IN-DEPTH SURVEY REPORT
EVALUATION OF A CUSTOM FABRICATED NEGATIVE AIR GLOVE BAG DURING THE REMOVAL OF ASBESTOS-CONTAINING PIPE LAGGING

Conducted at
The University of Massachusetts
Amherst, Massachusetts

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DISCLAIMER

INTRODUCTION

Under the Occupational Safety and Health Act of 1970, the National Institute for Occupational Safety and Health (NIOSH) was assigned responsibilities for conducting research in occupational safety and health, for disseminating information emerging from those studies, for recommending standards to regulatory agencies, and for supporting the training of professionals in occupational safety and health It was placed in the Department of Health and Human Services (formerly, the Department of Health, Education, and Welfare) to conduct research and education programs separate from the standard setting and enforcement functions conducted by the Occupational Safety and Health Administration (OSHA) in the Department of Labor

An important area of NIOSH research deals with methods for controlling occupational exposure to potential biological, chemical, and physical hazards The Engineering Control Technology Branch (ECTB) of the Division of Physical Sciences and Engineering has been given the lead within NIOSH to study the engineering aspects relevant to the control of these hazards in the workplace Since 1976, ECTB has conducted assessments of control technology methods used in industry on the basis of controls used within a selected industry, controls used for common industrial processes, or specific control techniques The objective of these studies has been to document and evaluate effective control techniques (e g , isolation or the use of local ventilation) that minimize risk of potential health hazards, and to create an awareness for the need for or the availability of effective hazard control measures A number of studies on control assessments, including the present study, have been performed in collaboration with the Environmental Protection Agency (EPA)

The results of a previous study[1] indicated that glove bags are a useful engineering tool to reduce worker exposure to asbestos during the removal of asbestos-containing materials (ACMs), however, as used in that study, they did not completely contain the asbestos being removed Because of the potential for leakage of the glove bag and accidental rupture of the bag or seals, the use of personal protective equipment (e g , disposable coveralls, respiratory pressure enclosure) was recommended for use during any glove bag operation The objective of the present study was to conduct a brief evaluation of the efficacy of a Custom Fabricated Negative Air Glove Bag to control worker exposure during its use in asbestos removal The Custom Fabricated Negative Air Glove Bag is designed to use local exhaust ventilation as an auxiliary control for glove bag containment The concept of the design is that if leakage of the seals occurs, outside air always will flow into the bag thereby preventing the flow of contaminated air out of the bag and into the workplace

The EPA also has interest in effective techniques for the control of emissions created by asbestos removal operations in order to prevent contamination of the environment and to protect the health of persons occupying or working in buildings where asbestos abatement is done and of the general population As part of a cooperative agreement with the EPA, additional work was performed to determine the efficacy of the Custom Fabricated Negative Air Glove Bag system to control ambient atmospheric asbestos concentrations when asbestos containing materials are removed

BACKGROUND

A pilot study of asbestos abatement operations conducted in 1984 by NIOSH researchers identified novel approaches that have been and are being developed to control asbestos fiber exposure to workers engaged in the removal of asbestos-containing materials [2] Two principle methods currently used to control airborne asbestos exposures are wetting the ACMs and the use of negative pressure enclosures in the workplace Wetting methods utilize fluids to saturate ACMs before and during the removal of these materials to reduce the potential for the asbestos fibers to become airborne Exposure control by negative pressure is accomplished by the use of fans or exhaust devices to remove contaminated air from work areas which have been isolated with temporary walls made of plastic sheeting, and to draw clean dilution air into these enclosed work areas. In order to contain and reduce airborne asbestos emissions, the exhausted air is filtered through high efficiency particulate air (HEPA) filters before being released to the atmosphere

NIOSH researchers believe that containing asbestos as it is removed provides a distinct advantage in controlling airborne asbestos levels The evaluation of source controls, such as containment or local ventilation applied at the source of the emission, is therefore of particular interest because these are generally the most effective in controlling both occupational exposure and environmental releases An asbestos abatement activity that is frequently performed is the removal of pipe lagging, (i e , ACM used to insulate pipes carrying heated or refrigerated liquids or vapors) Glove bags are often used as source controls during the removal of pipe lagging These are large plastic bags with long gloves sealed into the body of the bag The worker seals the bag around the material to be removed and then manipulates various removal tools within the bag by means of these gloves in order to remove the lagging The ACM and other debris falls to the bottom of the bag, where it is contained for final disposal as asbestos waste in accordance with regulations promulgated by the EPA and by State and local governments Glove bags may also be used for general plant maintenance where ACMs are removed only to gain access to valves or other insulation covered items that need repair The authors believe that reliable containment that does not depend on careful training is especially important in this case, because workers who only remove asbestos lagging occasionally should not be expected to remember detailed work practices

For general asbestos abatement operations worker training and the use of careful work practices are important because glove bags are often used without other means of containment, such as total 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 very important to assure the health of workers and to prevent contamination of the adjoining workplaces and the environment As noted previously, glove bag systems that utilize internal negative pressure, such as the Custom Fabricated Negative Air Glove Bag, have been developed to provide more reliable containment

SITE AND PROCESS DESCRIPTION

The asbestos removal process studied at the University of Massachusetts involved the construction of a Custom Fabricated Negative Air Glove Bag enclosure on site to fit the task and the removal of thermal insulation from three hot water pipes The University volunteered to participate in this research project and provided access to the test facility and an abatement work crew experienced in conventional abatement methods (including the use of glove bags) The crew received a half day of classroom instruction and one and a half day of hands on, on-site training This training was provided by Dr Joseph Guth of Interscience Research, Norfolk, VA on Saturday and Sunday He has provided similar training to the US Navy and other clients in the past The training included manuals and demonstrations with training aids

This study was performed in a 57-ft x 20-ft dormitory activity room which was divided into four test containments as shown in Figure 1 About 145 feet of Aircel thermal insulation was removed from approximately equal lengths of 1", 2", and 3" hot water pipes as was the asbestos magnesium insulation on 13 tees The Aircel contained 45 to 60% chrysotile and the joint cement 10 to 20% amosite and 30 to 40% chrysotile The three parallel pipes ran full length along one side of the room and across one end, about a foot below the 12-foot ceiling Each pipe run was separately enclosed in a poly envelope The lagging on the pipe along the end of the room was visibly damaged and was enclosed (Area A) for removal after the completion of this study

The remaining 48 feet of the pipe runs were divided into three areas Training was conducted in Area B (15 x 20 feet), the other two containments, Area C (15 x 14 feet) and Area D (9 x 15 feet) were areas used for the present study They were isolated by means of walls fabricated from 6 mil polyethylene from floor to ceiling Conventional abatement enclosure airlock entries were provided for Areas A, C, and D, access to Area B was through a double flap entry opening between Area A and B On Saturday, Area B was completed to provide a teaching area for the fabrication of a glove bag enclosure The glove bag was constructed under the direction of Dr Guth on Sunday On Monday, morning the walls for Areas C and D were erected except for the partition separating them Pre-removal, aggressive monitoring was accomplished in Area C/D while the training removal was conducted in Area B

On Tuesday morning, Area D was isolated from Area C and the remainder of the day was spent fabricating the bag in Area C On Wednesday morning, this bag was completed and removal was started The removal was completed in Area C that afternoon and good progress was made on the fabrication of the Area D bag Area C post-removal, aggressive sampling was completed that night On Thursday morning, workers were shown a video replay of the highlights of the previous day's activities and were also provided with constructive feedback The Area D bag was then completed and an air lock was constructed In the afternoon removal was completed and post-removal, aggressive sampling was performed that night

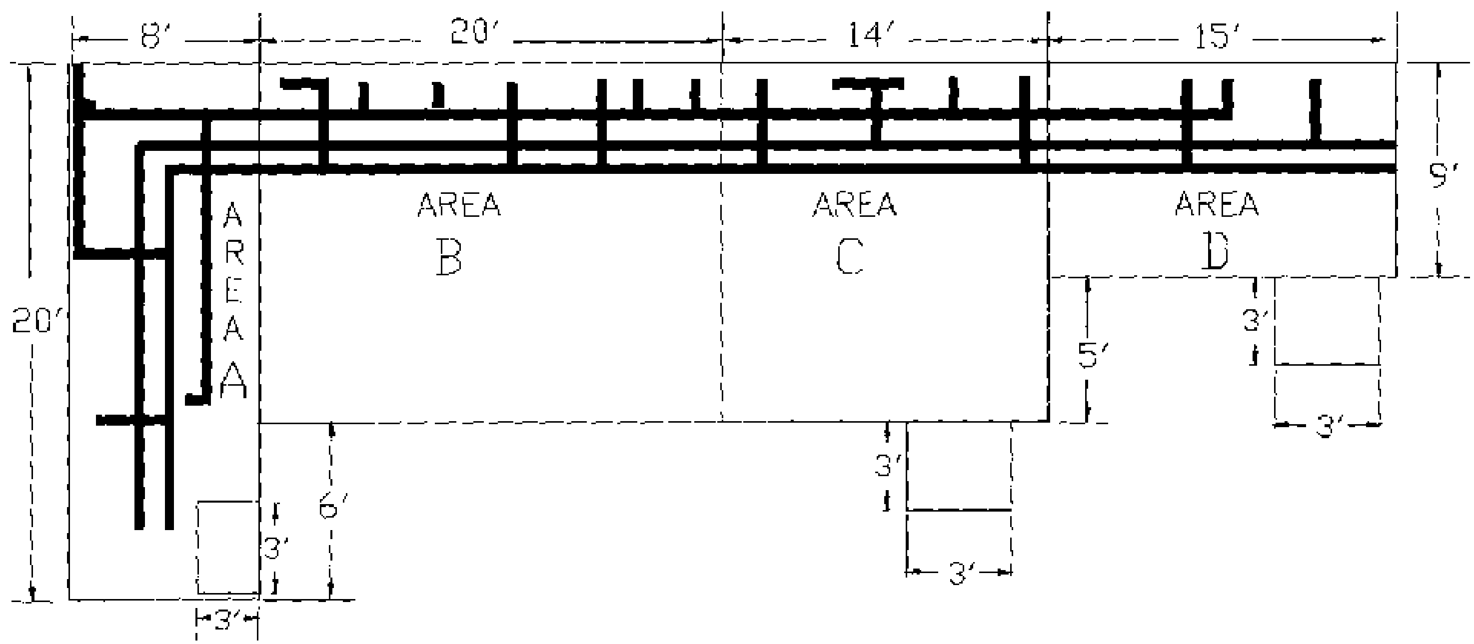


Figure 1. Negative Air Glove Bag Asbestos Removal Project
University of Massachussetts

The construction of a Custom Fabricated Negative Air Glove Bag was accomplished using large sheets of polyethylene, gauntlet gloves, spray adhesive, tape, and high efficiency particulate air (HEPA) respirator cartridges (See Figure 1A) Alternatively, prefabricated glove and arm inserts can be purchased from glove bag manufacturers for installation in the bag The bag was sized to contain the amount of removal work to be accomplished in one day A framework was constructed around the pipes from which lagging was to be removed to support the bag and to prevent it from collapsing under negative pressure This was fabricated from 1" PVC pipe for this study, and was suspended with wires from various available points of attachment, i e , pipes, pipe hangers, brackets, etc The bag was constructed to fit loosely around the removal area to allow the workers ample space to manipulate their arms and hands in the gloves within the bag Although Dr Cuth recommended laying out the poly to the dimensions of the bag and installing the gloves before hanging it over the framework, the work crew preferred to install the gloves after the bag was formed over the supporting framework

A large, three blower Nilfisk® HEPA vacuum cleaner was used to exhaust air from the bag The amount of vacuum necessary to maintain an effective negative pressure depends on the size and tightness of the construction The HEPA-filter respirator cartridges were installed in the walls of the bag to provide a restricted flow of replacement air and to prevent the release of asbestos due to backflow in case of a vacuum source failure or if the pressure in the bag became positive for a brief period due to work activity

Waste disposal chutes were built into the bottom of the bag at convenient intervals and waste bags were attached with adhesive and duct tape to receive the debris The waste bags were fitted into fiber drums which sat on the floor When a waste bag was filled, both the neck of the bag and the chute were twisted, separately sealed with duct tape, and then the bag was cut off between the seals A replacement waste bag (in a separate fiber drum) was taped to the chute After the duct tape sealing the chute was removed, the chute was untwisted so that additional debris could be removed from the same area During the first removal operation in the training area B, the disposal chutes were constructed of poly tubing which tended to collapse due to the negative pressure It required much manual manipulation on the outside of the chutes to force the debris into the waste bags To relieve this problem, the plain poly tubing was replaced with spiral wire wound reinforced poly tubing in the subsequently-constructed glove bags

The removal work inside the bag was performed under a net negative pressure Smoke tubes were useful to test the integrity of the construction, i e , to identify major leaks which developed in the course of removal and to determine the effectiveness of capture at small openings and minor leaks A magnahelic gauge was be used to measure the negative pressure (vacuum) in the bag

When the asbestos removal was completed, the pipes and the bag and its supporting structure were washed thoroughly, then the wet bag was collapsed by removing the pipe framework while the vacuum was operating The PVC pipe was wiped clean with a wet rag as it was extracted Next, the containment bag was cut free along the top and simultaneously rolled up under the pipes It was then bagged for disposal.

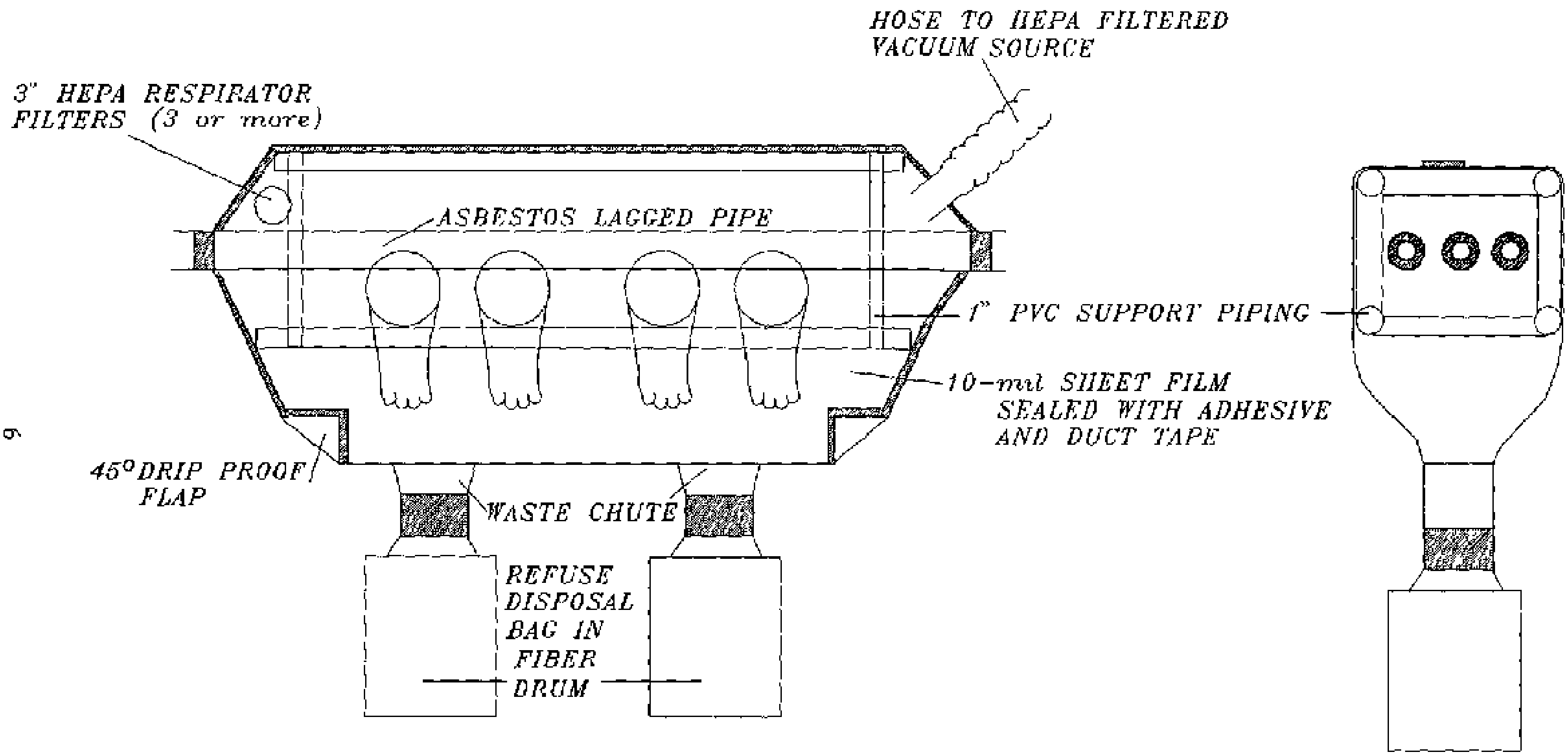


Figure 1-A. Custom Fabricated Negative Air Glove Bag

OCCUPATIONAL EXPOSURE CRITERIA

Because asbestos is a human carcinogen, NIOSH recommends that exposure of workers to asbestos be reduced to the lowest feasible limit In 1984, NIOSH reaffirmed its previously recommended exposure limit (REL) not to exceed 100,000 fibers greater than 5 micrometers (μm) in length per cubic meter (f/m^3) or 0 1 fibers per cubic centimeter (f/cc) based on the limit of quantification for analysis of samples by PCM [3] On January 23, 1991, at the hearing on OSHA's Notice of Proposed Rulemaking on Occupational Exposure to Asbestos, Tremolite, Anthrophyllite, and Actinolite,[4] NIOSH provided the following Statement of Policy

"On June 21, 1984, NIOSH testified at the OSHA public hearings on occupational exposure to asbestos and presented supporting evidence that there is no safe airborne concentration of fibers for any of the asbestos minerals [3,5] NIOSH stated that not even the lowest fiber exposure limit could assure all workers of absolute protection from exposure-related cancer This conclusion was consistent with previous positions taken by NIOSH in the 1976 criteria document on asbestos[6] and the joint NIOSH/OSHA report of 1980 [7] In its 1984 testimony, NIOSH urged that the goal be to eliminate exposures to asbestos, or where they cannot be eliminated, to limit them to the lowest possible concentration [3]

"NIOSH concluded (1) that for regulatory purposes, phase contrast microscopy (PCM) was still the most practical technique for assessing exposures to asbestos fibers when using the criteria given in NIOSH Analytical Method 7400 and (2) no distinction should be made between airborne exposures to asbestos fibers and their nonasbestiform analogues when they meet the criteria of a fiber as defined on a microscopic level [5] NIOSH also recognized that PCM lacks specificity when asbestos and other fibers occurred in the same environment, and that PCM cannot detect fibers with diameters less than approximately 0 25 micrometer NIOSH further stated that it might be necessary to analyze samples by electron microscopy where both electron diffraction and microchemical analysis can be used to help identify the type and concentration of asbestos fiber "

In the 1990 testimony NIOSH recommends the following to be adopted for regulating exposures to asbestos

"The current NIOSH asbestos recommended exposure limit is 100,000 fibers greater than 5 micrometers in length per cubic meter of air, as determined in a sample collected over any 100-minute period at a flow rate of 4 L/min This airborne fiber count can be determined using NIOSH Method 7400[8], or equivalent In those cases when mixed fiber types occur in the same environment, then Method 7400 can be supplemented with electron microscopy, using electron diffraction and microchemical analysis to improve specificity of the fiber determination NIOSH Method 7402[7] provides a qualitative technique for assisting in the asbestos fiber determinations Using these microscopic methods, or equivalent, airborne asbestos fibers are defined, by reference, as those particles having (1) an aspect ratio of 3 to 1 or greater, and (2) the mineralogic characteristics (that is, the crystal structure and elemental composition) of the asbestos minerals and their nonasbestiform analogues "

NIOSH also includes the following statement on asbestos in pertinent Health Hazard Evaluations

"NIOSH recommends as a goal the elimination of asbestos exposure in the workplace, where it cannot be eliminated, the occupational exposure to asbestos should be limited to the lowest possible concentration [3] This recommendation is based on the proven carcinogenicity of asbestos in humans and on the absence of a known safe threshold concentration

"NIOSH contends that there is no safe concentration for asbestos exposure Virtually all studies of workers exposed to asbestos have demonstrated an excess of asbestos-related disease NIOSH investigators therefore believe that any detectable concentration of asbestos in the workplace warrants further evaluation and, if necessary, the implementation of measures to reduce exposures

"NIOSH investigators use phase contrast microscopy (NIOSH Method 7400[8]) to determine airborne asbestos exposures, and electron microscopy (NIOSH Method 7402[9]) to confirm them The limits of detection and quantitation depend on sample volume and quantity of interfering dust The limit of detection is 0 01 fiber/cc [10,000 fibers/m^3] in a 1,000-liter air sample for atmospheres free of interferences The quantitative working range is 0 04 to 0 5 fiber/cc [40,000 to 500,000 fibers/m^3] in a 1,000-liter air sample

"The Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) for asbestos limits exposure to 0 2 fiber/cc [200,000 f/m^3] as an 8-hour TWA [10] OSHA has also established an asbestos excursion limit for the construction industry that restricts worker exposures to 1 0 fiber/cc [1,000,000 f/m^3] averaged over a 30-minute exposure period [11]"

One of the proposals of the January 23, 1991 hearing was to adopt a PEL for asbestos of 0 1 fiber/cc (100,000 fibers /m^3) for all general and construction industry workers There has been no final ruling promulgated at this time, however, NIOSH is fully in agreement with this proposal and presented the following additional discussion at the hearing [4]

"A significant consideration in establishing a PEL should be the lowest concentration that can be accurately measured using currently available analytical techniques NIOSH has concluded that (1) for regulatory purposes, PCM is the most practical technique for assessing asbestos fiber exposures when using the criteria given in NIOSH analytical Method 7400, and (2) concentrations below 0 1 fiber/cc can be accurately measured in certain occupational environments NIOSH recognizes that mixed-fiber exposures may occur in the workplace and that fibers may need to be identified In such cases, Method 7400 can be supplemented with electron microscopy as described in Method 7402, using electron diffraction and microchemical analysis to improve the specificity of the fiber determinations [5]

"In NIOSH's judgement, the establishment of a PEL or action level below 0 1 fiber/cc for most industrial or construction work sites would be difficult at this time However, any detectable concentration of asbestos found in the workplace warrants further evaluation and, if necessary, the implementation of measures to reduce exposures "

As stated, the determination of occupational exposure to asbestos according to the criteria contained in the NIOSH REL and the OSHA PEL are based on the use of the PCM analytical method This method has limitations based on the optics of the microscope and upon the ability of the microscopist to reliably discriminate fiber length to width ratios in a complex sample matrix NIOSH Method 7400[8] stipulates that only fibers longer than 5 μm be counted with a length to width ratio of either 3 1 (A rules) or 5 1 (B rules)

Exposures to airborne asbestos fiber concentrations are usually reported as the number of fibers per cubic centimeter (f/cc) of air In this report concentrations are also expressed as fibers per cubic meter (f/m^3) The amount of inspired air over the work shift of asbestos removal workers is typically 1 to 2 cubic meters of air per hour In an environment contaminated at the OSHA PEL of 0 2 f/cc [200,000 f/m^3] a worker with no respiratory protection could inhale over 2 million fibers visible by PCM during an 8-hour work shift! Because of the small size of airborne fibers, fibers observed and counted by PCM often represent only a small percentage of the total number of fibers inhaled by an unprotected worker

CONTROL TECHNOLOGY

Occupational exposures can be controlled by the application of a number of well-known principles, including engineering measures, work practices, personal protection, and monitoring These principles may be applied at or near the hazard source, to the general workplace environment, or at the point of occupational exposure to individuals. Controls applied at the source of the hazard, including engineering measures (i e , material substitution, process/equipment modification, isolation or automation, local ventilation) and work practices, are generally the preferred and most effective means of control both in terms of occupational and environmental concerns Controls which may be applied to hazardous agents that have escaped into the workplace environment include dilution ventilation, dust suppression, air filtration and recirculation, and housekeeping Control measures may also be applied near individual workers, including the use of remote control rooms, isolation booths, supplied-air cabs, work practices, and personal protective equipment

In general, a system comprised of the above control measures is required to provide worker protection under normal operating conditions, as well as under conditions of process upset, failure, and/or maintenance. Process and workplace monitoring devices, personal exposure monitoring, and medical monitoring are important mechanisms for providing feedback concerning effectiveness of the controls in use Ongoing monitoring and maintenance of controls to ensure their proper use and operation, and education and commitment of both workers and management to occupational health are also important ingredients of a complete, effective, flexible, and durable control system

Asbestos removal workers are often required to work in areas where there is a potential exposure to high levels of airborne asbestos fibers. Therefore, it is incumbent upon the employer of these workers to ensure that procedures which effectively reduce or eliminate exposure to asbestos and other hazardous materials or situations are used

DUST EXPOSURE CONTROL STRATEGY

In this asbestos removal activity, workers' dust exposures were controlled by enclosing the pipe lagging in a large custom-built glove bag which was maintained under a negative pressure (0 02 to 0 1 inches of water) by a HEPA-filtered vacuum system. The pipe lagging was wetted with amended water throughout the removal process This control system has several advantages

1 It uses wetting to inherently reduce the dustiness of the lagging that is being removed
2 It provides containment of the lagging at the source, as it is being removed
3 It provides some redundancy of control if any leakage of the seals occurs, workplace air will be drawn into the Bag due to the reduced pressure within the Bag
4 The asbestos waste is contained for subsequent handling and disposal throughout the removal process
5 The bag can be constructed to contain valves, fittings, etc and in irregular shapes to surround an amount of ACM that can be removed in a single day or less

CONTAINMENT OF THE WORK ENVIRONMENT

To provide a controlled condition for the measurement of airborne contaminants during removal activities, three test areas were isolated with plastic barriers It is good practice to isolate all work areas in order to prevent possible contamination of other areas unless source containment has been shown to be reliable

PERSONAL PROTECTIVE EQUIPMENT

The levels of worker exposure that occur while using the Custom Fabricated Negative Air Glove Bag were not well defined at the time of the study Therefore, to protect against potential exposures, the removal workers and the field investigators used respirators both during removal operations and during post-removal air sampling periods The removal workers used half-face dust respirators with high efficiency dust filters The NIOSH investigators also used half-mask respirators with high efficiency dust filters while observing the removal operations, however, when performing the aggressive sampling, Racal Air Stream Powered Air Purifying Respirators (Breatheasy-5®) with high efficiency filters were used This respirator incorporates a flexible hood which is flushed with air from a high efficiency filter system Both the workers and the investigators wore disposable Tyvek® coveralls which were replaced daily, or as needed

METHODOLOGY

Five types of samples were collected in order to characterize the effectiveness of containment by the Custom Fabricated Negative Air Glove Bag During removal operations, personal breathing zone (PBZ) samples were collected on workers and area air samples were taken within the work enclosures Area samples were also taken outside the work enclosure to determine the building background concentration in the building In addition, outdoor samples were taken to establish the background fiber concentrations outside the building To assess the overall efficacy of the asbestos removal and preliminary cleanup operations, additional samples were taken before and after the completion of the removal work using the Asbestos Hazard Emergency Response Act (AHERA)[12] aggressive sampling technique

PERSONAL AIR SAMPLES

PBZ samples were collected while workers were actively engaged in bag fabrication and installation and during asbestos removal operations and other associated activities including waste collection and disposal

AREA AIR SAMPLES

Area samples were collected continuously both inside and outside the enclosed work area at approximately the same time the personal sampling was performed

PRE- AND POST-REMOVAL AIR SAMPLING

Pre- and post-removal air samples were obtained by sampling in the aggressive mode for about 6¼ hours to obtain an approximate 3500-liter sample In accordance with the AHERA[12] procedure, dust and fibers were dislodged from walls, ceiling, floor and other surfaces during a 5- to 10-minute initial blowdown with a leaf blower, two 18-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 At the same time, five side-by-side outdoor ambient samples were collected for about 6 or 12 hours

EVALUATION METHODS

PERSONAL SAMPLING

The PBZ samples were collected using SKC Model 224-PCXR7 pumps at a measured flow rate between 2 5 and 3 5 lpm, each sample volume was approximately 300 liters of air. The sampling device consisted of a 25-mm diameter three-piece cassette, in an open-face mode with a 50-mm extension cowl The cassette contained a 0.8-μm pore size, cellulose ester filter, Type AA, and a backup pad, both manufactured by the Millipore Corporation Carbon impregnated polypropylene cassettes and cowls were used to minimize possible localized effects of static electricity

INSIDE AND OUTSIDE WORKPLACE AREA SAMPLING

Duplicate area samples were taken using two side-by-side 25-mm diameter cellulose ester filters The sampling devices were the same as those described for personal sampling

PRE- AND POST-REMOVAL AIR SAMPLING

Five 6¼-hour samples were collected simultaneously using 25-mm diameter, 0.45-μm pore size, mixed cellulose ester filters followed by a 5 0-μm pore size, cellulose ester filter between the primary filter and the backup pad All samples were collected in three-piece open-face cassettes which were hung face down approximately 5 feet above the floor Samples at each station were collected at a measured flow rate between 8 0 and 9 5 lpm, utilizing individual limiting orifices The vacuum source for these samples was a Gilian 110 volt, AC vacuum sampling pump

OUTDOOR AMBIENT SAMPLES

The outdoor ambient samples were collected on the same type of 25-mm cellulose ester filters as the pre- and post-removal samples for 8 to 16 hours to obtain approximately 3500 to 7000 liter samples The ambient outdoor samples were collected at a measured flow rate between 8 0 and 9 5 lpm

DISCUSSION OF ANALYTICAL METHODS

PCM has been used, historically, for the purpose of analyzing occupational exposures to airborne asbestos It 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 However, PCM does not differentiate between asbestos and other fibrous matter such as organic textile or cellulose fibers, nor does it detect very thin or small fibers The Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) is based on a method that utilizes PCM to manually count the number of fibers greater than 5 μm in length and with an aspect ratio of at least 3 1 (length width) collected on cellulose ester filter media [10]

NIOSH Method 7400 describes sampling and analytical procedures for determining fiber concentrations by PCM This method was first issued February 15, 1984 [14] The third and current revision was issued May 15, 1989 [8] However, the second revision, made August 15, 1987,[14] was in place at the time of this study and results are based on that revision It included two sets of counting rules "A" rules and "B" rules PCM samples from this study were analyzed using the "A" rules, which define a fiber as having an aspect ratio of 3 1 or greater

A note on the applicability of NIOSH Method 7400[8] 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 Unfortunately, the deposition of the fibers on the filter is not uniform For instance, Baron and Deye[15] note that " The change in particle trajectories caused by [electrostatic] charge effects can result in non-uniform deposits on the collecting filter surface and net loss of sample " Therefore, in spite of attempts to randomize counting areas, the specific fields counted may not be representative of the entire filter, and the interlaboratory coefficient of variation (CV = 0 45) is quite large The term "<u>index</u>" 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 This method does have the capability of producing results rapidly (less than 24 hours) and relatively inexpensively

As an alternative to PCM, transmission electron microscopy (TEM) is used for asbestos counting both because of the greatly enhanced resolution and contrast, and of the analytical capability to differentiate between asbestos and nonasbestos structures 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 because of the rapid settling of the heavier material Even though a proportionately higher concentration of airborne fibers less than 0 25 μm in diameter may be present in these circumstances, they will not be observed with PCM Thus, under these conditions, no conclusion can be made about their presence or absence. Because of the poorer resolving power of the PCM method, the EPA requires the TEM method to be used for quantitating asbestos fibers in clearing buildings for re-occupancy [12]

Widespread use of TEM has been limited by the relative high cost of analysis, the availability of equipment and trained personnel, and by the absence of a standardized method of analysis NIOSH Method 7402,[9] in place at the time of this study, used the same cellulose ester filter medium as does the PCM method (Method 7402 was revised on May 15, 1989,[16] but the use of a cellulose ester filter is still required) The EPA has developed a Yamate revised provisional method for TEM analysis of asbestos which allows the use of either a mixed cellulose ester or a polycarbonate filter medium [17] This method was further modified for regulatory purposes when the Asbestos Hazard Emergency Response Act[12] was promulgated in 1986, and is considerably different than the NIOSH method 7402 and the requirements of the OSHA Standard

There are several other factors in addition to aspect ratio that can affect the result of asbestos counting methods Perhaps the most important is that PCM is used for counting <u>total</u> fibers greater than 5 μm in length and 0 25 μm in diameter On the other hand, TEM counts include only fibers verified by crystalline asbestiform identification Furthermore, the minimum fiber diameter that can be routinely observed by PCM is approximately 0 25 μm Since many asbestos fibers have diameters less than 0 25 μm, they are not usually visible during PCM analysis Thus the use of 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 However, once fibers are speciated, TEM counts of asbestos fibers may actually be lower than the PCM count, especially for relatively low concentrations of mixed fiber type containing a high proportion of nonasbestos fibers In spite of these limitations, PCM analysis is recognized as an appropriate index of occupational exposure for approximating disease potential

The EPA had established "clearance" guidelines for determining when reoccupancy may occur after asbestos removal These guidelines were initially published in 1984 and 1985 as "recommended practices "[18,19] The revised EPA guidelines issued in 1985[19] recommended that after asbestos removal was completed a visual inspection of the work area be performed, followed by nonaggressive (quiescent) air sampling using PCM for fiber analysis NIOSH Method 7400 was recognized as an acceptable analytical procedure and a 3,000-liter sample was recommended in order to provide a minimum quantification limit of 0 01 f/cc (10,000 f/m^3) If fiber concentrations in the building after asbestos abatement activities exceeded this limit then the work areas were required to be recleaned until exposures were brought under control

Alternatively, these guidelines also recommended using aggressive (dynamic) sampling and the use of TEM analysis to determine asbestos concentrations In this study, aggressive sampling was performed by first dislodging dust and fibers from surfaces by means of a 5- to 10-minute blowdown with a leaf blower, two 18-inch fans, placed on the floor and pointed upwards at about a 45-degree angle, were operated during the sampling period to keep the dust and fibers airborne while the samples were being collected

In this study, pre- and post-removal aggressive samples were collected in accordance with the Asbestos Hazard Emergency Response Act (AHERA) and analyzed using the Yamate revised (level II) method [12] TEM analyses of the PCM samples collected during work periods were also performed by the level II method (instead of NIOSH Method 7402) for continuity in comparison with pre- and post-observations Although AHERA is applicable only to school buildings, it provides a useful method to assess contamination levels It requires the use of aggressive air sampling to determine if a response action (an asbestos containment or removal operation and clearance procedure for reoccupancy) has been satisfactorily completed The regulation requires a three-step process using TEM analysis for determining successful completion of a response action After visual inspection, the final two steps involve a sequential evaluation of five samples taken inside the work site, five samples taken outside the work site, two field blanks, and one sealed blank Final clearance is granted if the average asbestos fiber concentration determined from the samples collected in the work site is below the prescribed limit of detection (LOD) for the TEM method Additional evaluations are required if the LOD test fails

ANALYSIS

For this study, all PBZ and area samples were analyzed by PCM using the third revision of NIOSH Method 7400,[7] which was in effect at that time One of each of the duplicate samples was subsequently analyzed by TEM using the AHERA method[11] Pre- and post-removal and ambient samples were also analyzed by TEM using this method

FINDINGS AND OBSERVATIONS

FIELD BLANKS AND LOWER LIMITS OF DETECTION (LOD)

Field and quality control blanks were processed and were all within normal limits The data are included in Appendix A and B. No corrections were necessary for blank analysis

PHASE CONTRAST MICROSCOPY

The estimated LOD for Method 7400 is 7 fibers/mm^2 of filter area [8] This is equivalent to about 3,000 fibers per filter for 25-mm diameter filters, thus, for a 300-liter sample, the LOD is 10,000 f/m^3 The results of samples collected while the pipe lagging was being removed are shown in Table 1 Concentrations indicated as "less than" are below the LOD for the volume of the sample All of the personal samples and all but two of the area samples were above the LOD The PZB samples ranged from 8,000 to 67,000 f/m^3, area samples ranged from 5,000 to 67,000 f/m^3

TRANSMISSION ELECTRON MICROSCOPY

The authors are not aware of an appropriate estimate of the LOD for the modified Yamate method for use in this study. The laboratory performing the analysis of samples from this study indicated that filter blanks were less than about 12 structures per square millimeter (s/mm^2) At this concentration, about 4,800 structures could be found on a 25-mm diameter filter, thus for a 300-liter sample, an LOD of 16,000 structures per cubic meter (s/m^3) may be assumed

About half of the samples collected during asbestos removal were also analyzed by TEM These results are also shown in Table 1 and range from 7,000 to 187,000 asbestos s/m^3

Five samples were collected to determine the pre-removal concentrations of asbestos structures in Areas C and D before the dividing wall was constructed Five post-removal concentration samples were collected from each area after removal had been completed and the area was dried out (the 18-inch oscillating floor fans were operated several hours to assist the drying process) Outdoor ambient samples were collected, well away from the asbestos removal activities These results are shown in Table 2 These data indicate that area D post-removal samples are significantly lower than the pre-removal The 15 outdoor ambient concentrations were <1,400 s/m^3 As shown, the values for area D (<1,300 - 2,600) were only slightly above this level

Table 1 Fiber and Asbestos Structure Concentrations During Asbestos Removal Utilizing a Custom Built Glove Bag Under Negative Pressure				
Area	Date	Sample Volume (Liters)	Concentration By PCM (f/m^3)	By TEM (s/m^3)
Breathing Zone Samples				
B	08/22	528	12,000	69,200
B	08/22	544	13,000	
C*	08/23	706	29,000	115,000
C*	08/23	682	67,000	
C	08/24	386	11,000	187,000
C	08/24	493	12,000	
D	08/25	501	8,000	107,000
D	08/25	486	8,000	
Area Samples				
B - Inside	08/22	495	<6,000	109,000
B - Inside	08/22	493	14,000	
B - Outside	08/22	523	10,000	35,000
B - Outside	08/22	525	17,000	
C - Inside*	08/23	672	45,000	40,000
C - Inside*	08/23	672	45,000	
C - Outside*	08/23	688	30,000	7,000
C - Outside*	08/23	682	67,000	
C - Inside	08/24	658	5,000	32,000
C - Inside	08/24	658	<5,000	
C - Outside	08/24	652	14,000	<7,000
C - Outside	08/24	654	14,000	
D - Inside	08/25	525	6,000	53,000
D - Inside	08/25	523	6,000	
D - Outside	08/25	535	38,000	8,000
D - Outside	08/25	535	38,000	

* During glove bag construction - no asbestos removal
< = Less than the LOD for the sample volume

Table 2.
Pre- and Post-Removal Asbestos Concentrations
(structures/cubic meter)

Pre-Removal	Ambient	Post-Removal	Ambient
Area C			
14,800	<700	10,300	<1,100
5,500	<700	1,300	<1,300
9,100	<700	1,300	<1,000
10,100	<800	5,700	<1,200
16,800	<700	14,600	1,100
11,300	Average	6,600	
Area D			
14,800	<700	1,200	<1,400
5,500	<700	2,600	<1,400
9,100	<700	1,300	<1,300
10,100	<800	1,300	<1,300
16,800	<700	<1,200	<1,300
11,300	Average	<1,500	

< = Less than the LOD for the sample volume

DISCUSSION

Because of the limited resources sampling was restricted to two workers on each of three shifts Statistical analysis of so few data points has very little power, therefore, only a qualitative analysis is presented for the PCM data

The results of PCM analysis (Table 1) indicate that the Custom Negative Air Glove Bag, as used in this study, provided worker protection well below the OSHA PEL, i e , less than 100,000 f/m^3 The maximum PBZ measured was 67,000 f/m^3 which occurred during the construction of the containment and glove bag for area C on August 23 Levels measured during removal the next day were lower (12,000 f/m^3) TEM analyses were not consistent with the PCM results, in that higher TEM counts were seen on August 24th and 25th (187,000 and 107,000 s/m^3) when PCM levels were low (12,000 and 8,000 f/m^3) The results of PCM and TEM analysis would not necessarily be expected to be consistent because of the differences in these analytical methods that have been previously noted

The results of the pre- and post-removal sampling indicate that asbestos levels in areas C and D were lower after removal than before they were removed The pre-removal concentration in both areas averaged 11,300 s/m^3, the average post-removal concentration in C was 6,600 s/m^3 and less than the

LOD of 1500 s/m³ in Area C A t-test of the ln(concentration) shows that the pre- vs post-removal difference in Area D is significant at the 95% confidence level but that the pre- vs post-removal difference in Area C is not significant
The dimensions (length and width) of all asbestos structures counted in the TEM analysis are recorded As a result, it is possible to make a distributional analysis of the structures observed Figures 2 through 6 are plots of the cumulative concentration of asbestos structures by length Figure 2 shows the relationship of the pre- and post-removal samples collected in Areas C and D It is interesting to note that in Area D the post removal plot indicates very few structures present, and practically none less than 3 μm in length Figure 3 shows PBZ, inside, and outside asbestos concentrations measured during removal operations in Area B Figure 4 shows asbestos concentrations during the preparation and construction of the glove bag in Area C Figures 5 and 6 show concentrations during removal operations in Areas C and D, respectively.

Figures 7 through 10 are plots of the length-to-width relationship of the asbestos structures Figure 7 presents structures found in the pre-removal samples in Area C/D, Figures 8 and 9 present structures found in the post-removal samples in Areas C and D, respectively, and Figure 10 presents the structures found in all of the PBZ samples In the upper right hand corner of these plots is a "PCM window" which 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) These plots graphically illustrate that very few structures were in the visible PCM range in any of the sample collected

CONCLUSIONS AND RECOMMENDATIONS

Under the conditions of this study, worker exposures which occurred when the Custom Fabricated Negative Air Glove Bag was used for asbestos-containing pipe lagging were well below the OSHA PEL and the NIOSH REL criteria These comparisons were based on data analyzed by PCM The data from samples analyzed by TEM indicated that there may have been a increase in total fibers as a result of the asbestos removal procedure The authors are not aware of information that allows for a meaningful interpretation of this TEM information, however It is prudent practice to provide the most reliable protection possible for carcinogens such as asbestos The authors believe that the concept of a negative pressure glove bag is clearly better than that of standard glove bag, and that the use of negative pressure glove bags should be strongly encouraged when glove bag removal is done

This control method would be especially appropriate for removal of pipe-lagging where the use of ordinary glove bags would prove difficult Some typical situations are where there are multiple parallel pipe runs, where much branching exists, and/or where there are many fittings/fixtures It can be used on both horizontal and vertical pipe runs and other structures of irregular shape, such as tanks and reservoirs

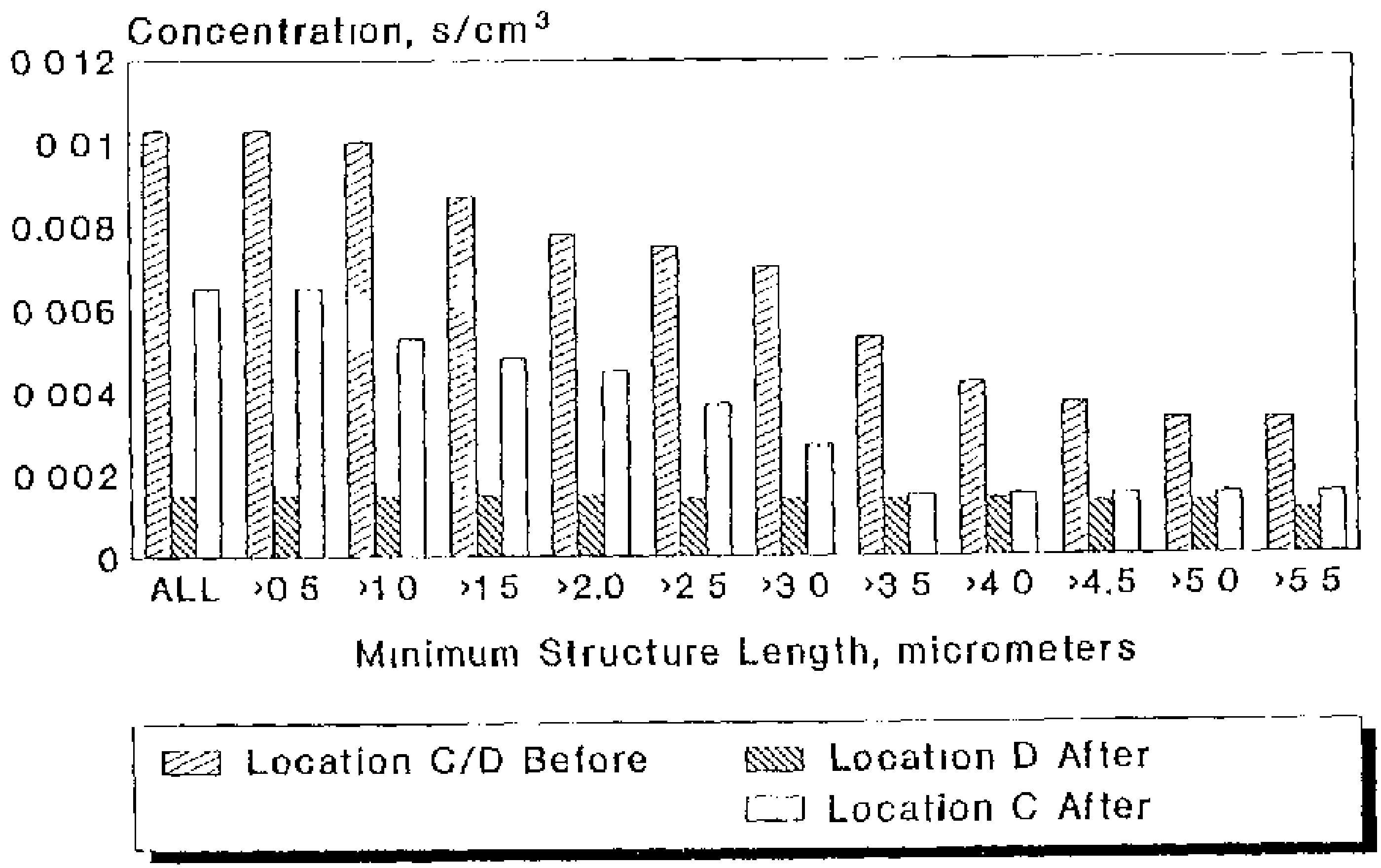


Figure 2 Cumulative asbestos structure concentrations by structure length for samples collected in Area C/D before and after asbestos pipe-lagging removal using the Custom Negative Air Glove Bag enclosure

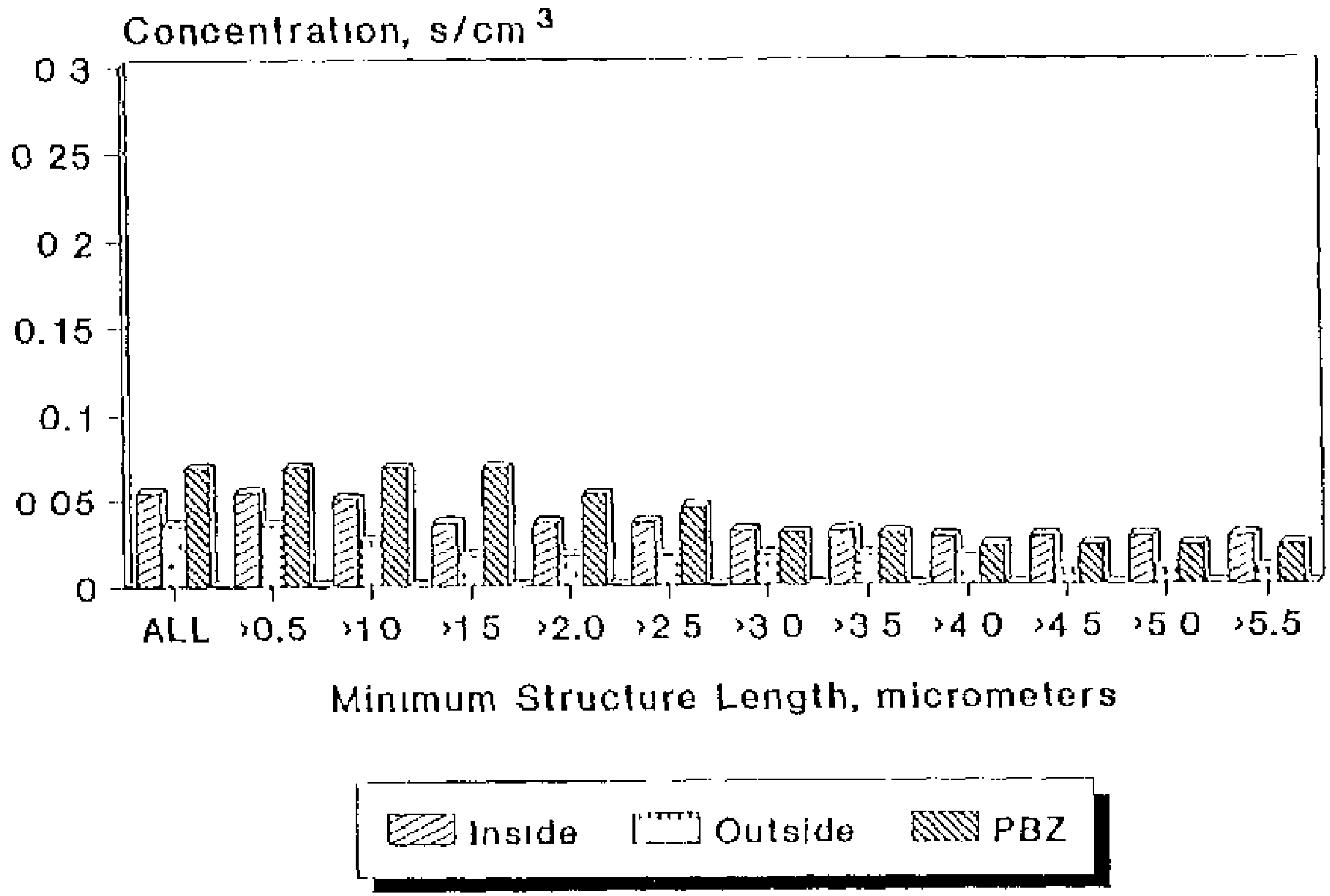


Figure 3 Cumulative asbestos structure concentrations by structure length for samples collected in Area B during asbestos pipe-lagging removal using the Custom Negative Air Glove Bag enclosure

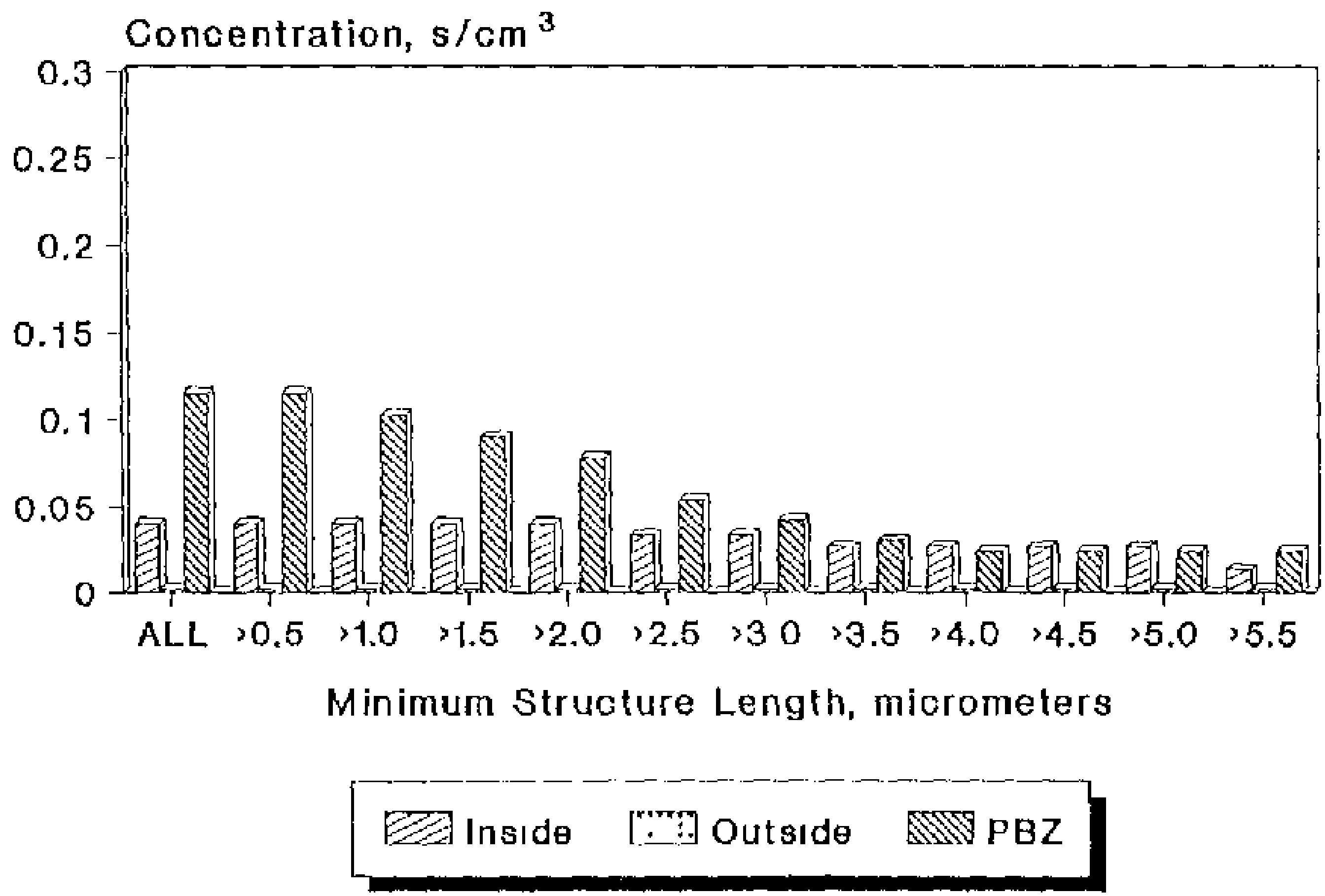


Figure 4 Cumulative asbestos structure concentrations by structure length for samples collected in Area C during preparation for asbestos pipe-lagging removal and construction of the Custom Negative Air Glove Bag enclosure

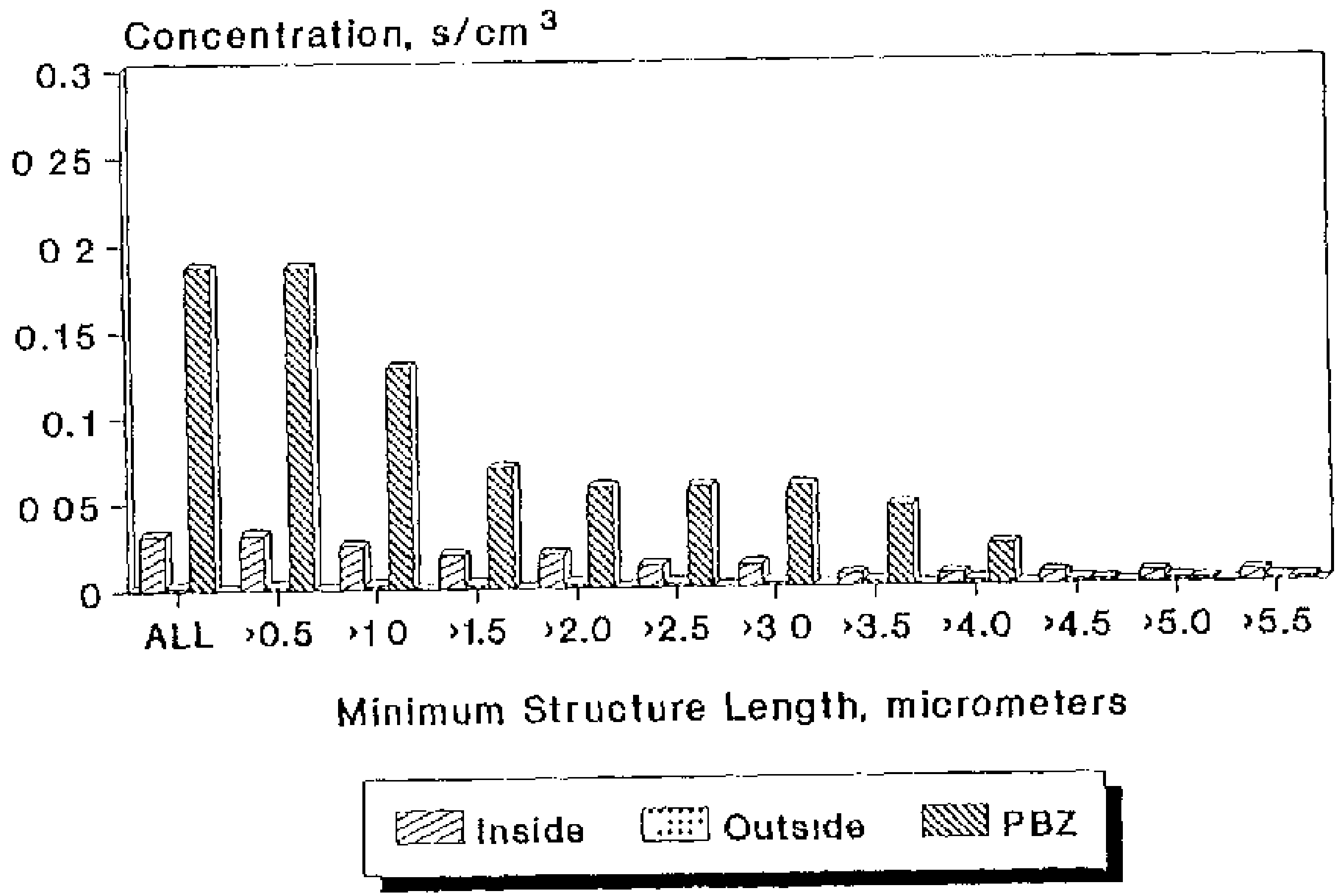


Figure 5 Cumulative asbestos structure concentrations by structure length for samples collected in Area C during asbestos pipe-lagging removal using the Custom Negative Air Glove Bag enclosure

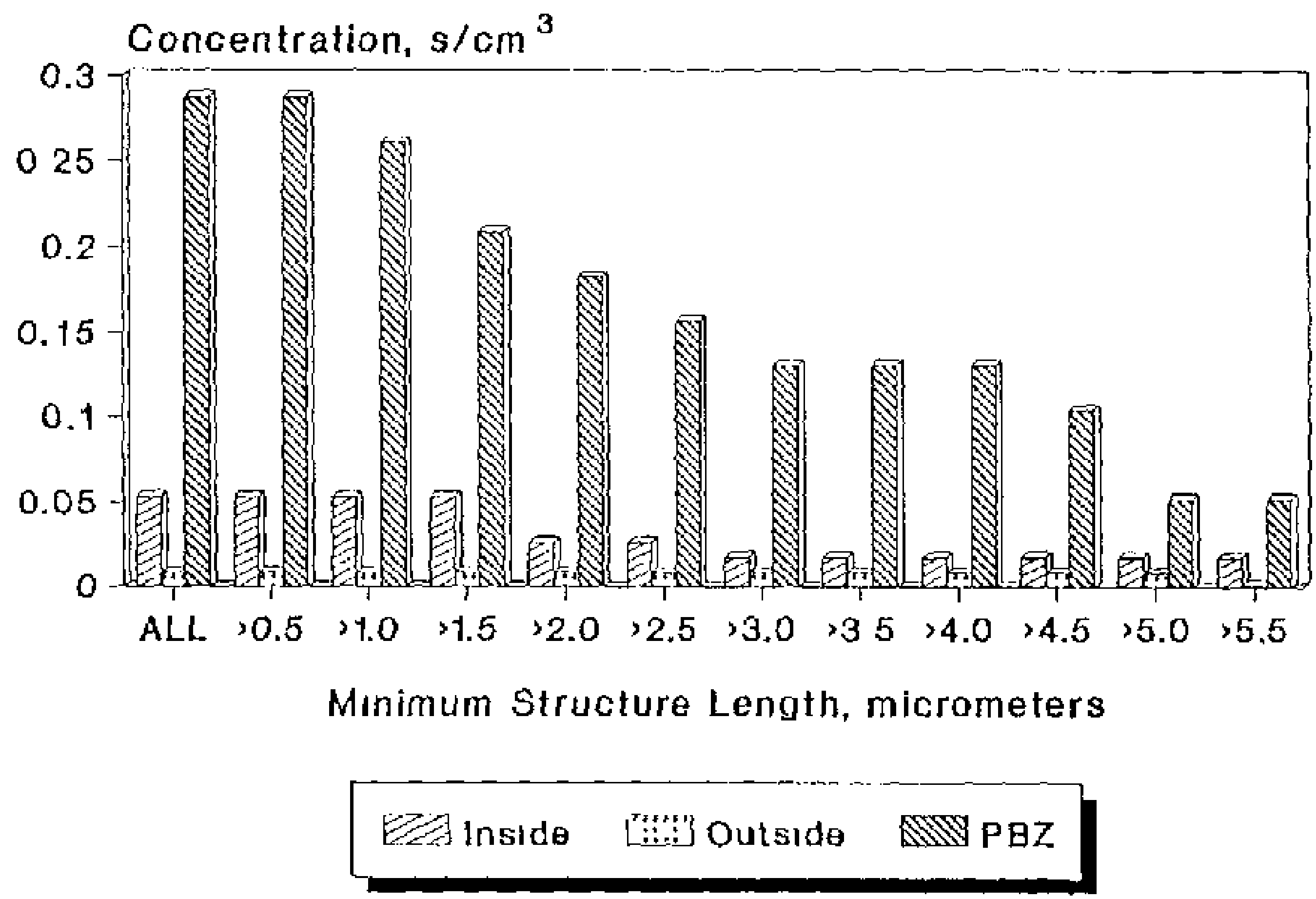
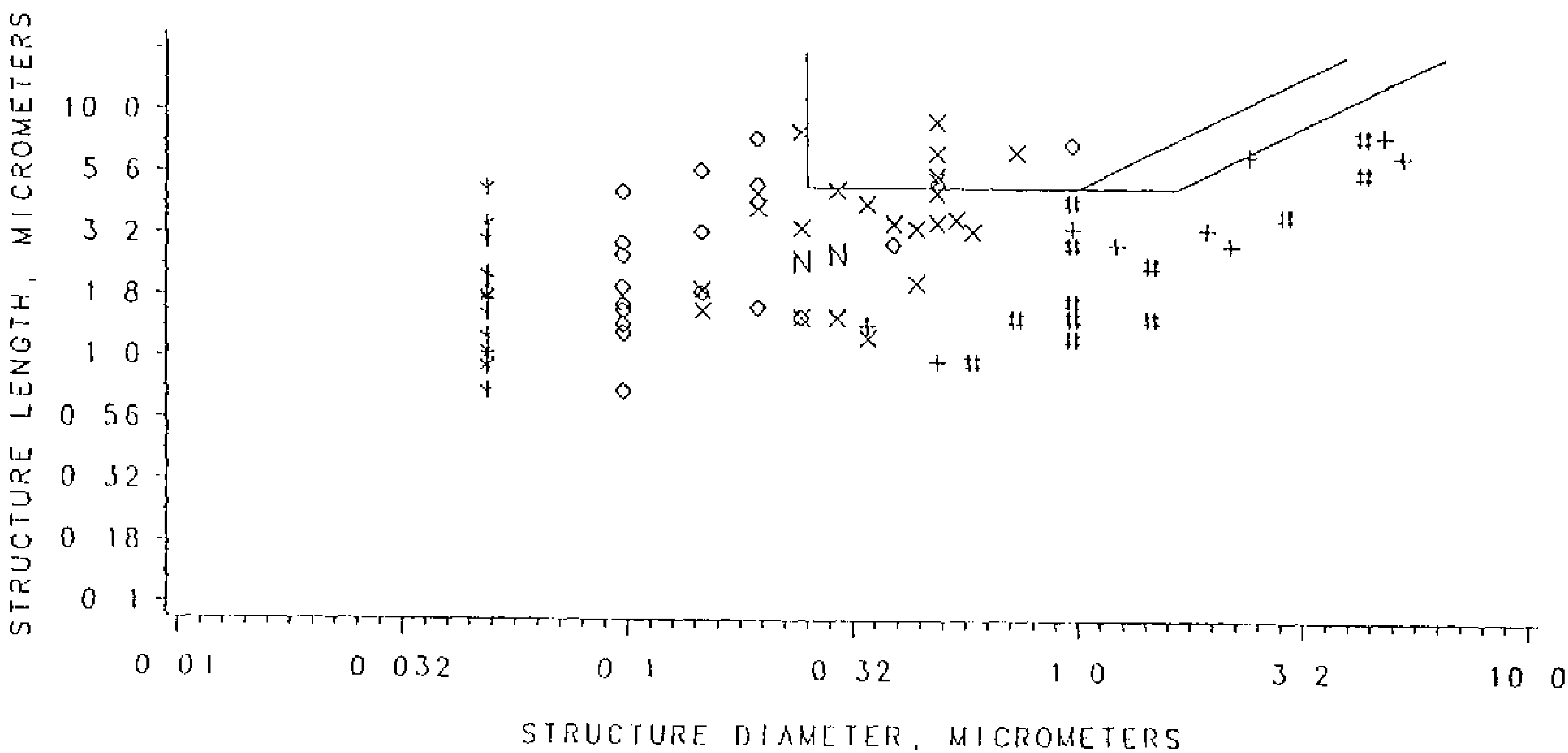


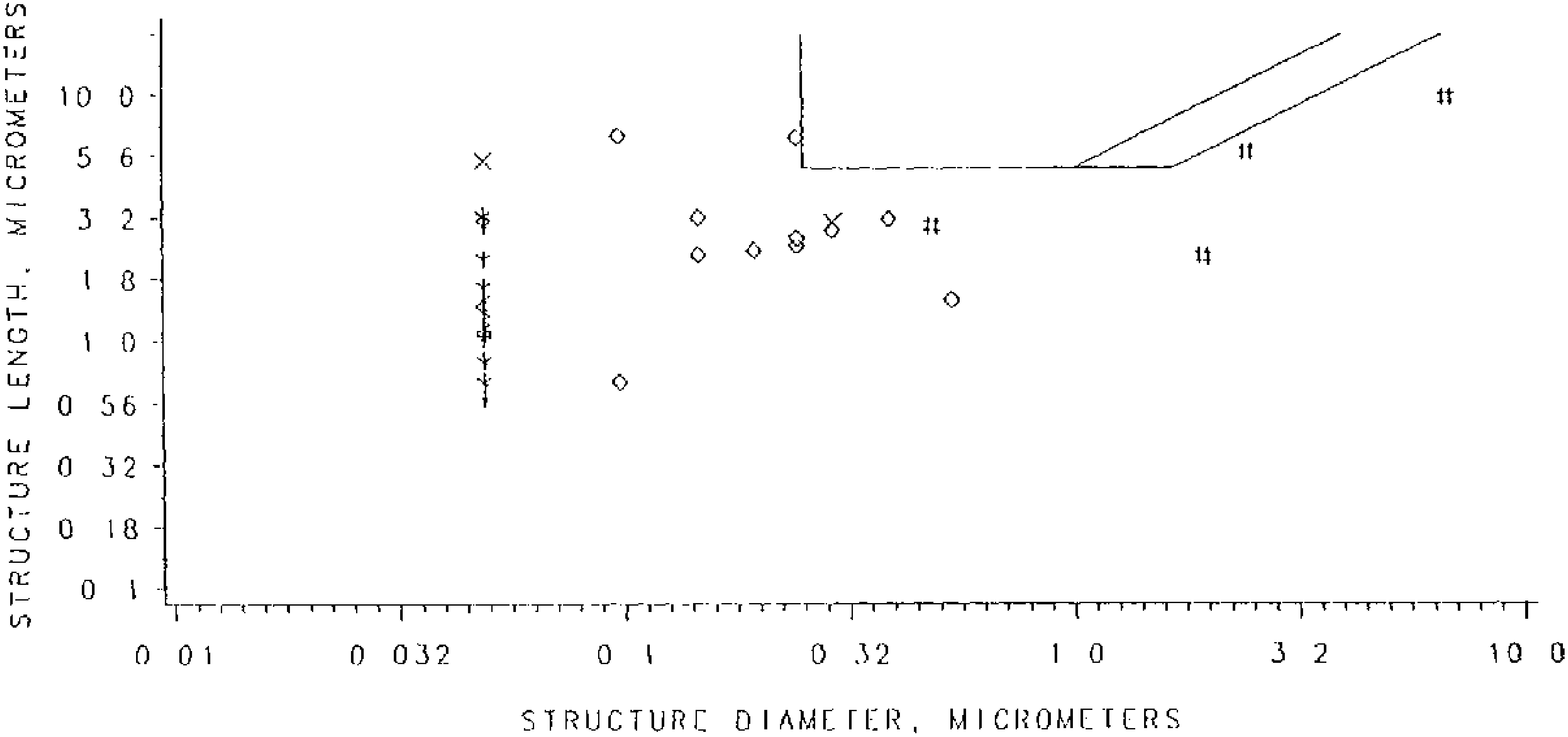
Figure 6 Cumulative asbestos structure concentrations by structure length for samples collected in Area D during asbestos pipe-lagging removal using the Custom Negative Air Glove Bag enclosure.



Structure Identification
* 1 Chrysotile Fiber
◇ 1 Chrysotile Bundle
1 Chrysotile Cluster
+ 1 Chrysotile Matrix
X 1 Amphibole Fiber
N 1 Non-asbestos Fiber

Note Fibers Visible by NIOSH Method 7400 are indicated in upper right hand window (See Text)

Figure 7 Plot of length to diameter relationship of asbestos structures on samples collected prior to asbestos removal in Area C/D

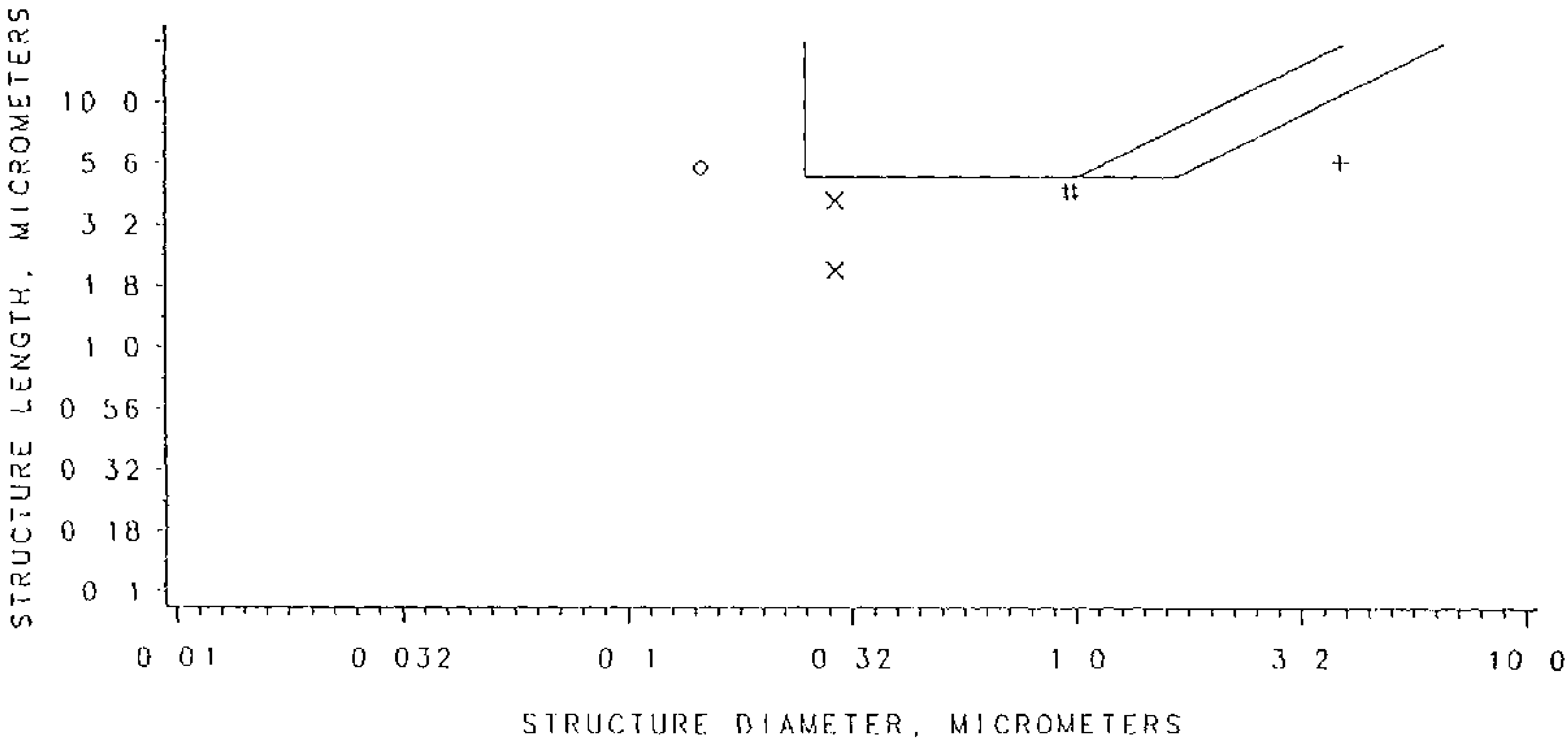


Structure Identification

- ✱ 1 Chrysotile Fiber
- ◇ 1 Chrysotile Bundle
- # 1 Chrysotile Cluster
- + 1 Chrysotile Matrix
- ✕ 1 Amphibole Fiber

Note Fibers Visible by NIOSH Method 7400 are indicated in upper right hand window (See Text)

Figure 8 Plot of length to diameter relationship of asbestos structures on samples collected after asbestos removal in Area C.

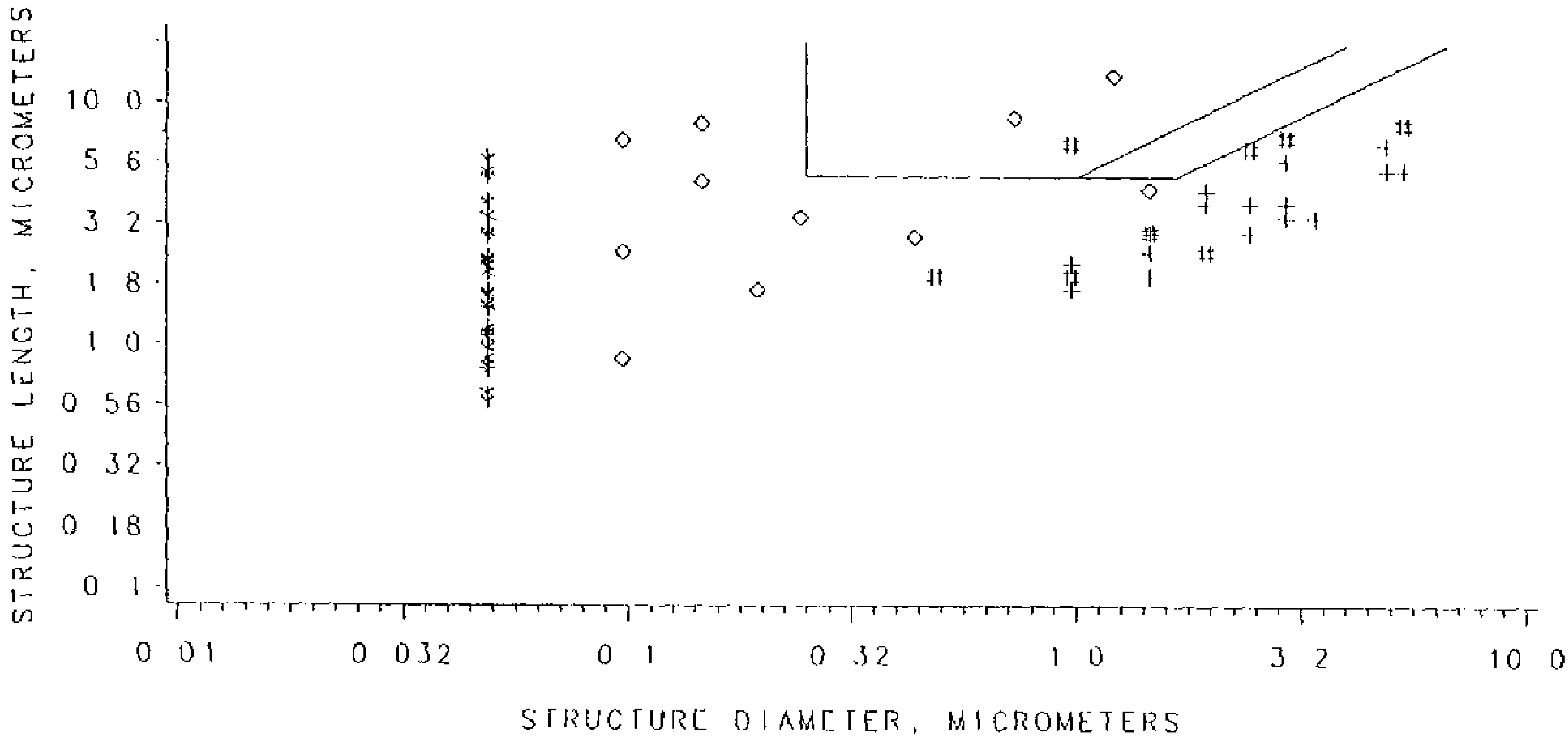


Structure Identification

- ✱ 1 Chrysotile Fiber
- ◇ 1 Chrysotile Bundle
- # 1 Chrysotile Cluster
- × 1 Amphibole Fiber

Note Fibers Visible by NIOSH Method 7400 are indicated in upper right hand window (See Text)

Figure 9. Plot of length to diameter relationship of asbestos structures on samples collected after asbestos removal in Area D.



Structure Identification
* 1 Chrysotile Fiber
◇ 1 Chrysotile Bundle
1 Chrysotile Cluster
+ 1 Chrysotile Matrix

Note Fibers Visible by NIOSH Method 7400 are indicated in upper right hand window (See Text)

Figure 10 Plot of length to diameter relationship of asbestos structures on personal breathing zone samples collected during asbestos removal in Areas B, C, and D.

It would be prudent to use respiratory protection and disposable coveralls when using a Custom Fabricated Negative Air Glove Bag for asbestos removal operations This would provide protection against accidental releases of asbestos which may occur because of the loss of vacuum, seal failure, or the rupture of a bag Back-up containment or isolation of the working area may also be necessary to avoid contamination of the surroundings if an accident should occur or where pre-existing contamination, i e , damaged pipe lagging or the presence of friable asbestos-containing materials, is likely to be disturbed Where possible, sampling in an aggressive mode to estimate the amount of contamination present before removal operations are begun is recommended, this can help establish the need for additional precautions

Although neither the source nor the health effects of the small asbestos structures observed in this study by TEM are well established, further study of this control under varied work conditions to validate its performance and better define optimum work practices is warranted Furthermore, data from this study 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, the authors recommend that respiratory protection be provided for workers whenever glove bags are used

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APPENDIX A UNIVERSITY OF MASSACHUSETTS DATA - PERSONAL AND AREA SAMPLES

Sample Number	Location	Date	Time (min)	Volume (Liters)	Concentration (TEM) (s/mm²)	(s/cc)	Concentration (PCM) (f/mm²)	(f/cc)
AA25772	B - Inside	08/22	165	493			7000	0 014
AA25273	B - Inside	08/22	165	495	140 252	0 109	<3000	<0 006
AA25253	B - Outside	08/22	175	523	47 985	0 035	5000	0 010
AA25272	B - Outside	08/22	175	525			9000	0 017
AA25794	B - PBZ	08/22	182	528	94 677	0 069	6000	0 012
AA25254	B - PBZ	08/22	182	544			7000	0 013
AA25778	Blank	08/22			<11 996		<3000	
AA25286	Blank	08/22			<12 346		<3000	
AA25299	Blank	08/22			<11 996		<3000	
AA25795	C1 - Inside	08/23	224	672			30000	0 045
AA25762	C1 - Inside	08/23	224	672	70 126	0 040	30000	0 045
AA25258	C1 - Outside	08/23	230	690			20000	0 029
AA25275	C1 - Outside	08/23	230	688	<13 062	<0 007	20000	0 030
AA25259	C1 - PBZ	08/23	236	682			45000	0 067
AA25281	C1 - PBZ	08/23	236	706	210 526	0 115	20000	0 029
AA25752	Blank	08/23					<3000	
AA25799	Blank	08/23			<11 996		<3000	
AA25282	Blank	08/23			<11 688		<3000	
AA25777	C2 - Inside	08/24	220	658			<3000	<0 005
AA25298	C2 - Inside	08/24	220	658	53 914	0 032	3000	0 005
AA25283	C2 - Outside	08/24	218	652	<11 688	<0 007	9000	0 014
AA25269	C2 - Outside	08/24	218	654			9000	0 014
AA25773	C2 - PBZ	08/24	165	493			6000	0 012
AA25279	C2 - PBZ	08/24	129	386	187 003	0 187	4000	0 011
AA25297	Blank	08/24			<11 996		<3000	
AA25487	Blank	08/24			<11 996		<3000	
AA25754	Blank	08/24					<3000	
AA25759	D - Inside	08/25	175	523			3000	0 006
AA25798	D - Inside	08/25	175	525	71 977	0 053	3000	0 006
AA25755	D - Outside	08/25	179	535	11 366	0 008	20000	0 038
AA25764	D - Outside	08/25	179	535			20000	0 038
AA25790	D - PBZ	08/25	162	486			4000	0 008
AA25792	D - PBZ	08/25	181	501	135 802	0 008	4000	0 022
AA25765	Blank	08/25					<3000	
AA25785	Blank	08/25			<11 688		<3000	
AA25270	Blank	08/25			<11 366		<3000	

APPENDIX B UNIVERSITY OF MASSACHUSETTS - AMBIENT AND PRE- AND POST-REMOVAL SAMP

Sample Number	Location	Date	Time (min)	Volume (Liters)	Concentration (s/mm^2)	(s/cc)
AH102	Ambient	08/21	661	6270	<10 988	<0 0007
AH103	Ambient	08/21	661	5900	<10 988	<0 0007
AH104	Ambient	08/21	661	6270	<11 587	<0 0007
AH105	Ambient	08/21	661	5742	<11 293	<0 0008
AH106	Ambient	08/21	661	6270	<11 293	<0 0007
AH112	Blank	08/21			<10 988	
AH113	Blank	08/21			<11 587	
AH114	C/D - Pre-removal	08/21	355	3080	135 517	0 0169
AH114R*	C/D - Pre-removal	08/21	355	3080	101 637	0 0127
AH115	C/D - Pre-removal	08/21	355	3221	46 350	0 0055
AH117	C/D - Pre-removal	08/21	355	3133	79 051	0 0097
AH119	C/D - Pre-removal	08/21	355	2956	69 525	0 0091
AH120	C/D - Pre-removal	08/21	355	3345	87 902	0 0101
AH120D*	C/D - Pre-removal	08/21	355	3345	142 841	0 0164
AH120D2	C/D - Pre-removal	08/21	355	3345	208 768	0 0240
AH121	Ambient	08/24	400	3996	11 588	0 0011
AH122	Ambient	08/24	400	3556	<11 918	<0 0013
AH123	Ambient	08/24	400	4276	<11 587	<0 0010
AH123R	Ambient	08/24	400	4276	<11 587	<0 0010
AH124	Ambient	08/24	400	3536	<10 988	<0 0012
AH125	Ambient	08/24	400	3836	10 988	0 0011
AH126	C - Post-Removal	08/24	335	3030	81 112	0 0103
AH127	C - Post-Removal	08/24	335	3214	10 716	0 0013
AH128	C - Post-Removal	08/24	335	3248	10 716	0 0013
AH129	C - Post-Removal	08/24	335	3114	46 350	0 0057
AH129D	C - Post-Removal	08/24	335	3114	46 350	0 0057
AH130	C - Post-Removal	08/24	335	3181	112 931	0 0137
AH130D	C - Post-Removal	08/24	335	3181	127 462	0 0154
AH131	Blank	08/24			<11 587	
AH133	Blank	08/24			<10 988	
AH135	Ambient	08/25	276	3147	<11 587	<0 0014
AH136	Ambient	08/25	276	3013	<10 716	<0 0014
AH139	Ambient	08/25	276	3380	<10 988	<0 0013
AH140	Ambient	08/25	276	3280	<11 293	<0 0013
AH141	Ambient	08/25	276	3415	<11 587	<0 0013
AH132	D - Post Removal	08/25	212	3675	11 293	0 0012
AH143	D - Post Removal	08/25	212	3300	21 976	0 0026
AH144	D - Post Removal	08/25	212	3300	10 716	0 0013
AH145	D - Post Removal	08/25	212	3570	11 588	0 0013
AH148	D - Post Removal	08/25	212	3570	<11 293	<0 0012
AH149	Blank	08/25			<10 988	

* R = Recount by the same microscopist   D = Recount by a different microscopist