used.

Figures 7–10 are plots of the length-to-width relationship of the asbestos structures. In the upper right hand corner of these plots is a "PCM window" that includes those structures having a length of at least 5 μm (horizontal line), a diameter of at least 0.25 μm (vertical line), and aspect ratios of 5:1 (left sloping line) and 3:1 (right sloping line). The preremoval and postremoval concentrations in Area C, when the APC system was used, are illustrated in Figures 7 and 8, respectively. Structures found in the preremoval samples in Area Y, when the CNAGB system was used, are shown in Figure 9 and structures found in the postremoval samples are shown in Figure 10. These plots graphically illustrate that very few structures were in the visible PCM range.

Conclusions/Recommendations

Under the conditions of this study, and based on data analyzed by PCM, worker exposures were well below the OSHA PEL and the NIOSH REL when the APC and the CNAGB systems were used for the removal of asbestos-

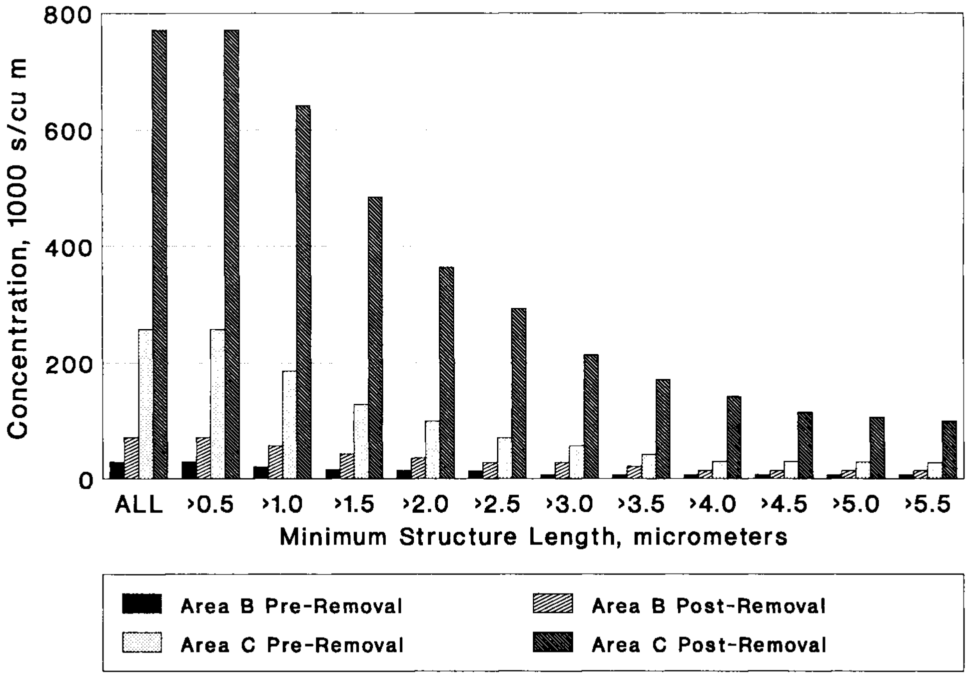

FIGURE 5. Cumulative asbestos structure concentrations (TEM) by structure length before and after removal with the Aero-Pipe Capsule.

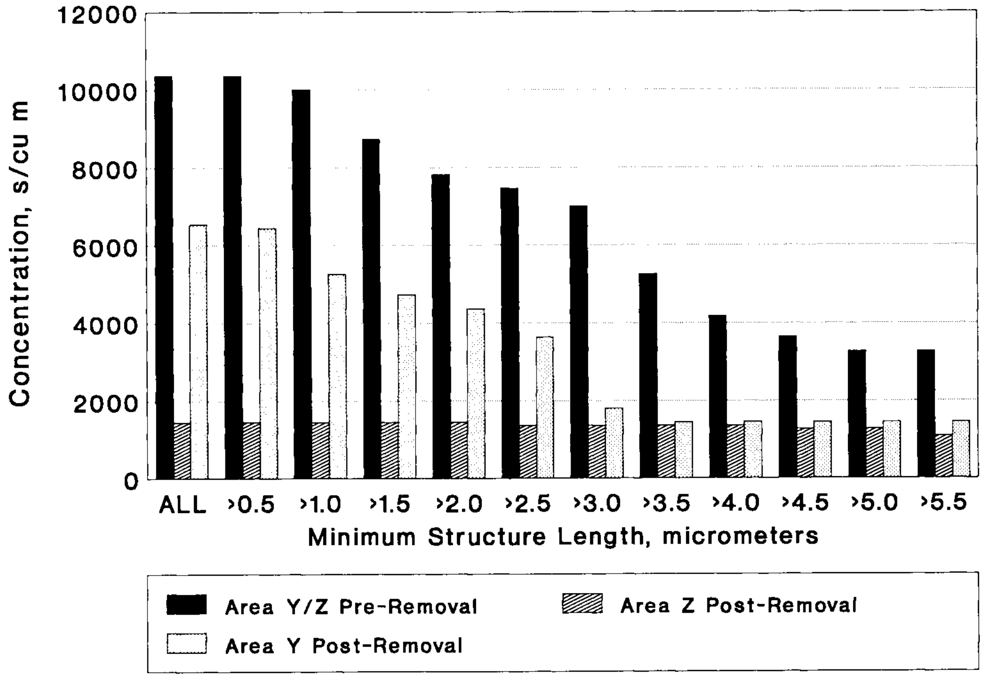

FIGURE 6. Cumulative asbestos structure concentrations (TEM) by structure length before and after removal with the custom negative-air glove bag.

containing pipe lagging. The data from TEM-analyzed samples indicated that there may have been a increase in total fibers as a result of the asbestos removal procedure. Prudent practice is to provide the most reliable protection possible against carcinogens such as asbestos. NIOSH recommends that asbestos exposure be reduced to the lowest feasible concentration. The concept of a negative-pressure glove bag is clearly better than that of standard glove bag; if leakage occurs, it will draw air into the bag rather than allow the contents to escape into the work area. Design of

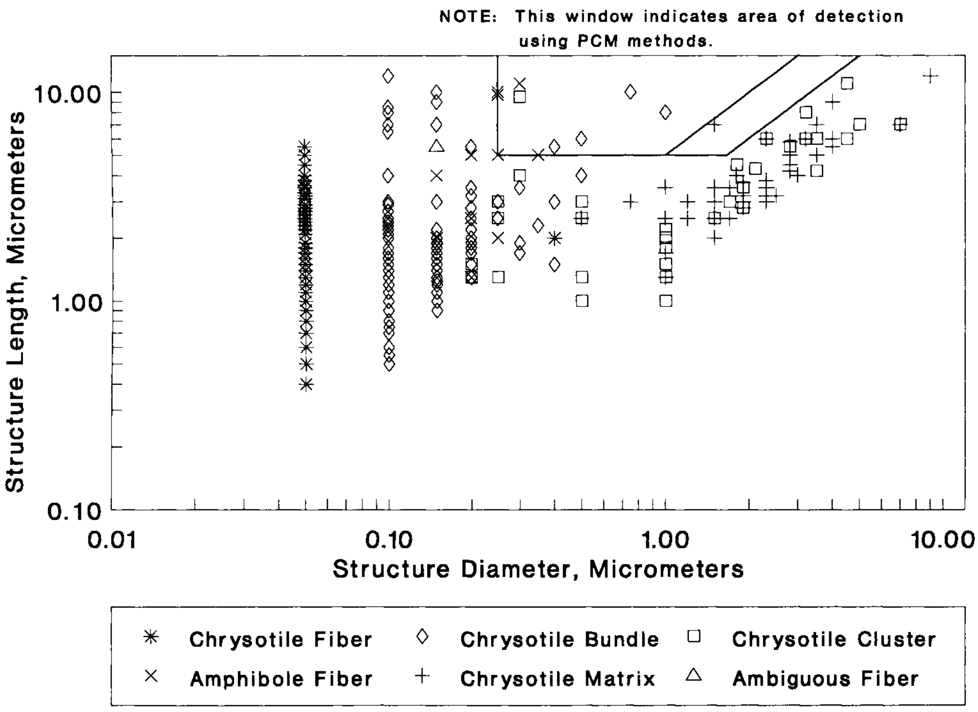

FIGURE 7. Length versus diameter plot of asbestos structures (TEM) collected in Area A prior to asbestos removal with the Aero-Pipe Capsule.

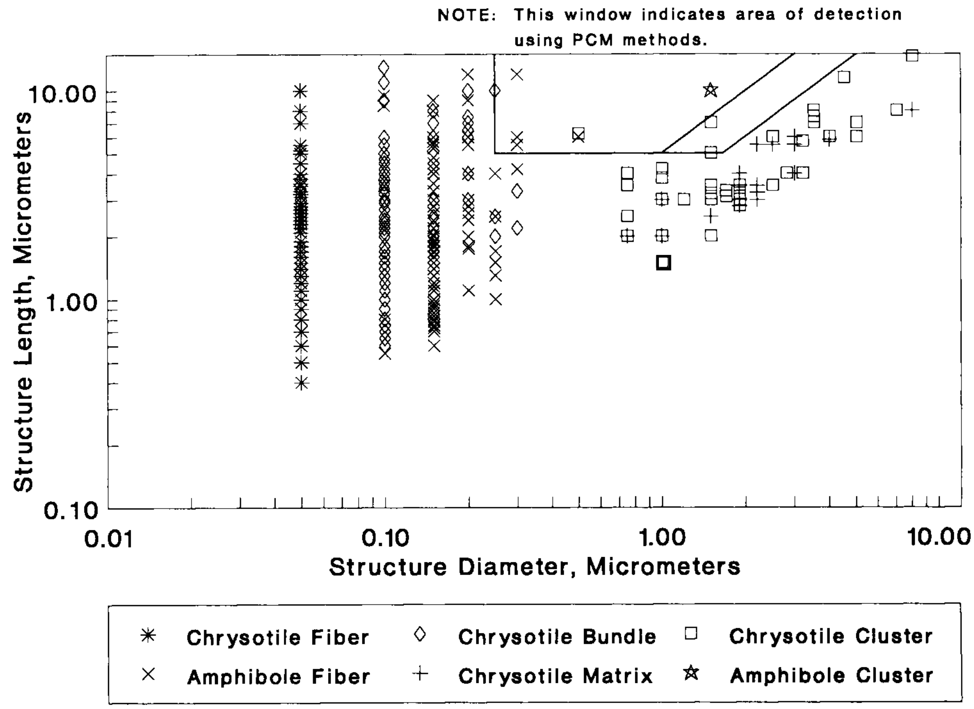

FIGURE 8. Length versus diameter plot of asbestos structures (TEM) collected in Area A after asbestos removal with the Aero-Pipe Capsule.

any negative-air bag or negative-air bag system should, however, be evaluated by air sampling to ensure that, under the conditions of use, sufficient pressure differential is maintained to prevent asbestos fibers from escaping the bag.

The CNAGB enclosure system would be especially appropriate for removing pipe lagging where the use of ordinary glove bags would prove difficult, such as situations where there are multiple parallel pipe runs, where much branching exists, where there are many fittings/fixtures, or

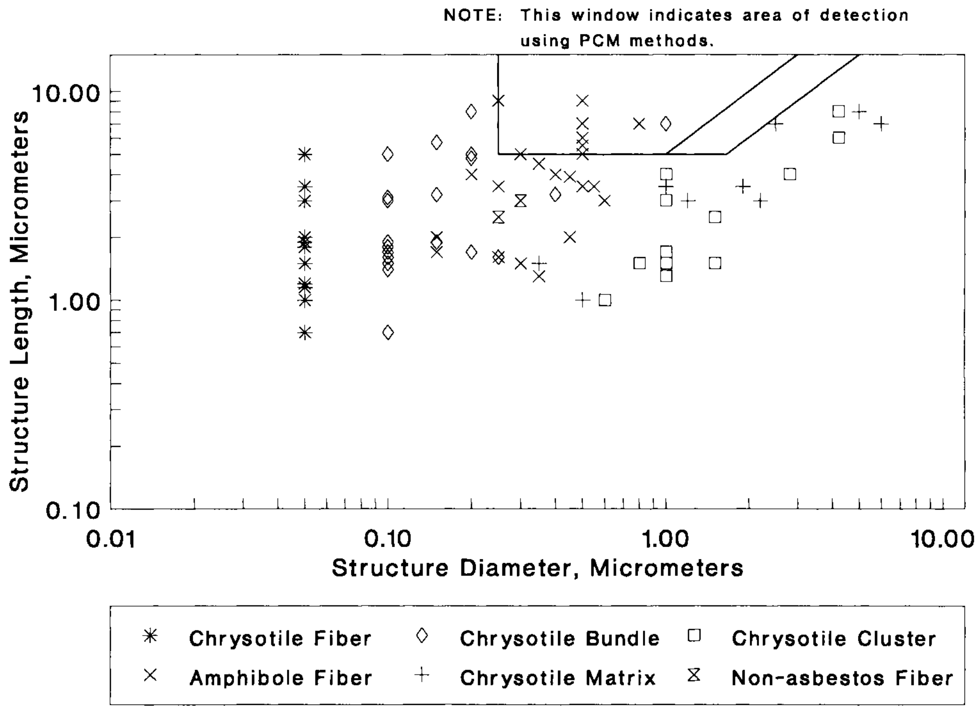

FIGURE 9. Length versus diameter plot of asbestos structures (TEM) collected in Area Y prior to asbestos removal with the custom negative-air glove bag.

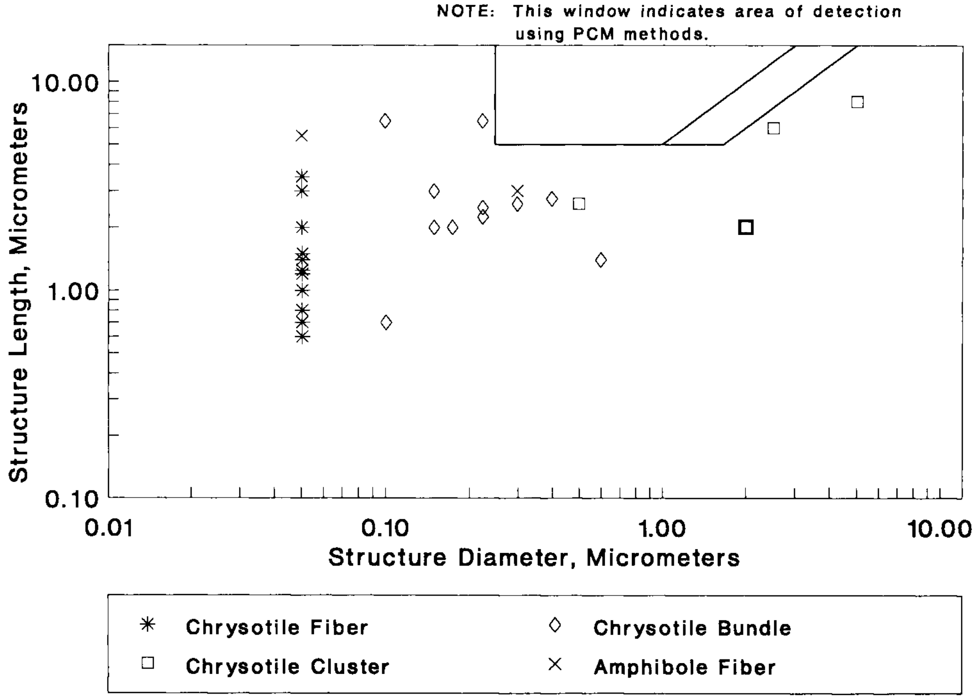

FIGURE 10. Length versus diameter plot of asbestos structures (TEM) collected in Area Y after asbestos removal with the custom negative-air glove bag.

where there is any combination of these. It can be used on both horizontal and vertical pipe runs and for other structures of irregular shape, such as tanks and reservoirs. Because of the materials of construction and the availability of heat-resistant gaskets, the APC system is especially useful when working on hot pipes. Although various capsule designs allow work on configurations other than straight-run piping, each capsule represents an investment, maintenance, and storage cost not associated with the expendable CNAGB system.

Respiratory protection and disposable coveralls should be used with either of these controls to provide protection against accidental asbestos releases that may occur because of the loss of vacuum, seal failure, or the rupture of a bag. NIOSH recommends the use of any self-contained respirator equipped with a full facepiece and operated in a pressure-demand or other positive-pressure mode, or any supplied-air respirator equipped with a full facepiece and operated in a pressure-demand or other positive-pressure mode in combination with an auxiliary, self-contained breathing apparatus operated in a pressure-demand or other positive-pressure mode when exposures exceed the NIOSH REL. Where exposure concentrations have been documented to be below the NIOSH REL, or where certain small-scale, short-duration tasks must be performed (e.g., maintenance and repair), or where the most protective respirators cannot be feasibly used, tight-fitting, high-efficiency, powered, air-purifying respirators and the non-powered, full facepiece, high-efficiency respirators are recommended.[8]

Back-up containment or isolation of the working area also may be necessary to avoid contamination of the surroundings if an accident should occur or where preexisting contamination (i.e., damaged pipe lagging or the presence of friable asbestos-containing materials) is likely to be disturbed. Where possible, when aggressive sampling will not cause additional contamination by disturbing damaged ACM, sampling should be done in an aggressive mode to estimate the amount of contamination present before beginning removal operations; this can help establish the need for additional precautions.

Further evaluation of these controls under varied work conditions is warranted to validate performance and better define optimum work practices. Data from these studies are insufficient to define conditions where negative-pressure glove bags can be used without back-up containment of the work area; additional work might establish these parameters. Even if it can be determined that such containment is unnecessary, because of the potential for accidental or inadvertent release of asbestos fibers, it is prudent that respiratory protection be provided for workers whenever glove bags are used.

These studies were performed in 1988 and represent state of the art at that time. We believe that since that time improvements have been made in the design of glove bags and in worker training. Perhaps the research suggested in the previous paragraph has been completed. We encourage investigators to publish their findings so that the occupational health community can be informed as to the efficacy of current techniques in use with negative-air glove bags.

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