IN-DEPTH SURVEY REPORT

EVALUATION OF THE AERO-PIPE CAPSULE (NEGATIVE PRESSURE GLOVE BAG) DURING THE REMOVAL OF ASBESTOS-CONTAINING PIPE LAGGING

CONDUCTED BY
The Dore and Associates Contracting, Inc , Bay City, MI
At an Asbestos Removal Site in Dearborn, MI

REPORT WRITTEN BY
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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, the 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 protection) and backup containment (e g , isolation, barriers, negative 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 the Aero-Pipe Capsule® to control worker exposure during its use in asbestos removal The Aero-Pipe Capsule 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 work environment

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 Aero-Pipe Capsule 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 Aero-Pipe Capsule, have been developed to provide more reliable containment

SITE AND PROCESS DESCRIPTION

This study was performed in a storage area above the kitchen of a cafeteria in a multipurpose office building Approximately 85 feet of 3-inch pipe lagging containing 50% chrysotile and 10 to 15% crocidolite was removed from a nominal 6-inch diameter steam pipe The pipe passed through three semipartitioned storage areas about 3 feet below the ceiling and 12 feet above the floor The partitions were constructed of wood paneling up to about 8 feet from the floor and continued to the ceiling (about 7 feet) with chain-link fencing The walls of the storage rooms were partially lined with lockers or shelving containing equipment and supplies Some freestanding lockers and stacked equipment were in the open areas, but sufficient space was available beneath the pipe for construction of scaffolding to support the workers while they were removing the lagging Figure 1 is a sketch of the area Several pipe fittings, hangers, valves, etc , that were included in this run of pipe are not shown in this simplified presentation Because of the design of the Aero-Pipe Capsule used in this study, lagging was removed from straight-run pipe sections only, to as close to the fittings or partitions as practical

Figure 2 is a photograph of the "Junior Enclosure" Aero-Pipe Capsule reproduced from sales literature It is essentially a fiber-reinforced plastic glove box, open at the bottom The box is split and hinged so that it may be opened and clamped on a horizontal pipe run Split gaskets at the ends of the capsule are removable and can be replaced with gaskets of appropriate size for the pipe diameter to create a snug fit Gaskets with different diameter openings are available and can be utilized to compensate for differences in diameter between the bare and the insulated pipe Gasket materials can be provided in various materials; some will resist softening at temperatures above 500°F

The capsule is provided with a connection for the attachment of a hose to a 90 cfm HEPA-filtered "Back-Pac" vacuum device manufactured by Aerospace America Inc The connecting hose contains an air bypass control to adjust the pressure in the capsule Another connection is provided for the attachment of a hose from a 5-gallon amended water or encapsulant supply system to an internal applicator This system contains an electric motor driven pump controlled by a foot-operated switch The capsule is also equipped with a clear plastic observation window and an internal shelf to retain pliers, saws, brushes, and other tools Waste is collected in a heavy plastic disposable bag suitable for landfill purposes which is attached to the open bottom with an elastic band The gloves are removable so that they may be replaced as needed Various designs of capsules can be fabricated to accommodate vertical pipe runs, as well as pipe elbows, tees, and valves of various configurations

The removal work was performed from a mobile scaffold and platform by a two-man team The clamshell-like capsule required about 6 inches of clearance to be clamped around the pipe One workman used the gloves to remove the insulation contained within the capsule and clean the bare pipe with knives, water, scrapers, brushes, and rags The cleaned pipe and the ends of the lagging were sprayed with encapsulant The capsule was moved down the pipe-run and lagging removal and cleaning was accomplished in sequential sections The interior and the upper walls of the bag were also washed

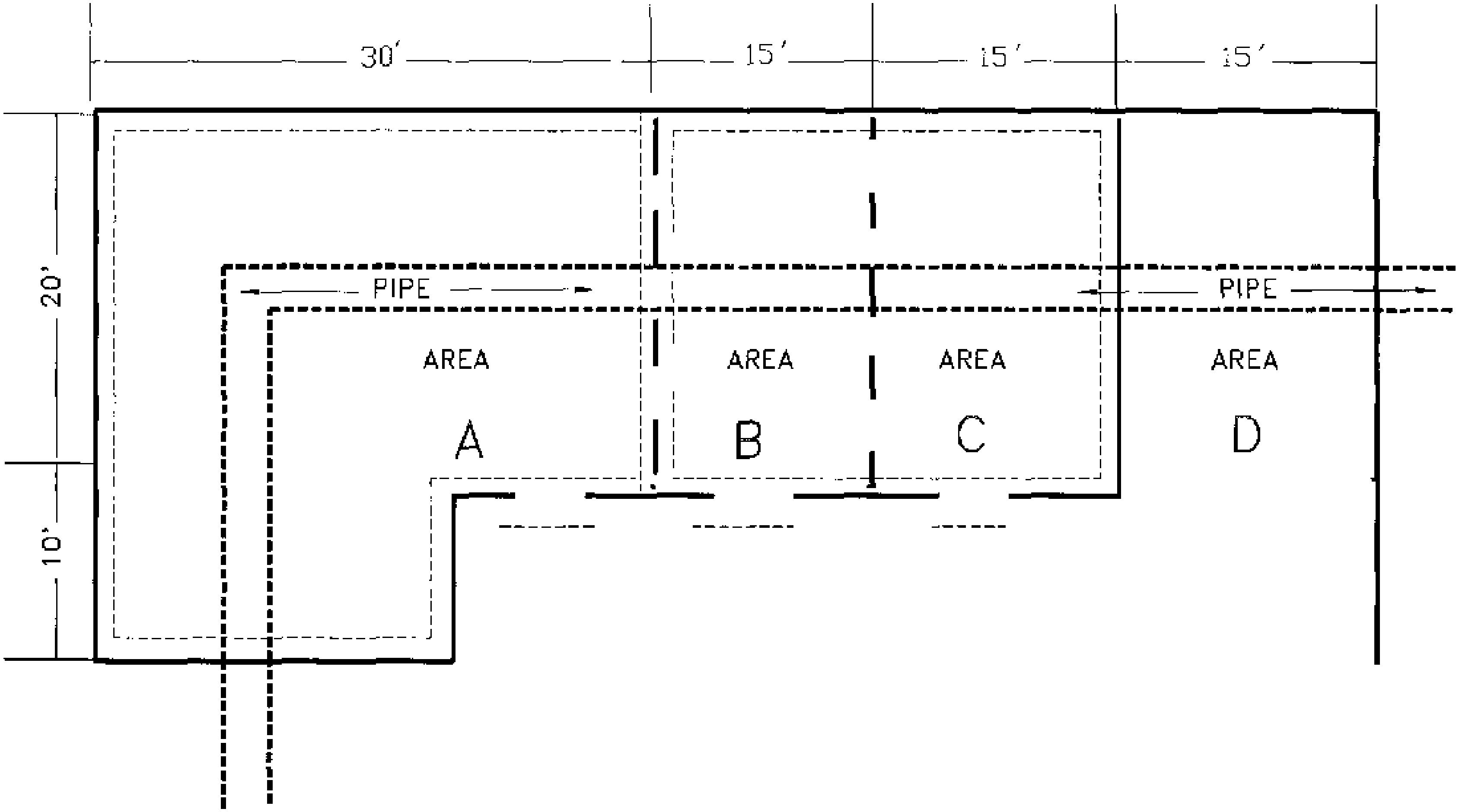


FIGURE 1. ASBESTOS REMOVAL SITE

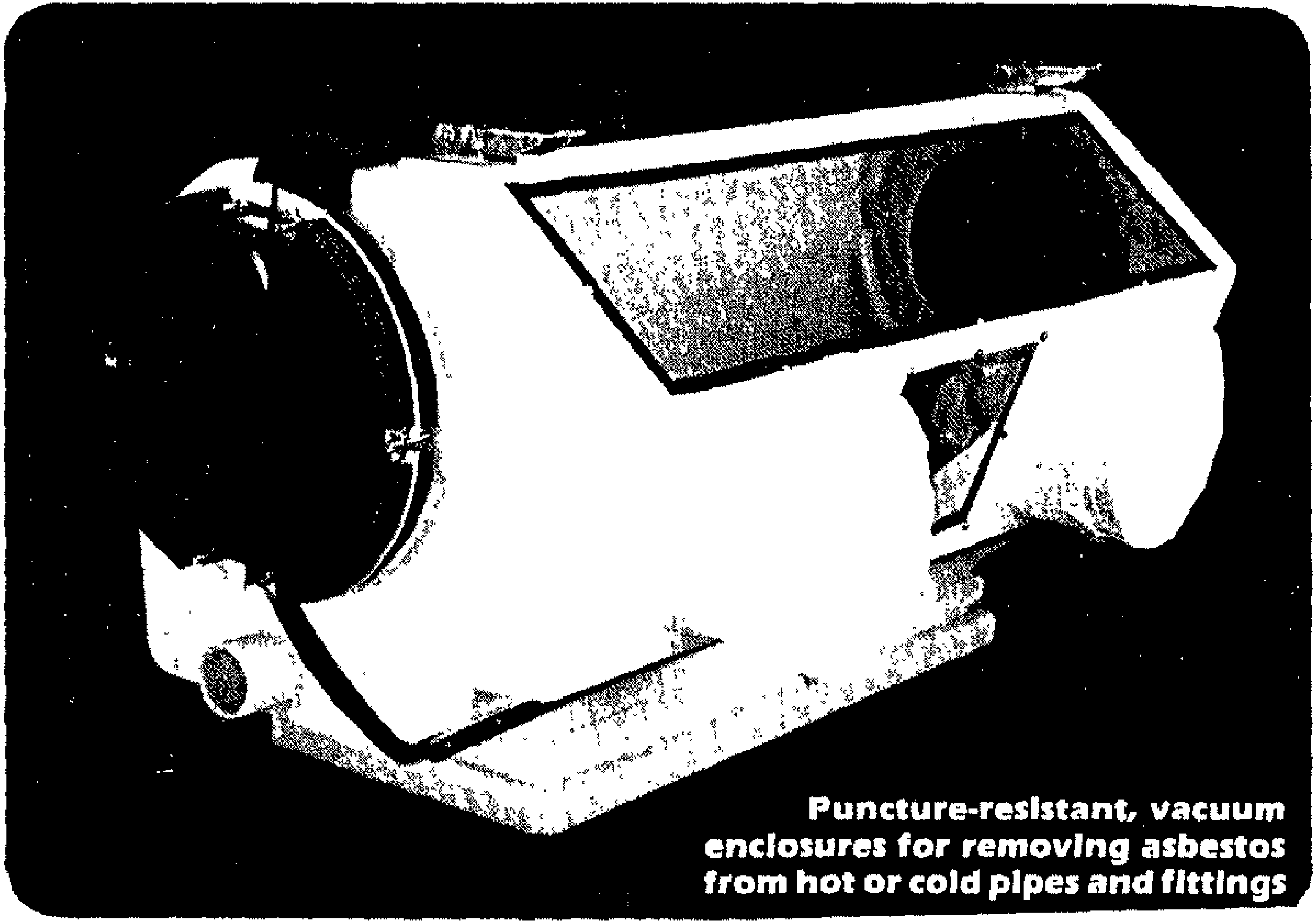


Figure 2 Aero-Pipe Capsule

thoroughly before the capsule was opened for movement After the initial section of insulation had been removed, the elastomer gasket in the opening of the trailing end of the capsule was replaced by one with a smaller diameter opening to seal against the bare pipe When sufficient debris had been accumulated, the bag was collapsed, sealed, double bagged, removed, and replaced When an obstruction was encountered (e g , a valve or tee) in the pipe-run, the unit was unclamped and reinstalled beyond the obstacle The exhaust ventilation was operated continuously throughout these operations When a new, empty bag was installed, the vacuum bypass was used until the bag was loaded with enough debris to prevent it from being drawn into the capsule In spite of this, the bag became partially collapsed from the negative pressure and the second worker had to frequently manipulate the debris to the bottom of the bag from the outside, either by pulling the walls apart or squeezing large pieces to the bottom

To determine the efficacy of the Aero-Pipe Capsule for preventing the release of asbestos into the environment during abatement operations, the rooms were isolated with polypropylene sheeting (poly) barriers Poly was taped or glued to the ceiling, walls, and floors to isolate the shelving and other equipment from the removal area and the rooms from the rest of the building The isolated areas were unventilated and entries to the rooms were closed off by double poly barrier flaps The small areas labelled "B" and "C" were not separated by poly over the chain-link fencing extension of the partition and were considered to be one area, Area B/C, for purposes of this study

Asbestos removal operations were conducted over four successive nights so that the normal daytime activities in this building would not be affected The isolation of Area B/C was completed the first night Immediately after the installation of the isolation barriers, pre-removal (base line) sampling was performed using the EPA aggressive (dynamic) sampling technique subsequently described in the Methodology Section Outdoor ambient samples were collected each night through a window in the downstairs cafeteria which was well removed from the abatement area

On the second night, instruction for using the Aero-Pipe Capsule was provided by the foreman during the removal operations in Area B/C because the workers were unfamiliar with this device They were, however, well experienced in other asbestos abatement techniques The instructor worked individually with each of the trainees and then observed and coached them as they worked together Personal and area sampling was performed during this training period Concurrent with this activity, other workers isolated Area A with poly barriers and aggressive pre-removal sampling in this area was performed immediately after the isolation was completed

On the third night, pipe lagging was removed in Area A Personal and area samples were collected during this removal activity Concurrently, aggressive post-removal samples were obtained in Area B/C Immediately following the completion of the removal activities in Area A, aggressive post-removal samples were collected

During the last (fourth) night, lagging was removed from Area D This area was not enclosed for pre- and post-aggressive sampling Area and personal samples were collected during the removal activities, but only two ambient samples were taken during this short shift

This work was performed in August when the weather was quite warm The pipe was carrying high pressure steam and, as a result, the temperature within the confines of the unventilated containment areas increased as the lagging was removed Crew members, wearing half-face, HEPA-filtered respirators and Tyvek® coveralls, rotated in and out of the work area about every 15 to 20 minutes and occasionally all three workers took breaks at the same time

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, Anthophyllite, 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 judgment, 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 two 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 Aero-Pipe Capsule, a structure similar to a portable glove box which was ventilated under a negative pressure of 0 02 to 0 5 inches of water by a HEPA-filtered vacuum system The capsule has been described in the Background Section 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 capsule due to the reduced pressure within the capsule

4 The asbestos waste is contained for subsequent handling and disposal

5 The capsule is fabricated of fiber-reinforced plastic and high temperature gaskets are available so that work on hot pipes can be performed (up to 500°F) without deterioration of the containment

CONTAINMENT OF THE WORK ENVIRONMENT

To provide a controlled condition for the measurement of airborne contaminants during removal activities, two 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 capsule 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 NIOSH investigators used Racal Air Stream-Powered, Air-Purifying Respirators (Breatheasy-5®) 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 Aero-Pipe Capsule 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 only during times when workers were actively engaged in asbestos removal and other associated activities including waste collection and disposal Because the temperature within the rooms was very high, the workers rotated activities quite frequently The personal samplers were, therefore, removed from the retiring worker and placed on his replacement to accumulate approximately three hours of sampling time for each filter Thus, each PBZ sample was a composite of exposures occurring during the removal activities of two or more workers Two PBZ samples were collected in Area B/C, four in Area A, and two in Area D, two short-term PBZ samples were also obtained in Area D

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 AIR 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 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 type as those used 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 for 8 to 16 hours to obtain approximately 3500 to 7000 liter samples using the same type of 25 mm cellulose ester filters as the pre- and post-removal 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 [13] 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 nonuniform 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 reoccupancy [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 PCM method (Method 7402 was revised on May 15, 1989,[16] however, a cellulose ester filter is still specified) 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 AHERA 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 <u>Total</u> 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 <u>asbestos</u> 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 3000 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, PBZ and area samples were analyzed by PCM by DataChem, Inc., using the third revision of NIOSH Method 7400,[8] which was in effect at that time. One of each of the duplicate samples was subsequently analyzed by TEM using the AHERA method.[12] Pre- and post-removal and ambient samples were also analyzed by TEM using this method. NIOSH recommends the use of NIOSH Method 7402 to determine the asbestos content in samples containing nonasbestos fibrous matter, however, EPA had a contract with Chatfield Technical Consulting Ltd. to perform TEM by the AHERA method. Although these methods employ different techniques, the results reported should be of the same magnitude.

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 Appendixes 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 3000 fibers per filter for 25 mm diameter filters, thus, for a 300 liter sample from an environment free from interferences, 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 calculated from the volume of the sample Six of eight personal 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 results approximated the LOD (3000 to 8000 f/m^3) and the other 11 were below the LOD

TRANSMISSION ELECTRON MICROSCOPY

There is no well-estimated LOD for the modified Yamate method The laboratory performing the analysis of samples from this study indicated that filter blanks were less than about 11 structures per square millimeter (s/mm^2) At this concentration, about 4500 structures could be found on a 25 mm diameter filter, thus an LOD of 15,000 structures per cubic meter (s/m^3) may be assumed for a 300 liter sample

About half of the samples collected during asbestos removal were also analyzed by TEM These results are also shown in Table 1 They ranged from 23,000 to 240,000 asbestos s/m^3

The results of samples collected to establish pre- and post-removal and outdoor ambient concentrations of asbestos structures are shown in Table 2 Outdoor ambient samples, collected through a downstairs cafeteria window well away from the asbestos removal activities, were all at or below the LOD of about 1200 s/m^3

Five samples were collected simultaneously to determine the pre- and post-removal concentrations of asbestos structures in each area These data indicate that in Area B/C the asbestos structure contamination increased from an average of about 27,000 s/m^3 before removal to 73,500 s/m^3 after removal was completed Contamination in Area A was about an order-of-magnitude greater than in Area B/C, it increased from an average of about 265,000 s/m^3 before removal to 783,000 s/m^3 after removal was completed

It should be noted that the results reported in this survey were obtained before the contractor had finished his work and do not represent the fiber concentrations which were attained at the completion of this asbestos removal operation Although asbestos removal from public buildings is subject to the AHERA regulations, there are no cleanliness (clearance) requirements for asbestos removal from commercial buildings

DISCUSSION

Because of limited resources, sampling was restricted to two work positions on 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 Aero-Pipe Capsule, as used in this study, provided worker protection well below the proposed OSHA PEL, i e , less than 100,000 f/m^3 However, the TEM results indicate the presence of many asbestos structures not visible by PCM

Table 1 Fiber and Asbestos Structure Concentrations During Asbestos Removal Utilizing an Aero-Pipe Capsule

			Concentration	
Area	Date	Sample Volume (Liters)	By PCM (f/m^3)	By TEM (s/m^3)
Breathing Zone Samples				
B/C	08/10	402	<8,000	159,000
B/C	08/10	402	8,000	
A	08/11	550	<6,000	237,000
A	08/11	552	<6,000	113,000
A	08/11	529	<5,000	46,000
A	08/11	571	4,000	
D	08/12	335	<9,000	115,000
D	08/12	347	<9,000	
D - Short Term	08/12	45	<68,000	185,000
D - Short Term	08/12	63	<48,000	68,000
Area Samples				
B/C - Outside	08/10	402	<8,000	76,000
B/C - Outside	08/10	402	8,000	
B/C - Outside	08/10	1009	<3,000	48,000
B/C - Outside	08/10	1012	3,000	
A - Inside	08/11	735	7,000	
A - Inside	08/11	745	<4,000	240,000
A - Inside	08/11	363	8,000	
A - Inside	08/11	363	<8,000	247,000
A - Outside	08/11	996	<3,000	167,000
A - Outside	08/11	996	3,000	
A - Outside	08/11	369	<8,000	56,000
A - Outside	08/11	357	<8,000	
D - Proximate	08/12	426	<7,000	
D - Proximate	08/12	426	<7,000	123,000
D - Vac Exhaust	08/12	345	<9,000	
D - Vac Exhaust	08/12	345	<9,000	26,000
Ambient	08/12	1209	<2,000	
Ambient	08/12	1208	<2,000	<3,000

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

Pre-Removal	Ambient	Post-Removal	Ambient
Area B/C			
36,700	1,200	74,400	<1,300
40,700	<1,200	67,900	<1,300
17,000	<1,100	61,800	<1,200
17,900	1,200	89,100	<1,300
23,300	<1,200	74,600	<1,300
27,100	Average	73,600	
Area A			
254,100	1,200	444,700	<1,300
299,300	<1,200	696,600	<1,300
300,900	1,200	687,900	<1,200
240,700	<1,300	1,502,000	<1,300
227,500	1,200	582,200	<1,300
264,500	Average	782,600	

The results of the TEM analyses are much less straightforward. Pre-removal concentrations of asbestos structures found in Area A, as measured by the aggressive sampling technique, were an order-of-magnitude greater than those found in Area B/C. A possible explanation for this difference is that vibrations created by the removal process in Area B/C may have been transmitted to the pipe isolated in Area A. Although the lagging appeared to be in good condition, as determined by visual inspection, the vibrations may have caused detrition of the lagging at the joints and fittings which resulted in asbestos emissions from these locations.

For both areas, the average post-removal levels of asbestos contamination were almost three times greater than the pre-removal levels (Table 2). In all cases, the differences of average concentrations were significant, based on the Students t-test, ($p = 0.05$). TEM analysis of the PBZ samples (Table 1) did not help to clarify the source of the increased contamination levels. In Area B/C, the one personal exposure sample indicated a concentration of 159,000 s/m^3 by TEM (Table 1), about twice the post-removal concentration. Because higher concentrations would be expected near the source of the emissions than at more remote locations, the higher PBZ concentration measured close to the point of asbestos release is consistent with the increased post-removal area concentrations measured.

In Area A, the TEM sampling results were more variable. The average PBZ concentrations (132,000 s/m^3) were lower than the average pre-removal contamination (264,000 s/m^3). The two area samples taken inside the room indicated that the average concentration of airborne asbestos in the room during removal (244,000 s/m^3) was about equal to the pre-removal concentration obtained by aggressive sampling The post-removal concentrations averaged 783,000 s/m^3 (602,800 without the outlier), these results are consistent with the well known variability that occurs in asbestos sampling data

The dimensions (length and width) of all asbestos structures counted in the TEM analysis are recorded As a result, it is possible to plot a size distribution of the structures observed Figure 3 presents the cumulative concentration of structures by length observed in the pre- and post-removal samples Figure 4 presents the cumulative concentration of structures collected by personal breathing zone samples and of samples collected inside and outside the enclosure during removal operations in Area A

It is also possible to plot the length-to-width relationship of the structures observed For samples taken in Area A, Figure 5 shows this relationship for the pre-removal samples, Figure 6 shows post-removal samples, and Figure 7 shows the PBZ samples In the upper right hand corner of these three 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, for all of the sampling results, very few fibers were in the PCM window

CONCLUSIONS AND RECOMMENDATIONS

Under the conditions of this study, worker exposures which occurred when the Aero-Pipe Capsule was used for asbestos-containing pipe lagging were well below the OSHA PEL and the NIOSH REL criteria, based on samples analyzed by PCM The data from TEM-analyzed samples indicated that there may have been an 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 the significance of the absolute levels of asbestos structures found by TEM, 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 a standard glove bag, and that the use of negative pressure glove bags should be strongly encouraged when glove bag removal is done

It would be prudent to use respiratory protection and disposable coveralls when using the Aero-Pipe Capsule 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 Backup containment or isolation of the working area may also be necessary to avoid contamination of the surroundings should an accident occur or where pre-existing contamination, i e , damaged pipe lagging or the presence of friable asbestos-containing materials, may 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

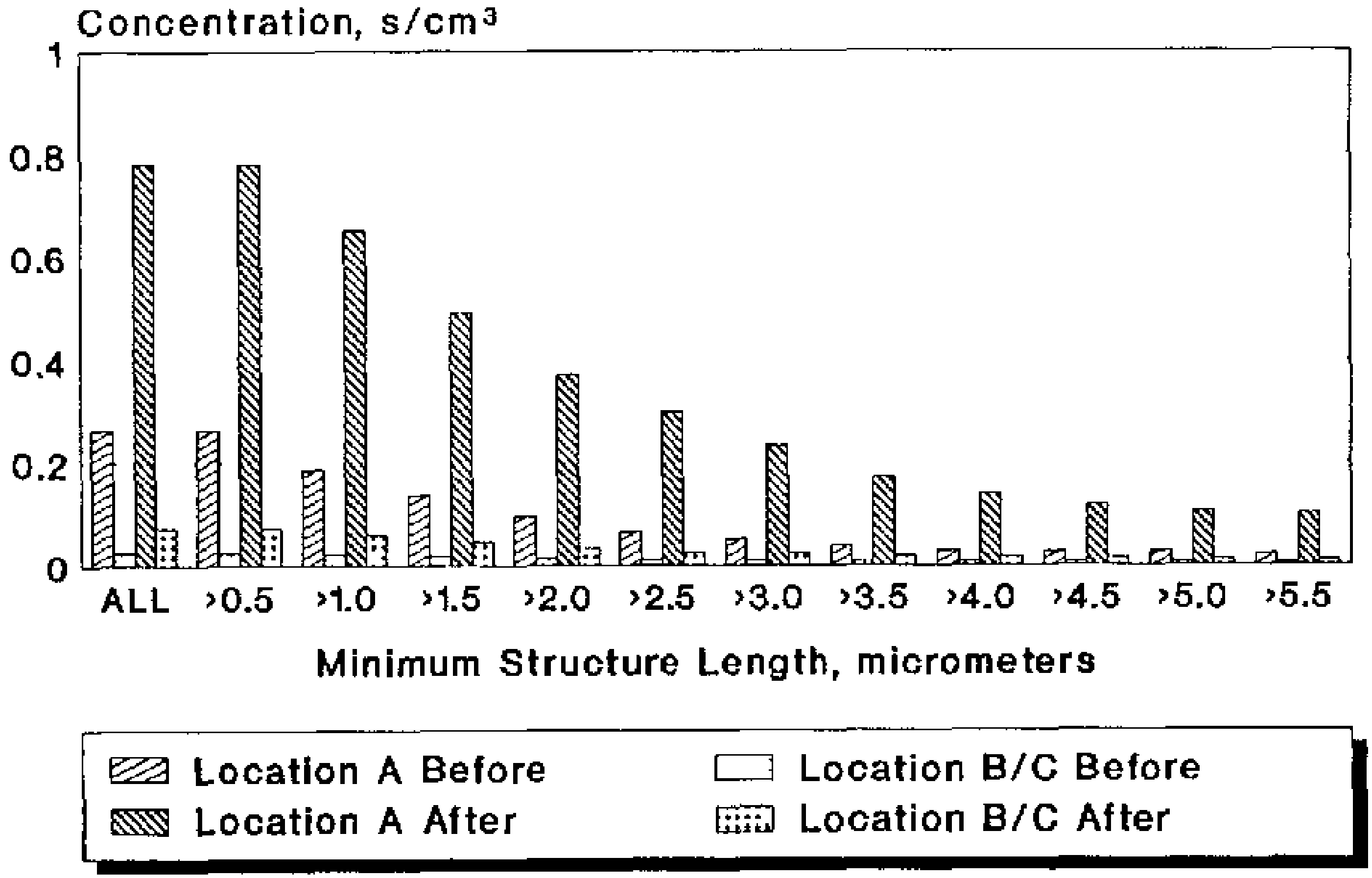


Figure 3. Cumulative asbestos structure concentrations by structure length before and after asbestos pipe-lagging removal using the Aero-Pipe Capsule negative air glove enclosure.

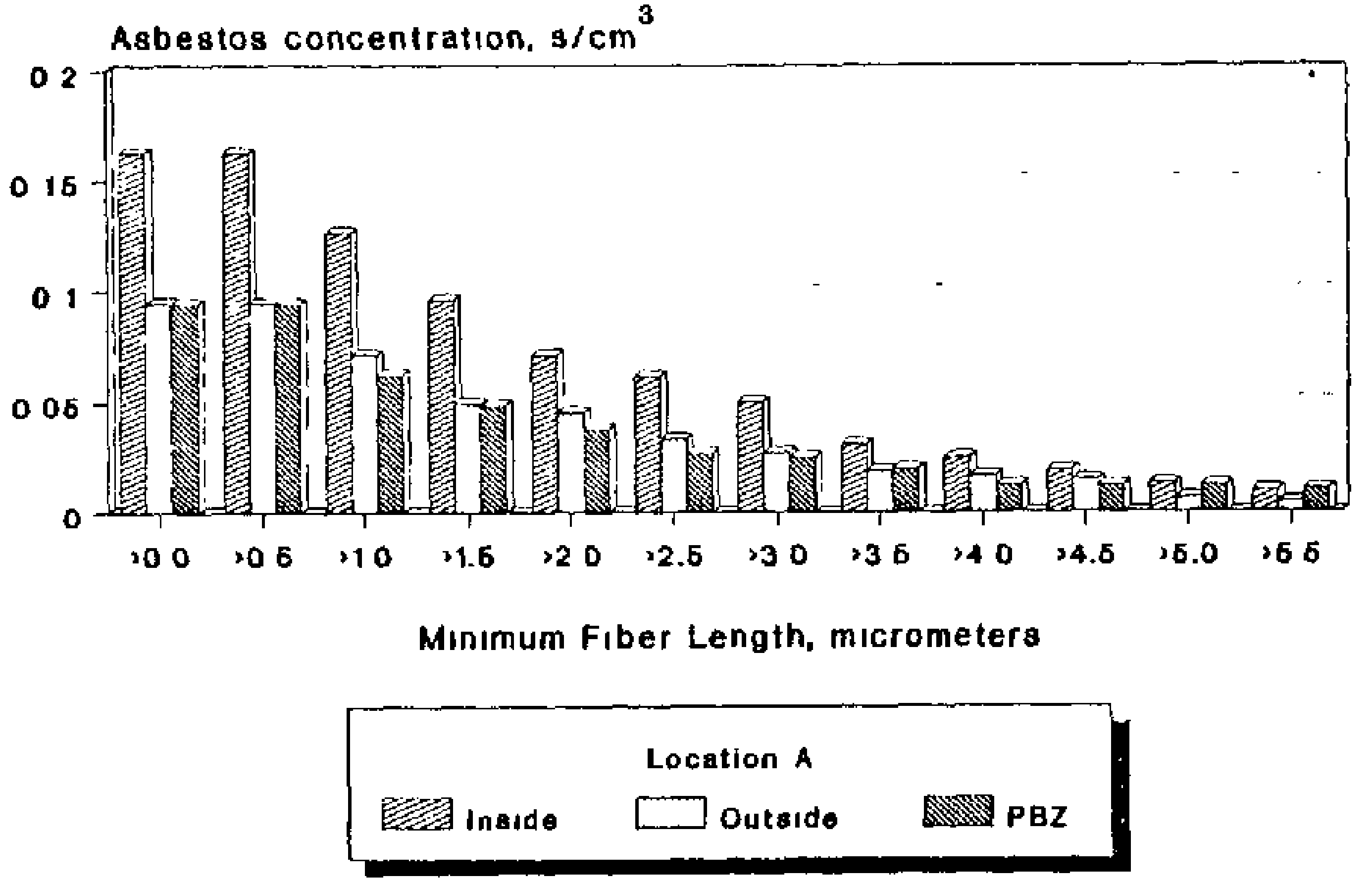
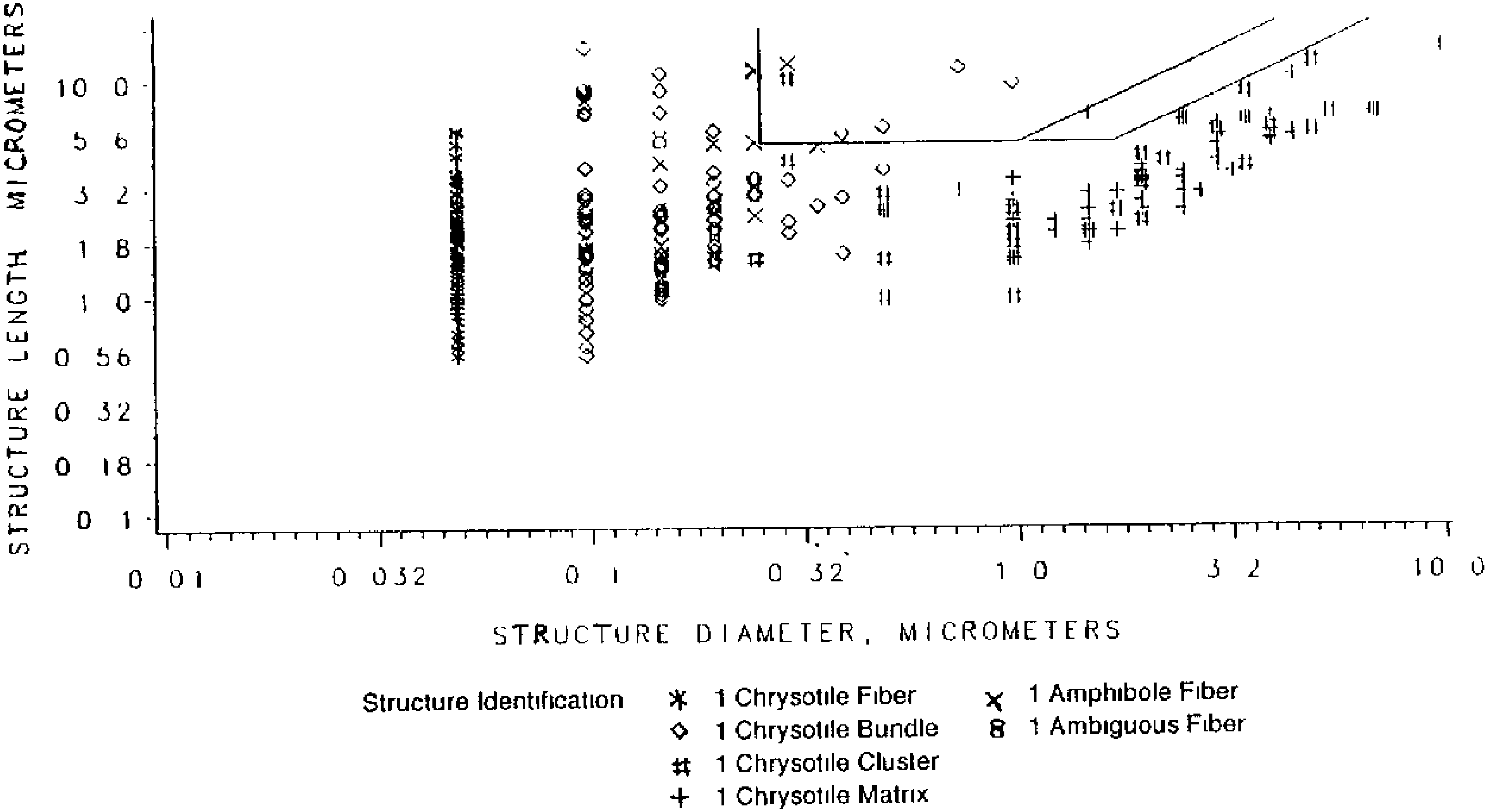
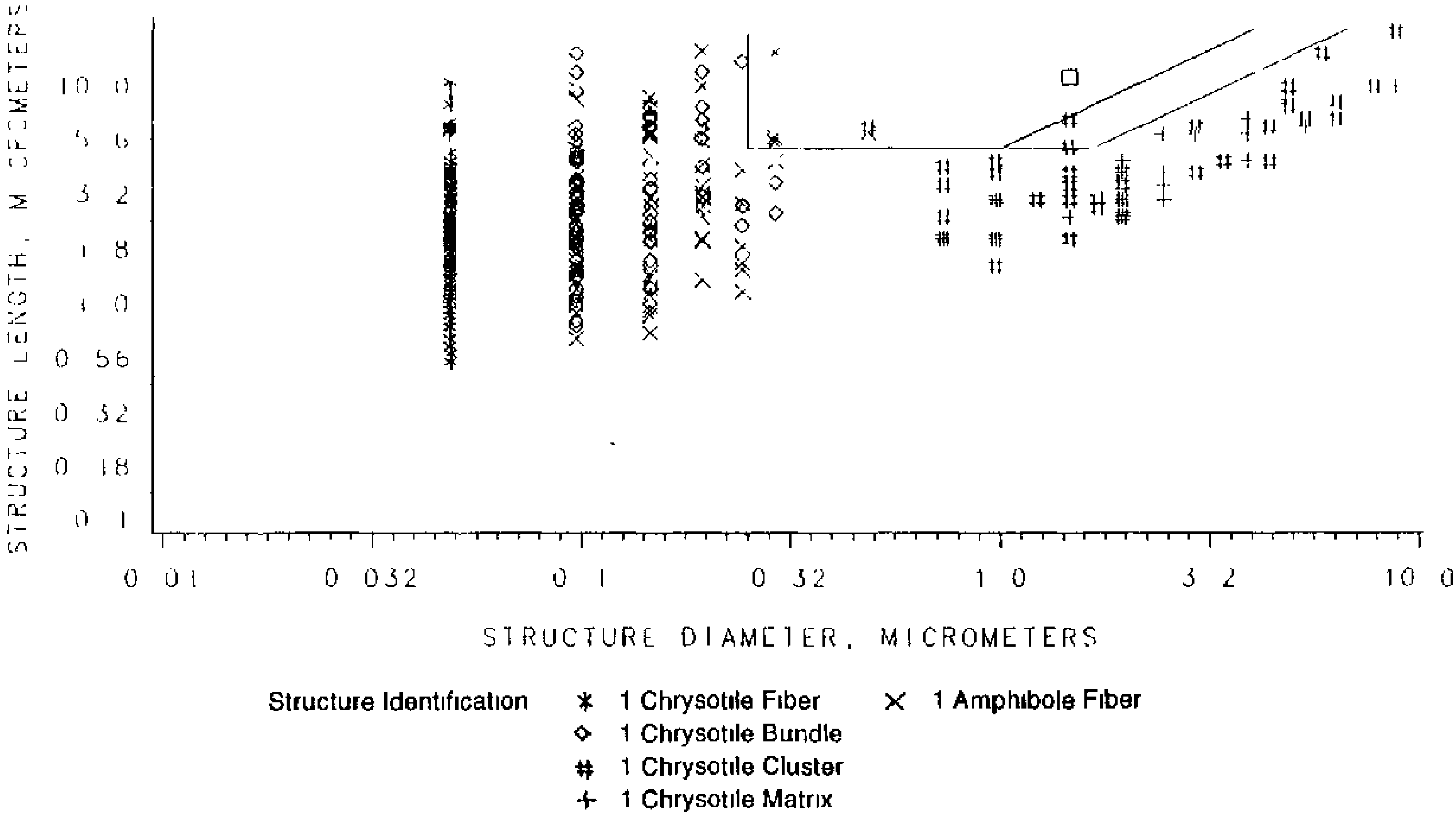


Figure 4. Cumulative asbestos structure concentrations by structure length during asbestos pipe-lagging removal using the Aero-Pipe Capsule negative air glove enclosure.



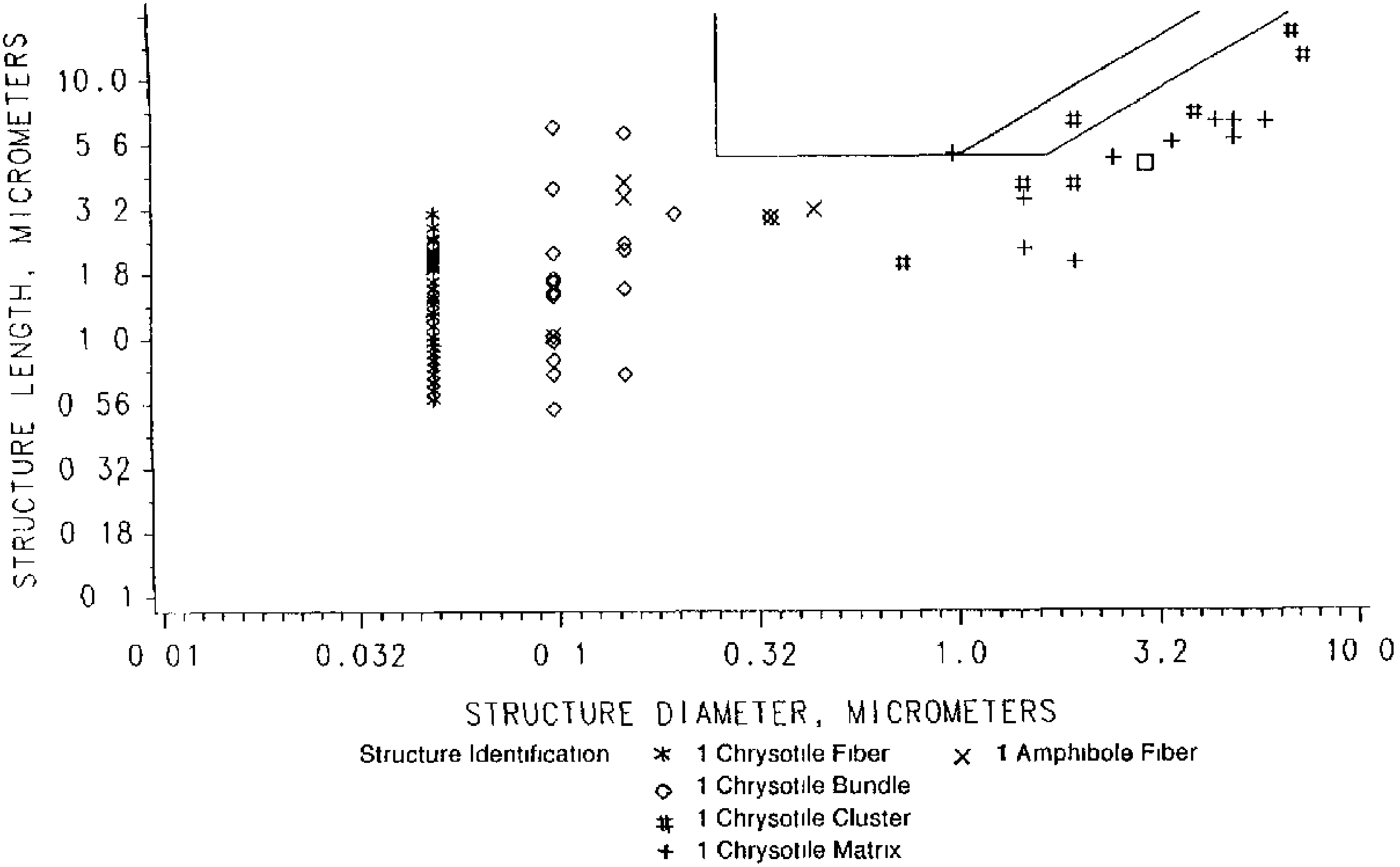
Note Fibers Visible by NIOSH Method 7400 are indicated in upper right hand window (See Text)

Figure 5 Plot of length to width relationship of asbestos structures sampled prior to asbestos removal in Area A.



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

Figure 6. Plot of length to width relationship of asbestos structures sampled after asbestos removal in Area A



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

Figure 7. Plot of length to width relationship of asbestos structures sampled from personal breathing zone samples during asbestos removal in Area A.

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 is insufficient to define conditions where negative pressure glove bags can be used without backup containment of the work area Additional work might establish these parameters Even if it can be shown that such containment is unnecessary, the authors believe that respiratory protection should be provided for workers whenever glove bags are used

REFERENCES

1 Hollett, B , Froehlich, P , Caplan, P , Cooper, T , and Shulman, S Technical Report An Evaluation of Glove Bag Containment in Asbestos Removal DHHS (NIOSH) Publication No 90-119

2 NIOSH 1985 Project Protocol for Control Technology Assessment of Asbestos Removal Processes August 1985 Unpublished

3 NIOSH 1984 Statement of the National Institute for Occupational Safety and Health, the Public Hearing on Occupational Exposure to Asbestos, June 21, 1984 Testimony of Proposed Rule Making at OSHA Hearings

4 NIOSH 1991 Testimony of the National Institute for Occupational Safety and Health on the Occupational Safety and Health Administration's Notice of Proposed Rulemaking on Occupational Exposure to Asbestos, Tremolite, Anthophyllite, and Actinolite, January 23, 1990 NIOSH policy statement Cincinnati, OH U S Dept of Health and Human Services Public Health Service Centers for Disease Control National Institute for Occupational Safety and Health

5 NIOSH 1990 Testimony of the National Institute for Occupational Safety and Health on the Occupational Safety and Health Administration's Notice of Proposed Rulemaking on Occupational Exposure to Asbestos, Tremolite, Anthophyllite, and Actinolite, May 9, 1990 NIOSH policy statement Cincinnati, OH U S Dept of Health and Human Services Public Health Service Centers for Disease Control National Institute for Occupational Safety and Health

6 NIOSH 1976 Criteria for a recommended standard occupational exposure to asbestos Cincinnati, OH U S Dept of Health and Human Services Public Health Service Centers for Disease Control National Institute for Occupational Safety and Health DHHS (NIOSH) Publication No 77-169

7 NIOSH 1980 Workplace exposure to asbestos review and recommendations NIOSH-OSHA Asbestos Work Group Cincinnati, OH U S Dept of Health and Human Services Public Health Service Centers for Disease Control National Institute for Occupational Safety and Health DHHS (NIOSH) Publication No 81-103

8 NIOSH 1984 Method 7400 National Inst for Occupational Safety and Health NIOSH Manual of Analytical Methods Third Ed , Vol 2 Cincinnati, OH U S Dept of Health and Human Services DHHS (NIOSH) Publication No 84-100 Revision #3 (May 15, 1989)

9 NIOSH 1987 Method 7402 National Inst for Occupational Safety and Health NIOSH Manual of Analytical Methods Third Ed , Vol 2 March 1987 Revision Cincinnati, OH U S Dept of Health and Human Services DHHS (NIOSH) Publication No 84-100

10 USDOL, OSHA 1986 Occupational Exposure to Asbestos, Tremolite, Anthophyllite, and Actinolite, Final Rules 29CFR1910 1001 and 29CFR1926 58 51FR22612 (June 20, 1986)

11 USDOL, OSHA 1988 Amendment to Occupational Exposure to Asbestos, Tremolite, Anthophyllite, and Actinolite, Final Rules 29CFR1910 1001 53FR35610 (September 14, 1988)

12 Public Law 99-519 Asbestos Hazard Emergency Response Act of 1986, Sec 2 Amendment to Toxic Substance Control Act, Title II-Asbestos Hazard Emergency Response Signed October 22, 1986

13 NIOSH 1984 Method 7400 National Inst for Occupational Safety and Health NIOSH Manual of Analytical Methods Third Ed , Vol 2 Cincinnati, OH U S Dept of Health and Human Services DHHS (NIOSH) Publication No 84-100 (February 15, 1984)

14 Ibid Revision #2 (August 15, 1987)

15 Baron, P and Deye, G 1990 Electrostatic Effects in Asbestos Sampling I Experimental Measurements American Industrial Hygiene Association Journal 51(2) 51-62

16 NIOSH 1987 Method 7402 National Inst for Occupational Safety and Health NIOSH Manual of Analytical Methods Third Ed , Vol 2 March 1987 Revision Cincinnati, OH U S Dept of Health and Human Services DHHS (NIOSH) Publication No 84-100 Revision #2 (August 15, 1987)

17 USEPA 1977 (Rev June 1978) U S Environmental Protection Agency Electron Microscope Measurement of Airborne Asbestos Concentrations Research Triangle Park, NC Office of Research and Development, USEPA EPA-600/2-77-178

18 USEPA 1983 U S Environmental Protection Agency Guidance for Controlling Friable Asbestos-Containing Material in Buildings Washington, DC Office of Toxic Substances and Office of Pesticides and Toxic Substances, USEPA EPA-560/5-83-002

19 USEPA 1985 U S Environmental Protection Agency Guidance for Controlling Friable Asbestos-Containing Material in Buildings Washington, DC Office of Toxic Substances and Office of Pesticides and Toxic Substances, USEPA EPA-560/5-85-024

APPENDIX A AERO-PIPE CAPSULE DATA - PERSONAL AND AREA SAMPLES

					Concentration			
Sample			Time	Volume	TEM Analysis		PCM Analysis	
Number	Location	Date	(min)	(Liters)	(s/mm^2)	(s/cc)	(f/mm^2)	(f/cc)
AA25631	B/C - PBZ	08/10	133	402	166 205	0 1592	<3000	<0 008
AA25650	B/C - PBZ	08/10	133	402			3000	0 008
AA25637	B/C - Outside	08/10	133	402	79 563	0 0762	<3000	<0 008
AA25617	B/C - Outside	08/10	133	402			3000	0 008
AA25645	B/C - Outside	08/10	333	1012			3000	0 003
AA25644	B/C - Outside	08/10	333	1009	125 028	0 0477	<3000	<0 003
AA25699	Blank	08/10			<11 080		<3000	
AA25654	Blank	08/10			<11 080		<3000	
AA25641	Blank	08/10					<3000	
AA25628	Blank	08/10			<10 520		<3000	
AA25610	Blank	08/10					<3000	
AA25495	A - PBZ	08/11	177	529	63 118	0 0459	<3000	<0 005
AA25649	A - PBZ	08/11	182	552	161 743	0 1130	<3000	<0 006
AA25639	A - PBZ	08/11	182	550	338 080	0 2370	<3000	<0 006
AA25139	A - PBZ	08/11	189	571			4000	0 004
AA25635	A - Inside	08/11	121	363	232 687	0 2468	<3000	<0 008
AA25621	A - Inside	08/11	121	363			3000	0 008
AA25686	A - Inside	08/11	245	735			5000	0 007
AA25640	A - Inside	08/11	245	745	463 662	0 2399	<3000	<0 004
AA25646	A - Outside	08/11	119	369	53 914	0 0563	<3000	<0 008
AA25642	A - Outside	08/11	332	996			3000	0 003
AA25630	A - Outside	08/11	119	357			<3000	<0 008
AA25632	A - Outside	08/11	332	996	431 307	0 1667	<3000	<0 003
AA25633	Blank	08/11			<10 783		<3000	
AA25659	D - PBZ	08/12	111	335	99 723	0 1146	<3000	<0 009
AA25638	D - PBZ	08/12	114	347			<3000	<0 009
AA25656	D - ST BZ	08/12	15	45	21 566	0 1845	<3000	<0 068
AA25687	D - ST BZ	08/12	21	63	11 080	0 0677	<3000	<0 048
AA25623	D - Vac Exhaust	08/12	114	345			<3000	<0 009
AA25657	D - Vac Exhaust	08/12	114	345	23 375	0 0261	<3000	<0 009
AA25695	D - Inside	08/12	142	426			<3000	<0 007
AA25629	D - Inside	08/12	142	426	136 395	0 1233	<3000	<0 007
AA25497	Ambient	08/12	186	1208	<10 520	0 0033	<3000	<0 002
AA25114	Ambient	08/12	186	1209			<3000	<0 002
AA25690	Blank	08/12					<3000	
AA25622	Blank	08/12			<11 688		<3000	

APPENDIX B· AERO-PIPE CAPSULE DATA - AMBIENT AND PRE- AND POST-REMOVAL SAMPLES

Sample Number	Location	Date	Time (min)	Volume (Liters)	Concentration (TEM Analysis) (s/mm²)	(s/cc)
AH01	Ambient	08/09	370	3404	10 434	0 0012
AH02	Ambient	08/09	393	3404	<10 434	<0 0012
AH03	Ambient	08/09	381	3402	<10 020	<0 0011
AH04	Ambient	08/09	369	3404	10 434	0 0012
AH05	Ambient	08/09	357	3348	<10 434	<0 0012
AH06	Blank	08/09	---	----	<11 222	
AH07	B/C Pre-removal	08/09	375	3550	338 792	0 0367
AH07R*	B/C Pre-removal	08/09	375	3552	282 326	0 0306
AH08	B/C Pre-removal	08/09	375	3550	375 054	0 0407
AH08D*	B/C Pre-removal	08/09	375	3549	514 359	0 0558
AH09	B/C Pre-removal	08/09	375	3550	156 511	0 0170
AH10	B/C Pre-removal	08/09	375	3550	164 817	0 0179
AH11	B/C Pre-removal	08/09	375	3550	214 568	0 0233
AH12	Ambient	08/10	370	3403	10 988	0 0012
AH13	Ambient	08/10	393	3403	<10 988	<0 0012
AH14	Ambient	08/10	382	3403	43 951	0 0050
AH14D*	Ambient	08/10	382	3525	10 988	0 0012
AH15	Ambient	08/10	369	3402	<11 293	<0 0013
AH17	Ambient	08/10	363	3403	10 988	0 0012
AH16	Blank	08/10	---	----	<11 463	
AH18	Blank	08/10	---	----	<11 918	
AH19	Blank	08/10	---	----	<10 988	
AH20	A Pre-removal	08/10	375	3550	2342 920	0 2541
AH21	A Pre-removal	08/10	375	3550	2759 320	0 2993
AH22	A Pre-removal	08/10	375	3550	2774 420	0 3009
AH23	A Pre-removal	08/10	375	3550	2219 540	0 2407
AH24	A Pre-removal	08/10	375	3550	2097 550	0 2275
AH26	Ambient	08/11	700	3345	<11 293	<0 0013
AH28	Ambient	08/11	700	3450	<11 587	<0 0013
AH41	Ambient	08/11	700	3458	<10 716	<0 0012
AH42	Ambient	08/11	700	3251	<10 988	<0 0013
AH46	Ambient	08/11	700	3514	<11 587	<0 0013
AH30	Blank	08/11	---	----	<11 222	
AH27	B/C Post-Removal	08/11	385	3401	657 354	0 0744
AH31	B/C Post-Removal	08/11	385	3551	626 305	0 0679
AH32	B/C Post-Removal	08/11	385	3513	563 446	0 0618
AH36	B/C Post-Removal	08/11	385	3551	821 693	0 0891
AH37	B/C Post-Removal	08/11	385	3551	687 758	0 0746
AH29	A Post-removal	08/11	371	3652	4216 070	0 4447
AH34	A Post-removal	08/11	371	3670	6549 970	0 6966
AH38	A Post-removal	08/11	371	3504	6260 430	0 6879
AH49	A Post-removal	08/11	371	3567	13668 600	1 5018
AH50	A Post-removal	08/11	371	3652	5522 470	0 5822

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