1. 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 reduce the risk of potential health hazards, and to create an awareness of the need for or the availability of effective hazard control measures. A number of these studies on control assessments, including the present research study on the use of glove bags in asbestos removal, have been performed in collaboration with the Environmental Protection Agency (EPA).

The original objective for this study was concerned primarily with control of occupational exposure; however, in collaboration with the EPA, environmental aspects were also included. Because the EPA was preparing legislation for asbestos abatement, that Agency was interested not only in the efficacy of glove bags for asbestos containment, but also in the development of test methods to evaluate asbestos contamination at very low concentrations. As a result, the study was undertaken with two objectives:

- To evaluate the efficacy of the use of glove bags as a control technique to prevent occupational exposure to airborne asbestos during the removal of asbestos-containing pipe lagging, and as a control technique to prevent contamination of the building environment. NOTE: The occupational exposure and building contamination aspects are discussed separately in the present report because they involve different analytical methods and regulatory agencies.

- To evaluate sampling and analytical techniques for determining concentrations of airborne asbestos for asbestos abatement clearance, specifically: (a) to compare airborne asbestos concentrations determined by "aggressive" and "nonaggressive" sampling methods, and (b) to compare analytical results determined by PCM and TEM procedures.

The evaluations were conducted during the removal of asbestos-containing pipe lagging in four public school buildings; all removal operations were conducted by the same work crew. The authors have attempted to accurately describe the operations and conditions observed during the surveys and to delineate the major difficulties encountered in the evaluations of the sampling and analytical methodologies. In many cases, the high variability of asbestos analytical results precluded the ability to obtain sufficient data to determine statistical differences; however, the data and observations reported indicate trends and other information useful to members of the asbestos removal industry for reducing asbestos emissions.

1.1. BACKGROUND

1.1.1. Technical

A pilot study of asbestos abatement operations conducted in 1984 revealed novel approaches that have been and are being developed to control asbestos fiber exposure of workers engaged in the removal of asbestos-containing materials (ACM).[5] Two principle methods currently used to control airborne exposure are wetting the ACM and the use of negative air pressure in the workplace. Wetting methods utilize fluids to saturate ACM before and during the removal of these materials to reduce the potential for 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 enclosed or controlled areas and to draw clean air into these areas. In order to contain and reduce airborne asbestos, this exhausted air is filtered through high efficiency particulate air (HEPA) filters before being released to the atmosphere.

The evaluation of source controls, such as containment or local ventilation applied at the source of the emission, is 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 which contain long gloves sealed into the body. The worker seals the bag around the material to be removed and then manipulates various tools within the bag by means of the gloves sealed into the side of the bag to remove the lagging. The 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. They 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 extremely important to assure the health of workers and to prevent contamination of the adjoining workplaces and the environment.

This study was initiated to determine if the use of glove bags can reliably control asbestos emissions during abatement operations. In addition, EPA methodologies for measuring room contamination levels of airborne asbestos for post-abatement clearance were evaluated.

1.1.2. Environmental Regulation

The EPA has been involved in regulatory activities to reduce asbestos emissions and contamination of the environment since 1972.[6,7] A major concern of this Agency is that degradation or disturbance of in-place ACM in buildings may cause asbestos to contaminate the buildings. The debris may become airborne from repeated episodes of agitation and thereby create a potential for exposure to the occupants. Although the application of asbestos fireproofing material is not permitted in buildings today, the eventual management and removal of in-place ACM poses a technical and economic dilemma. A part of the Toxic Substances and Control Act, the Asbestos-in-Schools Rule,[8] requires administrators of primary and secondary schools, both private and public, to have all buildings inspected for ACM; to document its presence and condition; and to inform their employees, the PTA or parents, and the State authority.

In the past, rather than promulgate specific regulations for asbestos abatement activities, the EPA has issued "Guidance Documents"[9,10] which have presented the "best engineering judgment" approach at that time. Based on these guidelines and on the present requirements of the Asbestos Hazard Emergency Response Act (AHERA),[11] ACM must be routinely monitored through an established operation and maintenance program. If abatement is needed, the accepted methods are: (1) encapsulation with a penetrating or bridging chemical; (2) enclosure to prevent access to public or to airflow disturbances; or (3) removal. EPA regulations also require the removal of ACM prior to demolition of a building,[12] so eventual removal of ACM is virtually inevitable.

Because the efficacy of certain control methods for asbestos removal is not well known, EPA and NIOSH initiated an Interagency Agreement to add to the planned evaluations of glove bag containment by NIOSH researchers. The added work involved documenting the effectiveness of glove bags in controlling airborne emissions that could potentially add to long term, low level building contamination. This required the determination of the airborne asbestos concentrations in work areas before asbestos removal was started and also after the activities were completed in order to determine whether there was a release of airborne asbestos during the removal. Two sampling methods, "aggressive" and "nonaggressive", were used to compare the effectiveness of these methods in evaluating asbestos contamination for building clearance assessment. They are described in detail in the Section 4.1.5, Pre- and Post-Removal Air Sampling.

1.1.3. Analytical Methods

At the time of the study, phase contrast microscopy (PCM) was the primary method used to determine airborne asbestos concentrations in the workplace.

Several investigators had developed transmission electron microscopy (TEM) methods with the capability of detecting fibers smaller than those visible by PCM. Another part of the Interagency Agreement was to provide some evaluation of these methods for detecting airborne asbestos at the very low concentrations encountered in environmental evaluations by using side-by-side sampling and subsequent analysis by both PCM and TEM.

1.1.3.1. Phase Contrast Microscopy--

PCM has historically been used 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. Epidemiologic studies have correlated 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 micrometers (μm) in length and with an aspect ratio of at least 3:1 (length to width) collected on cellulose ester filter media.[13]

NIOSH Method 7400 describes sampling and analytical procedures for determining fiber concentrations by PCM. This method was first issued February 15, 1984.[14] It was revised May 15, 1985,[15] and a second revision was made August 15, 1987;[16] the third and current revision was issued May 15, 1989.[17] The NIOSH Method 7400, in place at the time of the study,[14] included two sets of counting rules: "A" rules and "B" rules. PCM samples from this study were analyzed using the "B" rules, which define a fiber as having an aspect ratio of 5:1 or greater. A note under the "B" rules in this version states: ". . . The B rules are preferred analytically because of their demonstrated ability to improve the reproducibility of fiber counts." In the third and current revision of Method 7400,[17] the "B" rules are only included as Appendix C and an introductory note concludes: "NIOSH recommends the use of the 3:1 aspect ratio in counting fibers." (As discussed in Section 2.1, Occupational Exposure Criteria, it is not possible to estimate accurately "A" rule fiber counts based on "B" rule results.)

A note on the applicability of NIOSH Method 7400[17] 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. Baron and Deye[18] 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. For this and other reasons as discussed in Section 5.2, Confidence Limits, the interlaboratory coefficient of variation (CV = 0.45) is quite large. The term "index" is properly applied to the result of microscopic fiber counts, because quantitation of analytical results contains more uncertainty than does the analysis of most chemicals. However, this method does have the capability of producing results rapidly (less than 24 hours) and relatively inexpensively.

1.1.3.2. Electron Microscopy--

In addition to PCM, transmission electron microscopy (TEM) was evaluated 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 the 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 <0.25 µm in diameter may be present in these circumstances, they will not be observed at all with PCM. Thus, under these conditions, no conclusion can be made about their presence or absence. Because of the lower resolving power of the PCM method, the EPA requires the TEM method to be used for quantitating asbestos fibers.[11,19]

Widespread use of TEM has been limited by the relative high cost of analysis, the availability of equipment and trained personnel, and the absence of a standardized method of analysis. NIOSH Method 7402,[20] 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,[21] but the use of a cellulose ester filter is still required.) The EPA has developed a provisional method for TEM analysis of asbestos which requires a polycarbonate filter medium.[19] This method was further modified for regulatory purposes when the Asbestos Hazard Emergency Response Act (AHERA)[11] was promulgated in 1986, and is considerably different than the NIOSH method 7402 and the requirements of the OSHA Standard;[13] this is discussed further in Section 2.2, Environmental Exposure Criteria.

1.1.4. Facilities Surveyed

In the summer of 1983, a public school board employed a consultant to survey the school buildings to determine the type, location, and condition of ACM. Asbestos-containing pipe and/or boiler lagging was found in 90% of the buildings surveyed; asbestos-containing acoustical plaster, fireproofing, and/or acoustical ceiling tile were found in only a few buildings.[22] In addition, there were numerous occurrences of miscellaneous building materials (pressed asbestos-board, asbestos-cement sheeting, etc.) and other products (asbestos protective clothing, pot holders, gaskets, etc.) observed in these buildings. The consultant's recommendations for minimizing the risk of asbestos exposure included the removal of significantly deteriorated acoustical plaster and fireproofing, the repair and repainting of acoustical plaster in some areas, and the repair or removal of damaged and/or exposed asbestos pipe and boiler insulation. The establishment of an asbestos hazard management program was recommended to provide for employee training, monitoring, and management of all ACM that remained in these buildings. These recommendations were implemented by the school board and the priority asbestos removal and repair projects were completed. In 1985, a contractor was employed to remove all remaining asbestos-containing pipe lagging and materials. Arrangements were made with the school board for the NIOSH research team to conduct surveys at four school buildings and to collect samples to determine airborne asbestos contamination levels before, during, and after the removal of pipe lagging.

2. DISCUSSION OF THE HAZARD AND EXPOSURE CRITERIA

2.1. OCCUPATIONAL EXPOSURE CRITERIA

Because of the potential carcinogenicity of asbestos 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 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.[23] On May 9, 1990, at the hearing on OSHA's Notice of Proposed Rulemaking on Occupational Exposure to Asbestos, Tremolite, Anthrophyllite, and Actinolite,[24] this position was summarized as follows:

> ". . . 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 fiber concentration for any of the asbestos minerals.[23] 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[25] and the joint NIOSH/OSHA report of 1980.[26] In the NIOSH/OSHA report, NIOSH also reaffirmed its position that there is no scientific basis for differentiating health risks between types of asbestos fibers for regulatory purposes. In its 1984 testimony, NIOSH urged that the goal be to eliminate asbestos fiber exposures.[23] Where exposures cannot be eliminated, exposures should be limited to the lowest concentration possible.
>
> "When recommending an occupational exposure limit in its 1984 testimony, NIOSH acknowledged the limitations imposed by currently accepted methods of sampling and analysis. NIOSH concluded that for regulatory purposes, phase contrast microscopy (PCM) was still the most practical technique for assessing asbestos fiber exposures when using the criteria given in NIOSH Analytical Method 7400.[17] NIOSH also recognized that phase contrast microscopy (1) lacked specificity when asbestos and other fibers occurred in the same environment, and (2) was not capable of detecting fibers with diameters less than approximately 0.25 micrometers. 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 of mineral and assist in ascertaining asbestos fiber concentrations."

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 4L/min. This airborne fiber count can be determined using NIOSH Method 7400, 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[21] 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 analogs . . . ."

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.[23] 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[17]) to determine airborne asbestos exposures, and electron microscopy (NIOSH Method 7402[21]) 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.[13] 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.[27]"

At the time of this study (1985), the OSHA PEL was 2.0 fibers greater than 5 μm in length per cubic centimeter (2,000,000 f/m^3), averaged over an 8-hour work day, with a ceiling concentration of 10.0 f/cc (10,000,000 f/m^3), not to be exceeded over a 15-minute period.[27] There was also a provision for medical monitoring of workers routinely exposed to fiber concentrations in excess of 0.1 f/cc (100,000 f/m^3).

On June 20, 1986, OSHA issued a revised standard which reduced the PEL to 0.2 f/cc (200,000 f/m^3) greater than 5 μm in length, as an 8-hour time-weighted average (TWA) exposure.[13] It also set an action level of 0.1 f/cc (100,000 f/m^3) that triggers other requirements, including worker training and medical monitoring; in 1988 the standard was revised to establish a 1.0 f/cc (1,000,000 f/m^3) excursion limit.[27]

Many employees of local, state, or federal governmental agencies are exempt from OSHA regulations. To protect all workers in public schools where asbestos removal is performed, the EPA first adopted the provisions of the OSHA standard in effect in 1985 and then the June 1986 OSHA revisions in February 1987.[29]

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 inherent 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[14] stipulated 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). The A rules use the same aspect ratio required in the earlier NIOSH analytical method P&CAM 239[30] and the current OSHA PEL, and thus have the advantage of relating fiber concentrations to current and historical exposure data. There is no means to generically extrapolate fiber concentrations determined from the use of the B rules to that which may have been derived if the A rules had been used, because the distribution of fibers may vary from case to case. However, fiber counts of samples collected in this study at two schools were compared using TEM analysis to determine fiber dimensions and type of fiber. Using the fiber size distribution determined by TEM for samples in the present study, the difference between the number of fibers counted having aspect ratios greater than 5:1 and those having aspect ratios greater than 3:1 was under 20%.

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. Because 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 could 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 by occupational health professionals as an appropriate index of exposure for approximating disease potential.

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), because the amount of inspired air over the work shift of asbestos removal workers would typically be 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! As noted above, 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.

2.2. ENVIRONMENTAL EXPOSURE CRITERIA

The EPA had established "clearance" guidelines for determining when reoccupancy may occur after asbestos removal. These guidelines were initially published as "recommended practices."[9,10] In 1984 and 1985, the recommended practice was to perform visual inspection of the work area after asbestos removal, followed by quiescent air sampling using PCM for fiber analysis. Fiber concentrations were required to be below the lower quantifiable limit of detection using NIOSH Method P&CAM 239.[30] This limit ranged from 30,000 to 10,000 f/m^3 (0.03 to 0.01 f/cc) at the recommended sample volumes of 1,000 to 3,000 liters. 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.

The revised EPA guidelines issued in 1985[9] recognized NIOSH Method 7400 and recommended a 3,000 liter sample in order to provide a minimum quantification limit of 0.01 f/cc (10,000 f/m^3). These guidelines also recommended using aggressive sampling and the use of TEM analysis to determine asbestos concentrations. To permit reoccupancy using this evaluation methodology, the average fiber concentration of five samples collected from a "homogenous" area was to be statistically equal to or less than the ambient background fiber concentration. A typical ambient asbestos concentration is approximately 0.005 f/cc (5,000 f/m^3).[31]

The field work for the present study was conducted in June and July of 1985, based on the 1985 revised EPA guidelines,[9] for sampling and analysis. For the sake of completeness, a discussion of legislative revisions of environmental exposure criteria which have occurred since 1985 that affect current asbestos removal work is given in the following text.

In October 1986, the Asbestos Hazard Emergency Response Act (AHERA)[11] was passed which required the EPA to regulate asbestos in schools. On October 30, 1987, the final rule "Asbestos-Containing Materials in Schools" was published in the Federal Register.[32] This rule 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. For the first 2 years after the effective date of the rule (December 14, 1987), ". . . a local education agency (LEA) may analyze air monitoring samples for clearance purposes by PCM to confirm completion of removal, encapsulation or enclosure of ACBM [asbestos-containing building material] that is less than or equal to 3,000 square feet or 1,000 linear feet. The section [response action] shall be considered complete when the result of samples collected in the affected functional space show that the concentration of asbestos for each of five samples is less than or equal to the limit of quantitation for PCM, or 0.01 f/cc [10,000 f/m^3] of air."

After the first 2 years or if the job exceeds the minimum size criteria, 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.

A previous EPA guidance publication[33] noted that the basis for collecting five samples was to increase the statistical confidence in the measurement and thus reduce the possibility of wrongly approving a contaminated facility. Statistically, seven samples are required for a method with a CV of 1.5 to provide a 90% confidence of detecting a fivefold difference from the ambient concentration; however, for practical reasons, a minimum sample size of five was recommended. The same EPA publication also recommended that samples from the work site should be taken from one homogeneous area which is defined as "a contiguous area in which one type of abatement procedure was performed to remove the same type of ACM." Asbestos removal at most abatement sites is performed using various removal procedures to remove different types of ACM from a number of separated areas within a building. Even within contiguous areas, several different types of abatement procedures may be employed. The "homogenous area" requirement was omitted in the enactment of the AHERA regulation.

In addition to these changes in the sampling protocol and clearance strategy, AHERA prescribed a new TEM protocol which differs from NIOSH method 7402 and OSHA reference method (Appendix A of the revised standard[13]) in several ways:

Aspect Ratio - Fibers must have a 5:1 or greater aspect ratio to be counted, as opposed to the 3:1 ratio prescribed by NIOSH and OSHA for evaluating airborne exposure. A review[34] of several EPA studies (including this project) indicated that fiber counts based on a 5:1 aspect ratio ranged from 13 to 61 percent lower than fiber counts obtained using a 3:1 aspect ratio. Thus, lower airborne asbestos concentrations are reported when the 5:1 aspect ratio is used.

Filter Media - Air samples may be collected either on polycarbonate or cellulose ester media; however, the cellulose ester media specified is a 0.45 μm pore size filter with a 5.0 μm pore size backing filter. Both NIOSH Method 7402 and the OSHA standard specify a 0.8 μm pore size filter. This difference may affect the distribution and orientation of the fibers collected.

Filter Blank Contamination and Interlaboratory Variability - A more complicated issue involves the analysis of fiber contamination found on unused (blank) filters and the determination of the LOD. In 1985, the EPA provided polycarbonate filters from the same production lot for this and several other studies. The investigators for these studies reported high and variable fiber counts on blank filters as they were received from the EPA. A peer review workshop to discuss the topic was convened by the EPA in April 1986. The findings were presented in "Filter Blank Contamination in Asbestos Abatement Monitoring Procedures: Proceedings of a Peer Review Workshop."[35] Two major consequences of this contamination were identified: One was the need for improved quality control to reduce contamination in the polycarbonate media during its manufacture. The other was the high interlaboratory variability which became obvious when analyses of contaminated blank polycarbonate filter media were compared. Figure 2-1, which is reproduced from the report of this workshop, illustrates these comparisons.

In addition to variable contamination of the filters, a major confounding source of interlaboratory variability was the lack of standardization for sample preparation and analysis used between laboratories. Although the polycarbonate filters were analyzed by the Yamate modified EPA provisional method,[19] subtle differences in the preparation, instrumentation, and procedural interpretation by the analyst greatly affected the fiber count.[35] A fundamental treatment of this subject is presented in "Accuracy of Transmission Electron Microscopy for the Analysis of Asbestos in Ambient Environments."[36]

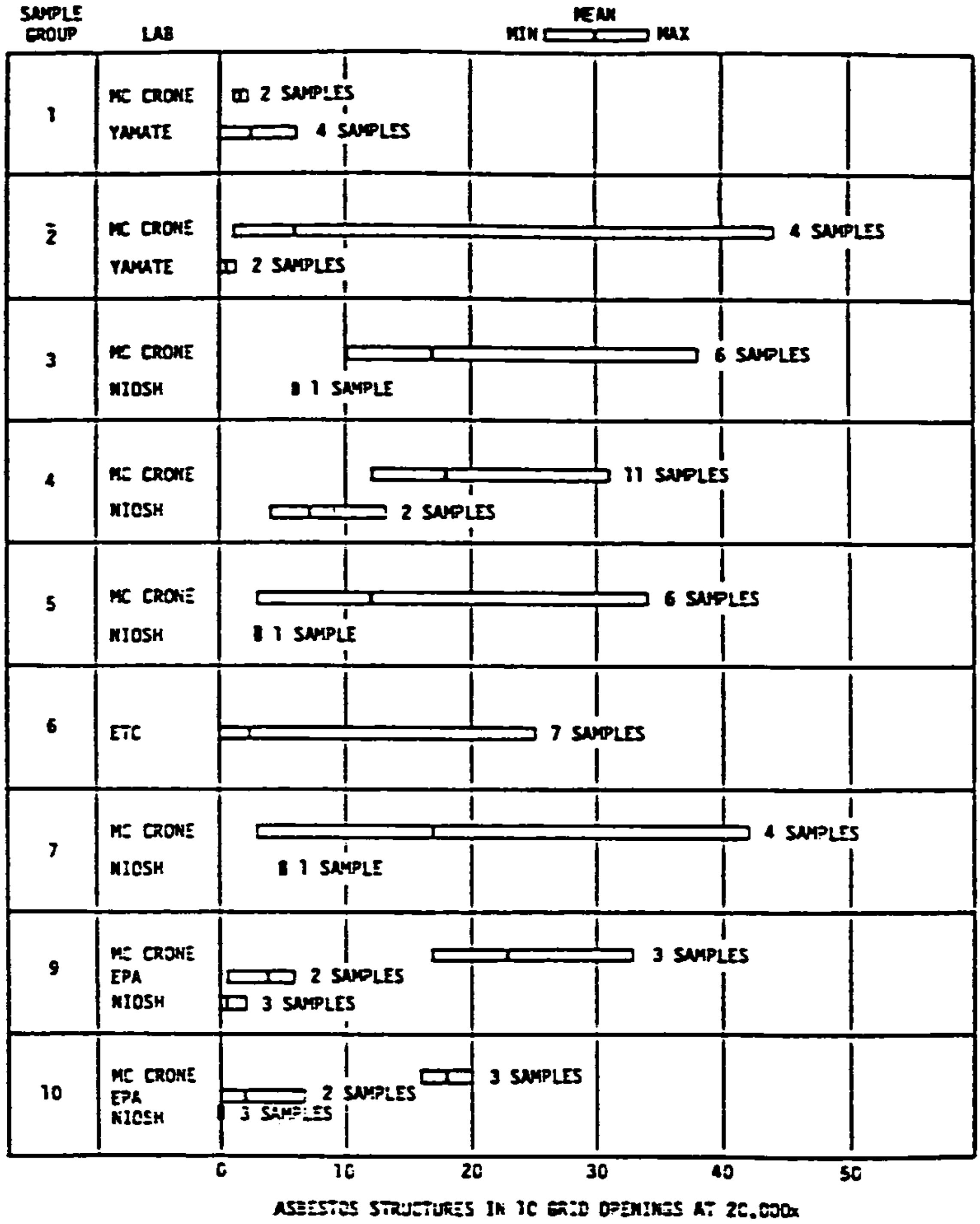
As a result of the workshop, the EPA evaluated asbestos contamination in a batch of newly-manufactured polycarbonate filters that were manufactured using improved quality controls to reduce asbestos contamination. This was compared to a batch of typical cellulose ester filters (which were not expected to show appreciably contamination based on past experience). Two laboratories analyzed 50 samples of each type. The mean asbestos contamination was found to be 10 fibers in 1,000 grids for the cellulose ester media, and 180 fibers per 1,000 grids for the polycarbonate. These values correspond to 2 structures/mm^2 and 35 structures/mm^2, respectively.

The ACM in Schools Regulation[32] states: "When volumes greater than or equal to 1,199 L for a 25 mm filter and 2,799 L for a 37 mm filter have been collected and the average number of asbestos structures on samples inside the abatement area is no greater than 70 s/mm^2 of filter, the response action may be considered complete without comparing the inside samples to the outside samples. EPA is permitting this initial screening test to save analysis costs in situations where the airborne asbestos concentration is sufficiently low so that it cannot be distinguished from the filter contamination/background level (fibers deposited on the filter that are unrelated to the air being sampled). . . . The value of 70 s/mm^2 is based on the experience of the panel of microscopists who consider one structure in 10 grid openings (each grid opening with an area of 0.0057 mm^2) to be comparable with contamination/background levels of blank filters . . . ." This "experience" refers to analyses of the contaminated polycarbonate filter medium described above. The analytical method requires laboratories to determine the actual contamination of the blank filters for each media lot. As noted above, however, AHERA permits a contamination level of 70 s/mm^2 to be assumed for clearance purposes, i.e., if the sample filters contain 70 or fewer s/mm^2, the room may be reoccupied.

If the average indoor sampling concentrations are greater than 70 s/mm^2, the area may be recleaned, retested, and analyzed as described above, or a Z-test may be performed. The Z-test is a statistical comparison of indoor clearance

Figure 2-1

Comparison by Laboratory of Asbestos Structure Counts on Blanks*



* From: Filter Blank Contamination in Asbestos Abatement Monitoring Procedures: Proceedings of a Peer Review Workshop.[26]

samples vs. outdoor ambient samples. It is used to determine whether the abatement response action is complete, i.e., if clearance has been achieved for reoccupancy. Powers and Cain reported the probability of passing the Z-test for various room, filter media, and ambient asbestos structure concentrations, as shown in Figures 2-2 and 2-3.[37] To illustrate the use of these figures, suppose that the filter media are contaminated with 70 s/mm^2 and a room is cleaned to the 0.005 s/cc (5,000 s/m^3) ambient asbestos concentration. The probability of passing is only 70%, whereas if the filter media contamination is less than 17 s/mm^2, the probability of passing is 99%. Thus the media contamination can lead to false positives for room contamination which would potentially require additional but unwarranted cleaning.

As noted above, the ACM in Schools Regulation states that clearance can be achieved without comparing inside samples to the outside samples if the inside samples pass a screening clearance criteria of 70 s/mm^2. This is done ". . . to save analysis costs where airborne asbestos concentration is sufficiently low so that it can not be distinguished from the filter contamination . . . ."[32] The value, 70 s/mm,^{2} is 4 times the analytical sensitivity of the polycarbonate method. The analytical sensitivity is stated to be no greater than 1 fiber in 10 grids, or 0.005 s/cc (5,000 s/m^3) for a 37 mm filter. Based on these assumptions, the clearance limit for TEM, using a 3,000 liter sample and a 37 mm filter, is 4 x 0.005 s/cc, or 0.02 s/cc (20,000 s/m^3). Ambient asbestos concentrations are usually an order of magnitude lower than this, typically in the range of 0.002 to 0.005 s/cc (2,000 to 5,000 s/m^3).[31]

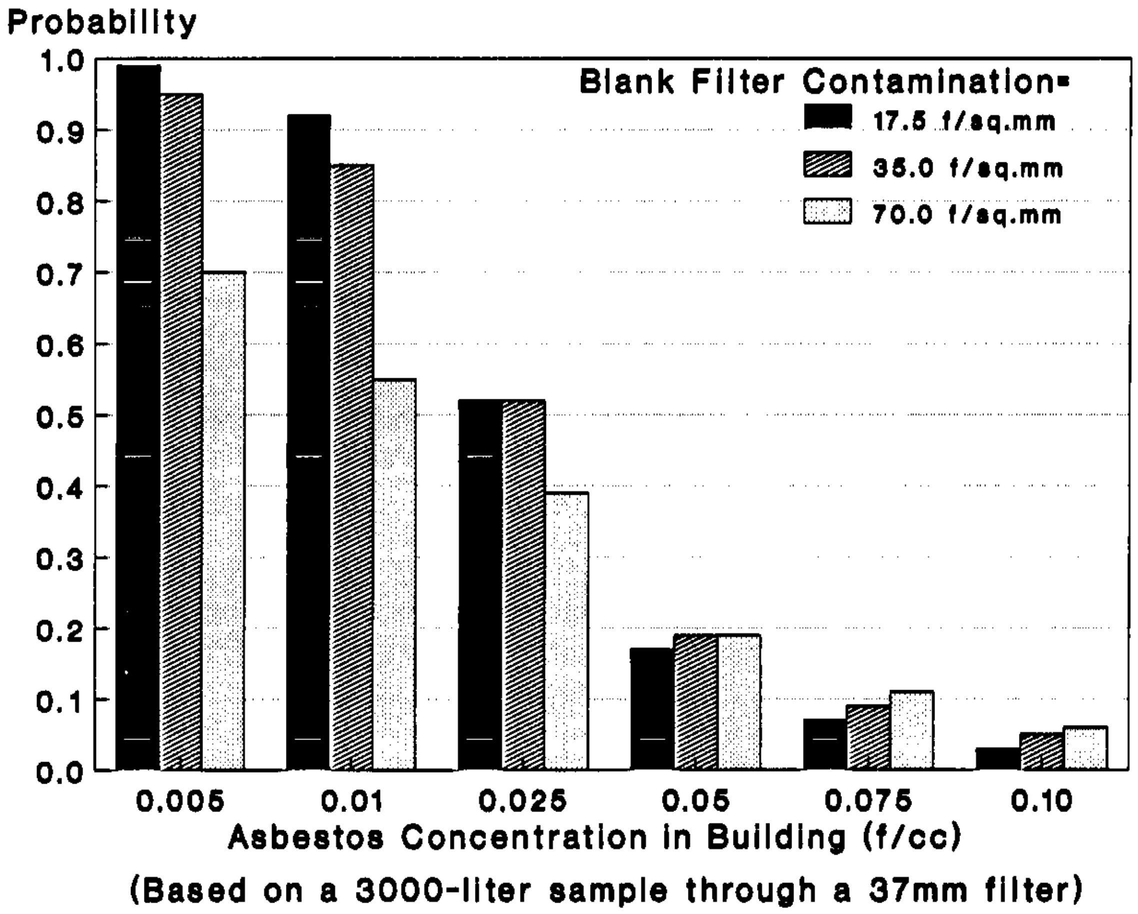
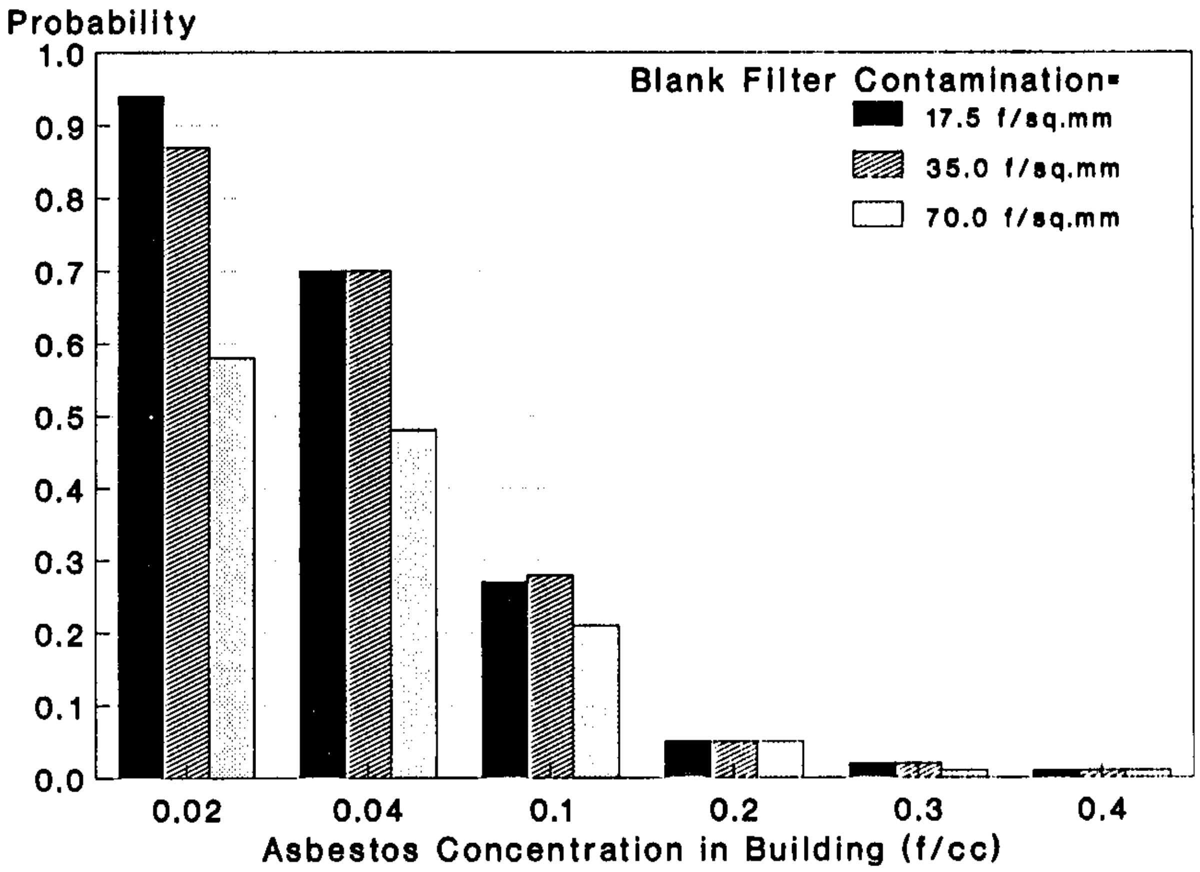


Fig 2-2 Probability of Passing the Z-Test for Asbestos Abatement Clearance when Outdoor Ambient Concentration is 0.005 (f/cc)



Based on a 3000-liter sample through a 37-mm filter

Fig 2-3 Probability of Passing the Z-Test for Asbestos Abatement Clearance When Outdoor Ambient Concentration is 0.02 (f/cc)

3. SITE AND PROCESS DESCRIPTION

3.1. SITE DESCRIPTION

This study was conducted in public school buildings typical of those found in a large city. Two rooms in each of four schools were selected for the measurement of airborne asbestos concentrations. The rooms were visually inspected and found to be fairly clean, having no apparent damage to the pipe lagging and little potential for contamination from the other types of fibers, e.g., textile and cellulose fibers from drapes, carpets, ceiling, etc. These "controlled areas" were isolated to restrict interaction with areas and activities outside the study area. All air ducts, holes, and windows in these rooms were sealed with polyethylene sheeting (poly) and duct tape; door openings were sealed off with a two-sheet poly baffle. After sealing the rooms, pre-removal asbestos levels were determined in each room using nonaggressive, then aggressive sampling methods. During ACM removal, personal and area samples were taken to determine asbestos exposures of removal workers during these operations. Finally, after the rooms were cleaned, but before final inspection by the removal contractor, nonaggressive and aggressive sampling methods were again used to determine asbestos in each room after the removal was completed.

Table 3-1 lists the survey dates and the dimensions of the rooms in which the asbestos abatement was performed and evaluated. The analyses of bulk samples taken from the pipe lagging indicated varying percentages of chrysotile (Table 3-1). No actinolite, tremolite, amosite, or anthophyllite asbestos were detected in these samples. Table 3-2 lists the number and types of pipe fittings and the linear feet of pipe from which lagging was removed at each site. The renovation included concurrent removal of ACM from other areas in the buildings at the time of these surveys. As can be determined by Table 3-2, the amount of pipe lagging removed from the rooms designated for study was roughly 10 to 40% of the total asbestos removal work performed in any one building. Personal and area samples of airborne asbestos were obtained during removal work in a third room in two buildings in order to increase the amount of data collected.

3.2. PROCESS DESCRIPTION

Asbestos removal is a complex and labor-intensive task which requires special knowledge, training, experience, and exceptional care to be performed safely. There is a need for careful planning and coordination of the activities involved. If an expert in asbestos removal is not available within the responsible organization, a competent consultant should be engaged to assure that the building owner, occupants, and removal workers are protected by a definitive and complete specification of work and that a reputable asbestos removal contractor is selected. On-site monitoring and control by a

TABLE 3-1. ASBESTOS-CONTAINING PIPE LAGGING REMOVAL STUDY

Facility	Survey Dates				Location	Dimensions (Feet)	Volume (Cubic Feet)	Bulk Sample Analysis	
	Walk-Through	Pre-Removal	Removal	Post-Removal				Chrysotile Asbestos	Cellulose/ Other fiber
#1	06/04	06/14	06/18-21	07/09	Room A	35 x 23 x 13.5	10,868	3-inch Pipe Lagging 1%	---
								2-inch Pipe Lagging 20-25%	---
					Room B	35 x 33 x 12.5	14,438		
					Room C	116 x 35 x 12.5	50,750	Pipe Lagging 30-35%	---
#2	06/04	06/12	06/25-28	07/11	Room D	33 x 22 x 15	10,890	Pipe Lagging 20-25%	---
					Room E	41 x 36 x 15	22,140		
#3	06/04	06/13	07/01-03	07/10	Room F	32 x 23 x 12	8,832	Airseal lagging 30-40%	40-50%
								Joint cement 10-15%	1-2%
					Room G	42 x 25 x 12	12,000	Pipe lagging 10-15%	1-2%
#4	06/04	07/12	07/15-17	07/18	Room H	29 x 25 x 11	7,975	Pipe lagging 5%	10-15%
					Room I	30 x 25 x 9	6,750	Pipe lagging 5-7%	2-3%
					Room J	29 x 24 x 11	7,656	Pipe lagging 20%	10-15%

TABLE 3-2. DESCRIPTION AND LINEAR FEET OF PIPE LAGGING REMOVED

Facility/ Room	Pipe Fittings			Pipe	Pipe*/	Linear Feet Removed During Survey							Removal Contract**	
	Ells No.	Tees No.	Flanges No.	Hangers No.	Surfaces No.	Pipe Size						Total	Linear	Number of
						6-in	5-in	4-in	3-in	2-in	1.5-in	Feet	Feet	Room/Areas
Facility #1														
Room A	15	5	-	7	7	-	-	-	45	53	-	98		
Room B	13	5	-	6	5	-	40	-	-	25	-	65		
Room C	10	5	-	7	4	-	-	91	9	25	-	125		
									Total			288	1800	15
Facility #2														
Room D	21	7	2	7	6	-	58	-	70	15	-	143		
Room E	9	4	1	3	6	45	-	-	12	2	-	59		
Room E***	13	4	1	5	6	30	-	-	45	2	-	77		
									Total			279	1230	13
Facility #3														
Room F	13	6	-	10	9	30	-	15	30	85	-	160		
Room G	18	6	-	4	8	45	-	15	9	-	-	69		
									Total			229	2350	12
Facility #4														
Room H	10	4	-	4	5	-	-	-	42	9	14	65		
Room I	10	5	-	4	9	-	30	-	50	28	5	113		
Room J	11	6	-	4	6	-	-	-	50	28	4	82		
									Total			260	710	10

* Intersections of pipe with walls or ceiling.

** Total linear feet of asbestos pipe lagging removed and number of areas cleaned in each facility.

*** Work completed by the removal crew prior to the post-removal study, but not observed by the survey team. In addition, approximately 27' of 6-inch pipe lagging was reportedly removed from a storage area adjacent to the original poly enclosure without the use of glove bag control techniques and while the poly barriers were open to the controlled area.

knowledgeable representative of the owner is also critical. These prerequisites should be provided prior to the start of the removal operations.

Typically, the removal work involves three phases: preparation, removal, and decontamination. A generic description of these activities is given below to provide an overview of industry practices; however, each abatement project will vary with the specific circumstances. A summary of the removal procedures observed at the four buildings surveyed in this study follows the generic description.

3.2.1. Generic Overview of an Asbestos Removal Activity

3.2.1.1. Preparation--

The site is cleaned, cleared of all movable materials, and isolated. Entrance and egress contamination control facilities are established: one with showers and change rooms for personnel; the other for waste material handling. All other access is sealed off by taping poly over windows, air vents, unused doors, etc. Surfaces, immovable furnishings, and structures not involved in the removal are covered and sealed with poly and the lighting fixtures are removed.

3.2.1.2. Removal--

The ACM are wetted (saturated, if possible) prior to and during their removal. Removal typically involves cutting, scraping, brushing, or other operations performed with hand tools to separate the ACM from the ceilings, beams, pipes, and other structures to which they were originally applied. The wet debris is collected, placed in sealed and properly labeled bags, and removed from the controlled area. Work is performed in small increments to avoid accumulation of waste. In order to contain the fibers and to prevent contaminating the outside air, the containment enclosure is maintained under "negative pressure," i.e., there is a net exhaust from the room or enclosure through HEPA filters to the outside of the building to provide a pressure differential. Air should be exhausted in sufficient quantity with the introduction of clean make-up air to achieve effective dilution. The airflow patterns within the enclosure should also be optimized to provide maximum benefit of the dilution air in reducing fiber concentration. The EPA recommends four air changes per hour;[9] however, some contractors use twice this amount. When large air volumes cannot be exhausted, a portion of the air which has passed through the HEPA filters is sometimes recirculated to the work area. Work should begin at the point furthest from the exhaust and proceed toward the exhaust. Local exhaust ventilation or vacuum pick-up may be used in the immediate proximity of the removal operation or other fiber release points. The workers inside the containment area must wear appropriate protective equipment, including approved respiratory protection and protective clothing.

3.2.1.3. Decontamination--

The asbestos fibers remaining after the removal operations must be removed from all surfaces and from the air. This usually requires several cycles of cleaning separated by sufficient time to allow the airborne fibers to settle. Some contractors include a "blowdown" similar to that used for "aggressive sampling" before the final cleaning procedure. These actions are combined with continuous air filtration in the containment area. All contaminated waste must be disposed of in accordance with EPA and local government regulations.

3.2.2. Asbestos Removal Practices Observed in this Study

For the present study, in which only asbestos pipe lagging was removed, glove bags were used as the primary control of asbestos release. Observations are summarized below. Based on these observations, many of the techniques delineated in Section 6 Recommendations should be considered.

3.2.2.1. Preparation--

The contract for asbestos removal in the buildings that were studied specified the use of glove bags as the primary emission control in lieu of total room containment and ventilation. It also required the installation of poly barriers in stairways and hallways to separate work areas from the rest of the building. Decontamination showers were not required. The floors beneath the pipes being abated were covered with poly to facilitate cleanup, except where concrete floors contained a floor drain. As noted previously, the rooms in which abatement clearance measurements were made were also enclosed in poly barriers, but neither exhaust nor make-up air was supplied to the enclosed areas.

Before starting the removal, the contractor enclosed all of the piping in an envelope fabricated from poly sheeting and duct tape. The surface of the lagging was misted with amended water (water containing wetting agents, penetrants, and/or other agents to enhance the wetting-down process) to control surface dust prior to enclosing it in the poly. A length of poly sheeting was brought up from underneath the pipe and draped over the pipe lagging. The two edges were rolled together and stapled at the top of the lagging to form a loose-fitting, cylindrical envelope around the pipe. Duct tape was used to seal the longitudinal seam and the ends of the envelope to the pipe lagging. Figure 3-1 shows two workers making an enclosure of poly around a pipe and a room ready for removal activity.

3.2.2.2. Removal--

Workers donned disposable work clothing and approved respirators before entering areas where the asbestos removal took place. Although the work crew in this study had had experience in the general removal of asbestos, they were not trained in the proper use of glove bags. During the first day of asbestos removal, the glove bags were hung at widely separated intervals and taped to the poly envelope over the pipe lagging with duct tape. The workers did not use the gloves in the bags, but rather used the bags as receptacles for collecting the debris. The top of the bag was left open and the workers reached in through the open top to cut away the poly envelope, loosen the lagging and allow it to drop into the bag. The bag was then moved along the pipe and the process was repeated. The lagging was wetted as it was removed from the pipe. Water sprayers (2- to 3-gallon, hand-pump garden sprayers) fitted with 30-inch hoses were elevated to the working level and were often hung from the pipes. This required workers on ladders and platforms to climb down periodically to refill the sprayer with amended water and pump up the pressure. The pipe was washed with water and rags, usually after the bag had been moved to the next location.

As the work progressed, the workers learned to better utilize the glove bags based on recommendations from the survey team, on trial and error, on

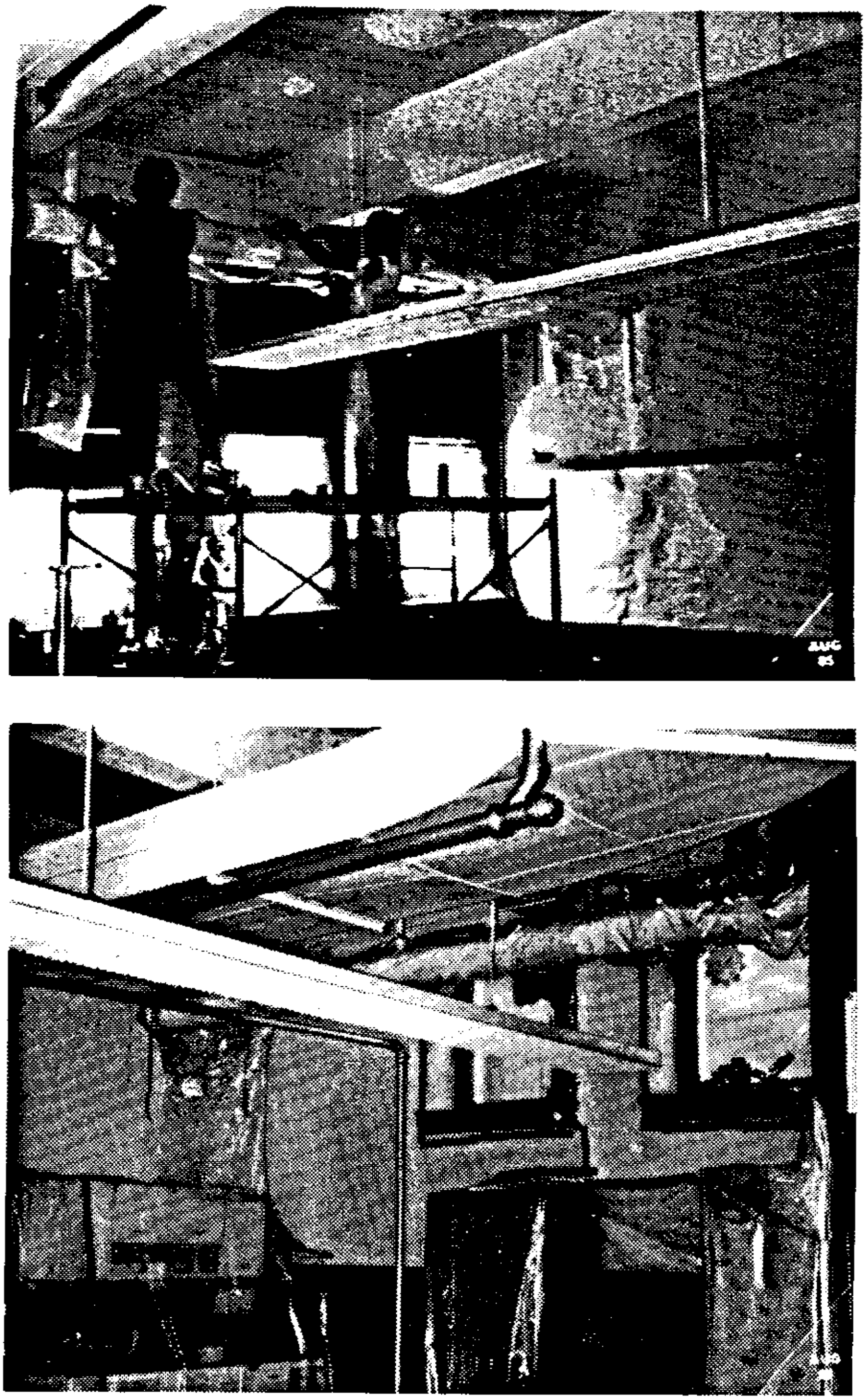


Figure 3-1. Preparation for Removal of Asbestos-Containing Pipe Lagging.

In the upper photograph workers are wrapping a pipe with polyethylene. The insulation had been previously misted with water to reduce the potential for generating dust. The lower photograph shows a room ready for removal operations to begin. Pipes and immovable objects are covered and windows and ducts are sealed with poly and duct tape. An empty glove bag is in place at the wall/pipe intersection at the left.

videotaped instructions[38] and on training by a National Asbestos Council glove bag instructor.[39] Although the study was not designed to provide these instructions, it was the opinion of the NIOSH researchers that much improvement in work practices had been achieved by the end of the study. The following techniques were in general use by the end of the study, and the authors believe them to be appropriate work practices and procedures:

- Tools for cutting metal bands and lagging were placed inside the glove bag, and the bag was hung from the poly wrapped, lagged pipe. Depending on the type of bag, it was taped or zipped to form a seal along the length of pipe and the bag ends (sleeves) were taped or strapped to the poly-jacketed pipe. The workers preferred to use straps for sealing the bag ends.

- The poly-envelope and metal bands enclosed within the sealed bag were first cut and removed. Then the lagging was wetted, cut longitudinally along the full length of one preformed block, and circumferential cuts were made with a wire saw or blade, preferably at the block joints. The asbestos block was pried apart at the seam, rewetted, and dropped to the bottom of the bag. Amended water was sprayed onto the lagging and the bare pipe within the glove bag was washed clean with wet rags.

- Hard-to-clean places were brushed with a nylon-bristle bottle brush. All work was performed within the bag using the gloves (Figure 3-2). The end sleeve straps were loosened or the sleeves were untaped and the bag was slid along the poly-covered pipe to the next removal site (Figure 3-3).

- The spray nozzles and wands were inserted into the bags through special ports and sealed with duct tape if necessary. They were fitted with 10- to 15-foot hoses, so that the tanks did not have to be elevated to the working level. A support worker, at floor level, refilled the sprayer tank with amended water and pumped up the pressure. It greatly enhanced the ability and inclination of the removal workers to use sufficient wetting for control of fiber emissions.

- After sufficient debris had been collected, the interior surface of the bag was washed down; a HEPA-filtered vacuum system was used to evacuate air from the bag and a strap was used to cinch the bag closed prior to release of the seal and removal from the pipe. The bags were then resealed and then placed in a second bag on which asbestos warning labels were printed. The outer bag was also sealed and subsequently removed for disposal.

3.2.2.3. Decontamination--

Spilled material was removed from the floor with a HEPA-filtered vacuum cleaner throughout the shift. As work was completed in each area, the floor was wet mopped. The sealed bags of waste were removed from the enclosure prior to post-removal air sampling, but the poly seals on windows, vents, and doors were kept in place to minimize contamination from other areas and activities.

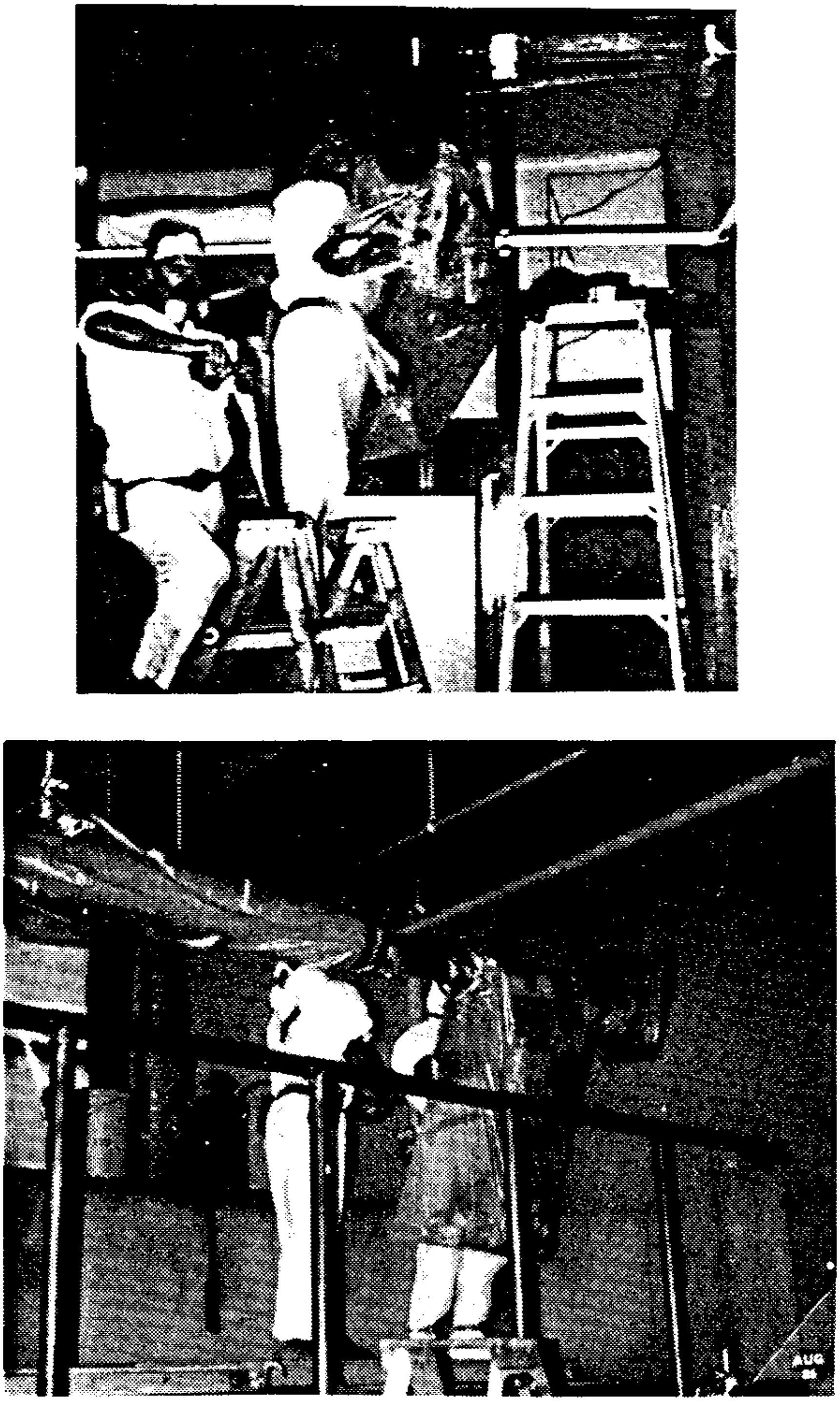


Figure 3-2. Working in a Glove Bag

The upper photograph shows two workers working on ladders. One worker has his hands inside the glove bag and is removing asbestos pipe lagging. The other worker is assisting by taping up a loose enclosure point. In the lower photograph workers are on a scaffold. The second worker is using a portable sprayer to wet down debris in the bag.

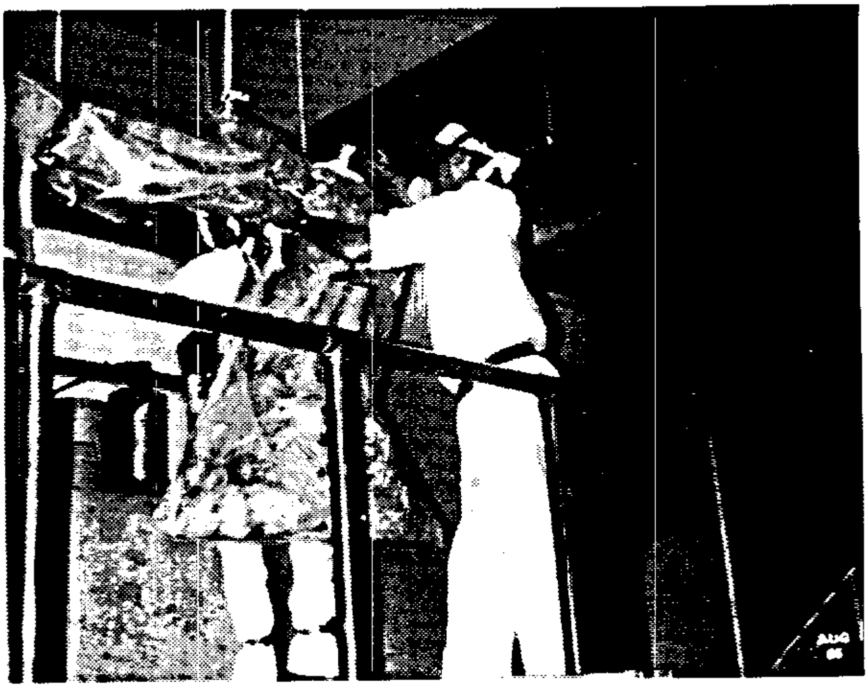


Figure 3-3. Moving a Glove Bag

This is a critical task. The inside walls of the bag and the debris contained have been washed down with water and the top of the bag opened to move it down the pipe. The photo shows the top untaped and the two workers are supporting its weight and maneuvering it over the next section of poly-wrapped pipe. Obstructions such as pipe hangers, pipe fittings, and valves make this a difficult task. Workers must use very good work practices to reduce the potential for fiber release.

4. METHODOLOGY

4.1. AIR SAMPLING STRATEGY

4.1.1. Overview

In order to characterize the effectiveness of containment by glove bags, personal breathing zone (PBZ) samples were collected on workers and area air samples were taken within the work enclosure. Area samples were also taken in adjoining hallways outside the work enclosure to determine the potential interaction with other removal activities occurring outside and within the controlled areas. Ambient samples were taken outside the building to establish background fiber concentrations. To assess the overall efficacy of the asbestos removal and cleanup operations, additional samples were taken prior to and following the completion of the removal work. Because of time constraints, the post-removal samples were collected after initial cleaning by the removal crew, but prior to the clearance testing performed by the contractor.

4.1.2. Personal Air Samples

PBZ samples were collected only while workers were actively engaged in site preparation, asbestos removal, and other associated activities including waste collection and disposal, decontamination, and equipment operation and maintenance. Normally, two sequential 2- to 3-hour personal samples were taken daily for each of the four workers to determine time-weighted-average exposures. In addition, six to eight 15-minute, short-term exposure samples were collected during the performance of work tasks. As a result, about 14 to 16 PBZ samples were collected during each 5- to 6-hour work shift.

4.1.3. Area Air Samples

Area samples were collected both inside and outside the controlled work area on approximately the same schedule as the personal samples. Two 2- to 3-hour interior samples were collected daily using a cart-mounted, mobile, sampling tree that was positioned proximate to the removal activity. These samples were located so as to provide an indication of the effectiveness of the source controls and the magnitude of exposure during different activities. A similar series of area samples was collected in the middle of the room, away from the workers, during the removal activity to determine the fiber concentration in the room during preparation and removal. Figure 4-1 is a photograph showing both the cart-mounted apparatus used to collect samples proximate to the work site and the stationary sampling tree used to obtain background samples of the general room contamination. Daily samples were collected in the hall adjacent to the survey area, and ambient samples were taken by drawing outside air through filters located in open windows well removed from the work area.

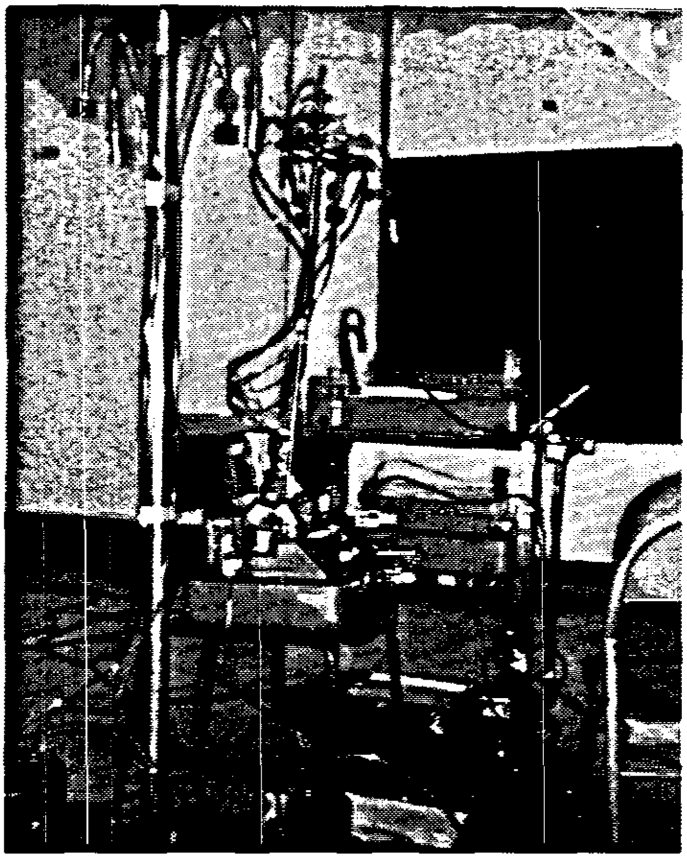


Figure 4-1. Area Sampling Equipment.

In the foreground is a sampling tree used for obtaining room background air samples at a point remote from the removal activity. A sampling tree mounted on a mobile cart, shown in the background, was used to obtain samples proximate to the work activity.

4.1.4. Direct-Reading Monitors

Direct-reading GCA Fibrous Aerosol Monitors (FAM), Model No. 1, were used to observe short-time fluctuations in fiber concentrations and to determine if a correlation existed between the work practices and exposure levels. One FAM (with a data logger for storing the output from the FAM) was positioned adjacent to the interior work area sample tree. This data logger recorded the background fiber count inside the enclosure at 1-minute intervals. Two cart-mounted, mobile FAMs were used to detect changes in fiber concentration every 10 minutes in the vicinity of the various work activities. The removal operations were also videotaped to assist in subsequent interpretation of the FAM readings.

4.1.5. Pre- and Post-Removal Air Sampling

To compare the two contamination assessment methods, both pre- and post-removal air samples were obtained by sampling for an 8-hour period in the nonaggressive mode, followed immediately by sampling for an 8-hour period in the aggressive mode. Nonaggressive (static) sampling was performed in a quiescent atmosphere, allowing at least 24 hours for the room to dry out when the sampling followed removal and cleaning. For aggressive (dynamic) sampling, dust and fibers were dislodged from surfaces during a 5- to 10-minute blowdown with a leaf blower; two oscillating pedestal fans were then operated to keep the dust and fibers suspended during the entire 8-hour sampling period. Two samples were collected adjacent to, but outside, the poly-baffled entrance to the room during both the nonaggressive and aggressive sampling periods. Two side-by-side outdoor ambient samples were collected throughout the 16-hour period in which these sampling methods were performed.

4.2. EVALUATION METHODS

4.2.1. Personal Sampling

The sequential 2- or 3-hour, PBZ samples were collected using DuPont P-4000 pumps at a measured flow rate between 2.5 and 3.5 lpm; each sample involved approximately 400 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. The cassettes were wrapped with metal foil, as a precaution to minimize possible localized effects of static electricity; conductive cowls were not available at that time.

4.2.2. Workplace Area Sampling

Duplicate area samples were taken using side-by-side 37 mm diameter polycarbonate and 25 mm diameter cellulose ester filters. The 25 mm sampling devices were the same as those described for personal sampling. The 37 mm sampling device consisted of a three-piece cassette using a 0.4 μm pore size polycarbonate filter with a 5.0 μm pore size cellulose ester backup filter and a supporting pad. The polycarbonate filters, manufactured by Nucleopore Corporation, were supplied by the EPA Manufacturing and Service

Industries Branch. During sampling, the cassette covers were removed to provide open-face sampling. DuPont P-4000 pumps, as described above, were used to collect these samples. The same sampling array and flow rate was also used to collect area samples adjacent to but outside the poly-baffled entrance to the room.

The ambient outdoor samples were collected at a measured flow rate between 2.0 and 3.5 lpm to obtain approximately 1,500 liter samples (ca. 8 hours).

4.2.3. Pre- and Post-Removal Air Sampling

Nine 8-hour samples were collected simultaneously using three different media: (1) 37 mm diameter, 0.4 μm pore size, polycarbonate filters followed by a 5.0 μm pore size, cellulose ester filter between the primary filter and the backup pad, (2) 37 mm diameter cellulose ester filters (0.8 μm pore size) with a backup pad, and (3) 25 mm diameter cellulose ester filters, as described under "Personal Sampling." All samples were collected in three-piece open-face cassettes. The 25 mm cassettes were wrapped with metal foil to minimize possible effects of static electricity. Six of the nine samples at each station were collected at a measured flow rate between 3.0 and 3.5 lpm, utilizing individual limiting orifices. The vacuum source for the nine samples was a manifold connected to a Gast 0485 vacuum pump in parallel with a smaller Thomas 106-83F pump. One sample of each filter type was also collected at each station using DuPont P-4000 pumps at a measured flow rate between 2.5 and 3.5 lpm. The sample cassettes were hung face down in alternated positions from a ring which was supported approximately 5 feet above the floor (Figure 4-1).

The outdoor ambient samples and the samples located in the corridor outside the surveyed rooms were collected on 25 mm cellulose ester filters for 8 to 16 hours to obtain approximately 1,500 to 3,000 liter samples.

4.2.4. Real-Time Fiber Monitoring

GCA Fibrous Aerosol Monitors (FAM), Model No. 1, were used to monitor variations of fiber concentrations during the work shift. Two units were placed near the removal operations to observe variations in fiber concentrations as a result of work practices; a third unit was used to monitor airborne fiber contamination in the removal area. Metrosonics Model No. 331 Data Loggers were utilized to record sequential FAM readings.

Air temperature and relative humidity were determined using an aspirated psychrometer.

4.3. ANALYSIS

4.3.1. Phase Contrast Microscopy

4.3.1.1. Manual--

The 25 mm cellulose ester filters were analyzed by PCM in accordance with NIOSH Method 7400.[14] All fibers with a 5:1 (or greater) length-to-width ratio were counted using the B counting rules. Analyses were performed by NIOSH in Cincinnati, OH and by UBTL Inc. (now Datachem) in Salt Lake City, UT.

4.3.1.2. Magiscan II--

A Magiscan II (M-II) image analysis system with asbestos fiber counting software was used to augment the PCM. The M-II system is attached to a standard phase contrast light microscope and an image of the particulates collected on the filter is displayed on a video monitor. A computer program produces a fiber count based on the aspect ratio and length.

4.3.2. Transmission Electron Microscopy

Polycarbonate filters were analyzed by the Yamate Revision to the EPA Provisional TEM Method.[19] All structures were identified and sized, and were categorized as individual fibers, fiber clusters, bundles, and clumps. The sum of all these categories was reported as the total asbestos structures. Selected area electron diffraction (SAED) was used to identify fibers as either amphiboles, chrysotile, or nonasbestos. When a diffraction pattern could not be evaluated, Energy Dispersive X-ray Analysis (EDXA) was performed to further assist in the identity of these structures.

The TEM analyses were performed by NIOSH scientists and personnel from PEI, Inc., using facilities in the NIOSH laboratory. Some analyses were performed in another laboratory, but they did not correlate well with the results from the NIOSH laboratory. Because the work performed in the NIOSH laboratory was carefully scrutinized and quality controlled, a number of these samples were reanalyzed in the NIOSH laboratory. All TEM sample results reported are from analyses made in the NIOSH laboratory.

Several cellulose ester filter samples which PCM analysis had indicated to contain high, medium, and low fiber were also analyzed in the NIOSH laboratory by TEM using the modified Burdett and Rood[40] or the NIOSH 7402 method.[20] All structures were identified in the same manner as that described above for the samples collected on polycarbonate.