United States
Environmental Protection
Agency

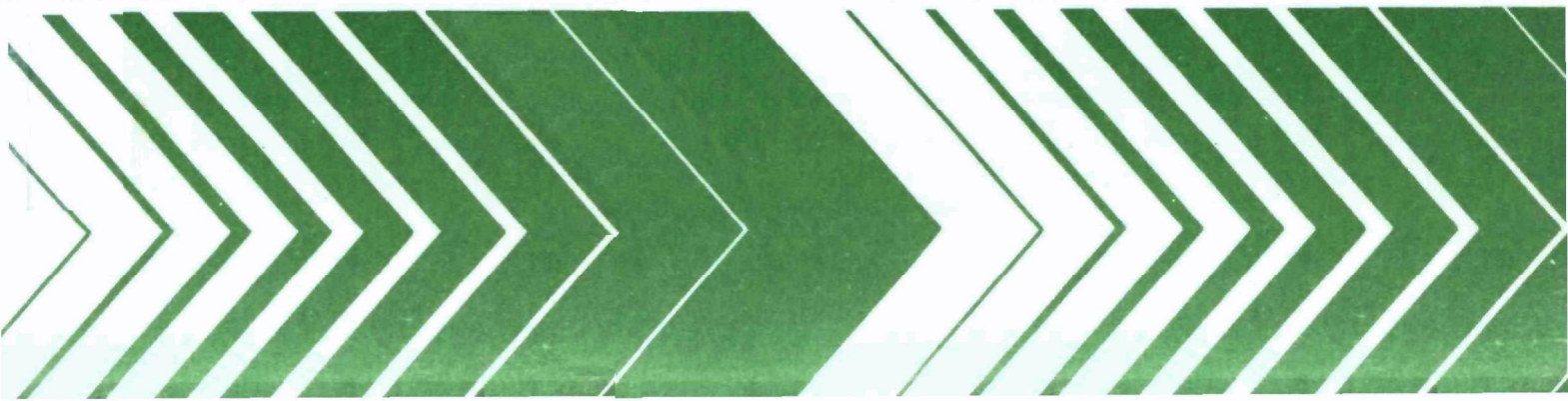
Industrial Environmental Research
Laboratory
Research Triangle Park NC 27711

EPA-600/2-80-088
May 1980

Research and Development

EPA

Evaluation of a Commercial Vacuum System for the Removal of Asbestos



RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment, and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

EPA REVIEW NOTICE

This report has been reviewed by the U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policy of the Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

EPA-600/2-80-088

May 1980

Evaluation of a Commercial Vacuum System for the Removal of Asbestos

by

R.W. Welker, D.F. Finn, J.D. Stockham,
and R.P. Hancock

IIT Research Institute
10 West 35th Street
Chicago, Illinois 60616

Contract No. 68-02-2617
Task No. 10
Program Element No. C1Y-L1B

EPA Project Officer: David C. Sanchez

Industrial Environmental Research Laboratory
Office of Environmental Engineering and Technology
Research Triangle Park, NC 27711

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, DC 20460

ABSTRACT

Personal, area and environmental asbestos exposures resulting from wet and dry asbestos removal using a commercial vacuum system were measured in a brief field study. Personal and area (indoor) asbestos concentrations during dry removal were less than one fiber per cm^3, as measured by NIOSH P&CAM 239 when the vacuum system was used. Asbestos released to the environment from the vacuum system's three-stage exhaust filter was negligible. Asbestos was released from the system operator's protective garments when he exited the work area to service the vacuum system.

Sources of asbestos fiber release associated with vacuum system operation were identified; these occurred during operation disassembly and asbestos disposal. Following vacuum shutdown, liquid drained out of the collection reservoir due to inadequate door seals. During vacuum hose disassembly, bulk losses of asbestos-containing materials occurred. During disposal, the exterior of the vacuum truck became contaminated as the reservoir was emptied. The need for additional dry removal testing has been clearly identified.

This report is submitted in partial fulfillment of Contract No. 68-02-2617 by IIT Research Institute under the sponsorship of the U.S. Environmental Protection Agency. The study covered the period October 21, 1979 to December 21, 1979, and work was completed as of February 4, 1980.

CONTENTS

CONTENTS (continued)

FIGURES

TABLES

ACKNOWLEDGMENTS

Several individuals and organizations contributed to the success of this study. The authors wish to express their gratitude to Mr. Jerry Regan of the Environmental Protection Agency (EPA), Revion V, and Dr. Jack Wagman of EPA's Environmental Sciences Research Laboratory for the loan of the fibrous aerosol monitors; to Dr. Joseph Breen of EPA's Office of Pesticides and Toxic Substances and the Technical Project Officer, Mr. David Sanchez of EPA's Industrial Enviromental Research Laboratory, for their valuable assistance and guidance; to Mr. Edward Swoszowski, Jr., and Mr. Harold Kraus of Environmental Technology, Inc., who directed the removal operations; to Mr. Robert DeMane of Diversified Vacuum Systems, Inc. for providing sampling ports and data on the vacuum system; and, finally, to Mr. Alden Cole of the Federal Aviation Administration facility at Bucks Harbor, Maine, for his cooperation and hospitality.

SECTION 1

INTRODUCTION

The U.S. Environmental Protection Agency (EPA) is concerned with the release of asbestos into the environment during demolition or renovation of buildings containing functional or decorative asbestos. Whereas guidelines currently exist for wet removal procedures which minimize worker exposure and environmental contamination, wet removal cannot be tolerated in all places where friable asbestos materials exist and must be removed; nor is information presently sufficient to allow the EPA to prescribe guidelines for dry asbestos removal, with or without a vacuum system, where site conditions prohibit wet removal. A preliminary study was thus undertaken to assess personal exposure and environmental emissions associated with a commercially available asbestos removal and collection system.

In summary, the objectives of this program were to:

- determine the ambient and building interior asbestos concentrations before, during, and after asbestos removal using a commercial vacuum system,
- determine the collection efficiency of each stage of the vacuum collection system and of the system as a whole, and
- determine the level of asbestos emissions associated with the operation and disassembly of the system and the transfer of the collected asbestos to the ultimate disposal site.

The objectives were partially accomplished in a field sampling survey. Airborne asbestos concentrations were determined by personal, area, and high-volume air sampling before and during removal of asbestos from portions of the ceiling of the Federal Aviation Administration (FAA) radar facility garage at Bucks Harbor, Maine. Wet and dry removal methods using a truck-mounted vacuum system owned and operated by a private contractor were evaluated. Overall filtration efficiency and the filtration efficiency of each of the three stages of the vacuum system filters were determined by isokinetic sampling upstream and downstream of each stage. Asbestos emissions during disassembly and disposal of the system were measured and visually observed. Filter loading during air sampling was optimized using the GCA Fibrous Aerosol Monitor (FAM) which had previously been calibrated in the laboratory. Based upon the results of the survey, several preliminary recommendations and conclusions have been formulated.

Four elements of the overall program were not completed. Quantitative evaluation of asbestos losses during system disassembly was not made. The vacuum hose was not decontaminated during the study. Disposal of asbestos collected by the dry method of asbestos removal was not characterized, and building interior and ambient asbestos concentrations were not measured after asbestos removal. Numerous vacuum system malfunctions limited the amount of ceiling material removed and prevented complete characterization of system performance. These malfunctions, coupled with the fact that the removal process was more time consuming than anticipated, led to the decision by the FAA to temporarily halt the removal operation. Thus, asbestos removal from the garage area was never finished and post-removal samples could not be taken.

IIT Research Institute's contract with the U.S. Environmental Protection Agency was restricted to the monitoring of the asbestos removal operations. Included were personal, area, and environmental sampling and analysis as well as visual observations of the protocols used for the removal and disposal of the asbestos-containing material. Site preparation, safety, support equipment, and coordination of the various contractors were the responsibility of the FAA and their consultant, Environmental Technology, Inc., West Hartford, CT. The actual removal operations were performed by Diversified Vacuum Systems, Newark, NJ using laborers from a local labor pool. Ultimate decision making authority rested with the FAA.

SECTION 2

CONCLUSIONS

1. Fiber concentrations down wind of the vacuum system were less than 0.1 f/cm^3.

2. Fiber concentrations in the work area during wet asbestos removal were less than 1.5 f/cm^3.

3. Fiber concentrations in the work area during dry asbestos removal were less than 0.15 f/cm^3.

4. The shower room and other non-work areas of the building were not contaminated with asbestos during wet or dry removal procedures.

5. The asbestos removal and collection vacuum system performed with an estimated minimum collection efficiency of 99.997%.

6. Visible emissions of the collected asbestos material were observed during the dumping operations at the waste disposal site. Thorough wetting of the material may alleviate these emissions.

7. Asbestos fiber concentrations during disposal were less than 0.2 f/cm^3 as measured by personal and area samplers.

8. Sources of personal exposure to or environmental emission of asbestos during operation disassembly and disposal were: water which leaked from the door of the collection reservoir after vacuum shut-off; disassembly of the vacuum hose from the collection reservoir; contamination of the truck exterior body and frame during disposal; and water spray from the truck body during decontamination after disposal.

9. The Fibrous Aerosol Monitor determines amosite fiber concentrations in agreement with NIOSH P&CAM 239.

10. Chrysotile fiber concentrations determined by the Fibrous Aerosol Monitor substantially underestimate those determined by NIOSH P&CAM 239.

11. The Fibrous Aerosol Monitor was a useful monitoring tool in identifying activities that were sources of asbestos emission, e.g., the exiting of the operator to service the vacuum system.

SECTION 3

RECOMMENDATIONS

1. Further work is needed to develop a protocol for testing non-approved asbestos removal methods.

2. Evaluation criteria must be formulated so that environmentally acceptable asbestos removal methods may be characterized and made subject to EPA approval.

3. A definitive study is required to investigate the disagreement between fiber concentrations reported by the Fibrous Aerosol Monitor (FAM) and those determined by NIOSH P&CAM 239, especially insofar as fiber diameter effects occur.

4. A field sampling survey should be conducted to characterize the diameter distributions of environmental asbestos and to determine the impact of variable asbestos fiber diameter on concentrations determined using the FAM.

5. Field calibration techniques should be investigated to facilitate adjustment of the FAM versus variable asbestos fiber types.

6. Tools to facilitate asbestos removal must be developed.

7. Methods must be developed to prevent in-line freezing of amended water used in spray-equipped vacuum trucks. Methods of unclogging filters or preventing filter freeze-up need to be developed.

8. A removable control and monitor panel interconnected with the vacuum system by an umbilical cable should be provided to minimize the need for the operator to exit the work area.

9. Alternate methods of asbestos disposal must be identified; on-board bagging of dry asbestos and slurry disposal by dumping or pumping appear worthy of investigation.

10. Decontamination techniques for equipment used in wet and dry removal must be fully investigated.

SECTION 4

BACKGROUND

SITE DESCRIPTION

The FAA radar facility at Bucks Harbor, Maine--a nearly windowless five-story structure approximately 150 feet square--stands on an isolated hilltop where contamination from background asbestos fibers should be negligible. The ceilings of the fourth floor and the garage are coated with asbestos, presumably for noise abatement. As can be seen from Figure 1, the garage ceiling is in a deteriorated state. The fourth floor houses most of the functional electronic equipment used for air traffic control, equipment that must be continuously operational. In fact, the area is staffed continuously.

The need to update and service the electronic equipment has periodically brought FAA personnel in contact with the friable ceiling, further aggravating its poor condition. FAA recognition of the potential health hazard posed by the release of asbestos into the workplace motivated the removal of the ceiling.

The sensitive nature of the electronic equipment, which is intolerant of extreme fluctuations of humidity and temperature, made wet removal an unacceptable method. The need to man and operate the electronic equipment on a continuous basis eliminated the possibility of using conventional dry removal, which releases significant amounts of asbestos fibers into the air.

The garage, however, is a relatively open area containing few pieces of sensitive equipment, as illustrated in Figure 2, and FAA personnel have a limited need to be there. The garage was therefore selected for trial wet and dry asbestos removal using the vacuum system. If this trial proved successful, it was planned to then remove the asbestos from the fourth floor ceiling.

SITE PREPARATION

The site was prepared in general accordance with EPA guidelines[1] to prevent emission of asbestos to nonwork areas in the building and outdoors. That is, plastic enclosed framing was constructed to provide removal

---

[1] Sawyer, R.N. and C.M. Spooner. Asbestos-Containing Materials in School Buildings: A Guidance Document, Part 2. EPA C00090. U.S. Environmental Protection Agency, Washington, D.C., 1979. 133pp.

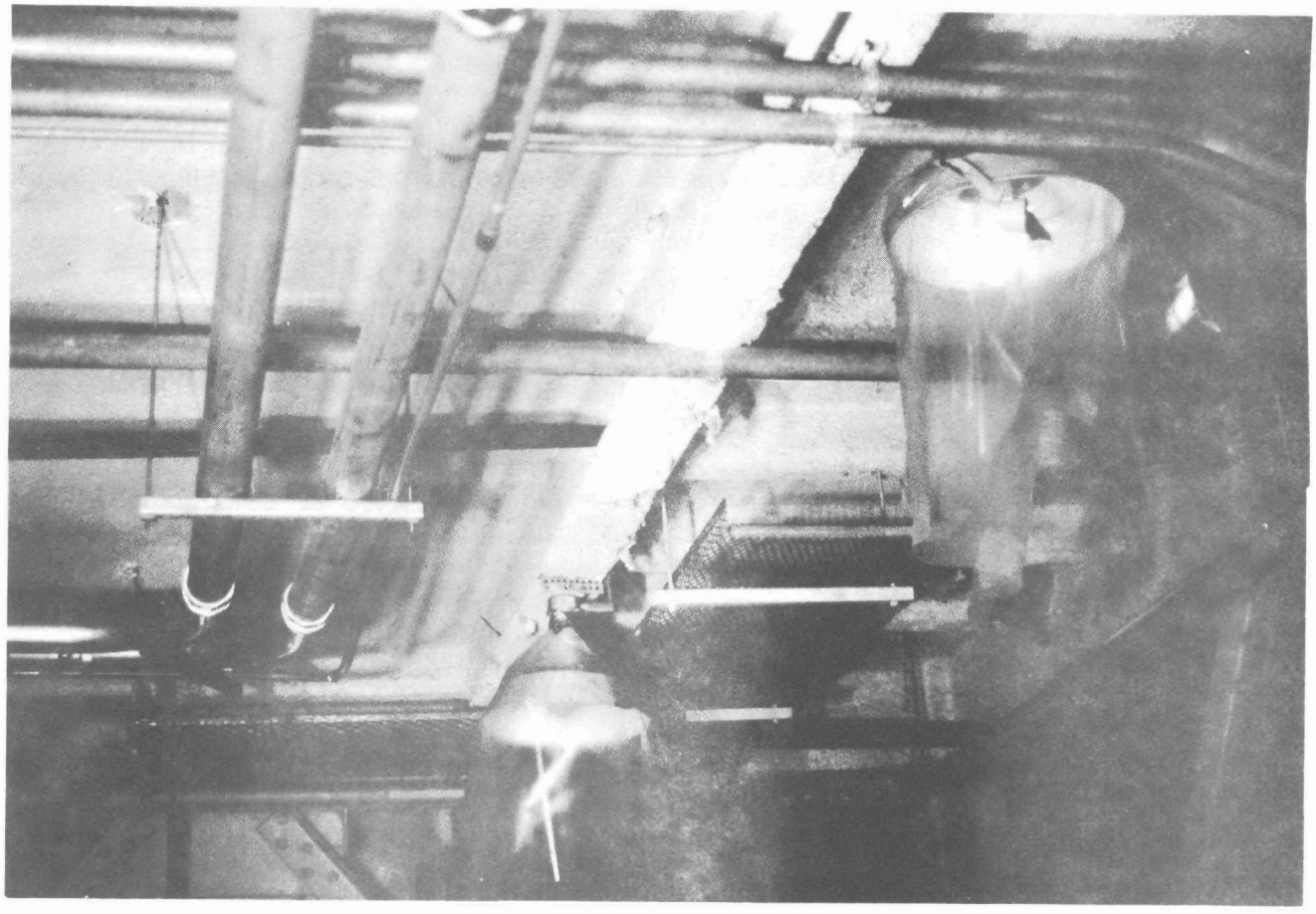


Figure 1. Photograph of delaminating ceiling material in FAA radar facility.

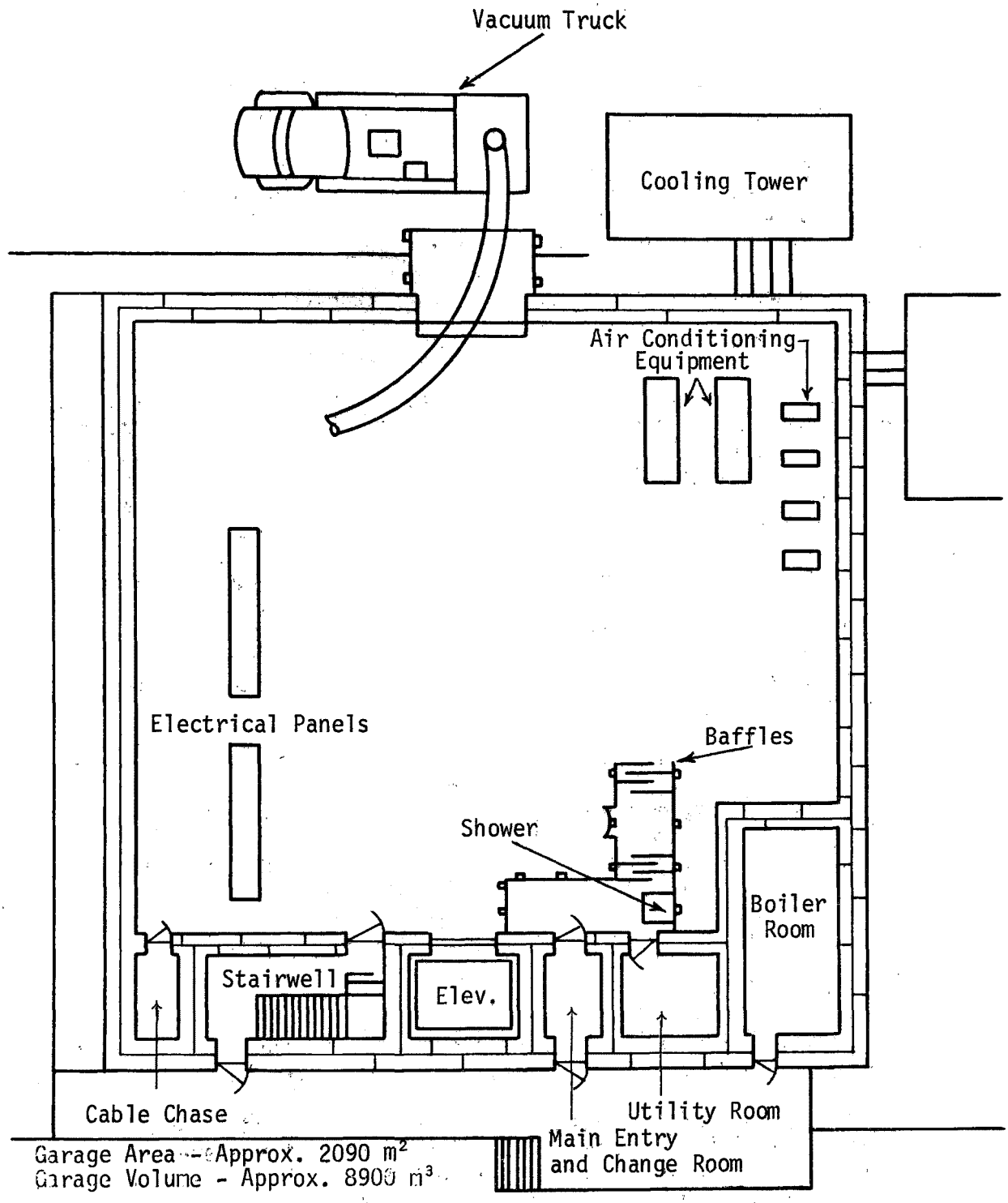


Figure 2. Garage area at FAA Radar Facility.

personnel access to the garage area through a double-baffled anteroom, shower room, and change room. The areas, described in Section 5, where the removal of asbestos was actually performed were not enclosed with framing due to physical and time constraints. The stairwell door to the work area was canopied with a single baffle to permit make-up air to enter the room while the vacuum system was operating. The roll door on the northeast side of the building was draped on the inside, allowing a plastic-baffled opening for passing power cords and the hose from the vacuum truck. This opening was also used periodically by the vacuum system operator in order to monitor system functions. Air conditioning vents, doorways, and the elevator door were sealed to prevent contamination. The walls and nonelectrical structures were not draped with plastic, since they were already heavily dust laden and would require decontamination as part of the cleaning operation.

SAFETY CONSIDERATIONS

Occupational Safety and Health Administration (OSHA) regulations pertaining to asbestos removal or stripping were observed. Specifically, personnel whose presence was required in the work area were briefed on the potential dangers of exposure to asbestos and instructed as to the proper use of all safety equipment. Respiratory protective devices were required whenever exposure limits were expected to be exceeded. Air purifying respirators were used when asbestos concentrations of up to 10 times the exposure limit were anticipated. Continuous flow, supplied air respirators (minimum flow 6 lpm) were used when asbestos concentrations of up to 100 times the exposure limit were anticipated. Disposable Tyvec® coveralls with attached head coverings and boots were worn at all times by personnel in the work area. Caution labels pertaining to "asbestos hazard" were posted at all points of access to the building.

Prior to beginning the removal operation, the workers entered the change area, Figure 2, where they donned clean coveralls and respirators. They then proceeded to the utility room where they picked up additional equipment, such as replacement tools. On leaving the work area, each worker brushed the gross contamination from his coveralls, removed all clothing except the respirator, and disposed of them in a suitable container. They then proceeded to the shower; only when the worker was thoroughly wet was the respirator removed. After showering, the worker dressed in fresh coveralls or street clothes.

VACUUM SYSTEM DESCRIPTION

A detailed description of the vacuum system and its mode of operation is presented in Appendix A; only a summary will be provided here.

The truck-mounted vacuum system, provided by Diversified Vacuum Systems, Inc., consisted of a sprayer-equipped receiving chamber, three stages of exhaust filtration, and vacuum blower, as illustrated in Figure 3. The intake of the vacuum was located on the top center of the receiving chamber and was connected to the work area with a 15.2 cm i.d. ribbed plastic hose. The intake pipe extended about 20 cm into the chamber beyond the face of the primary filters to aid particle sedimentation. Air was exhausted through diffusers

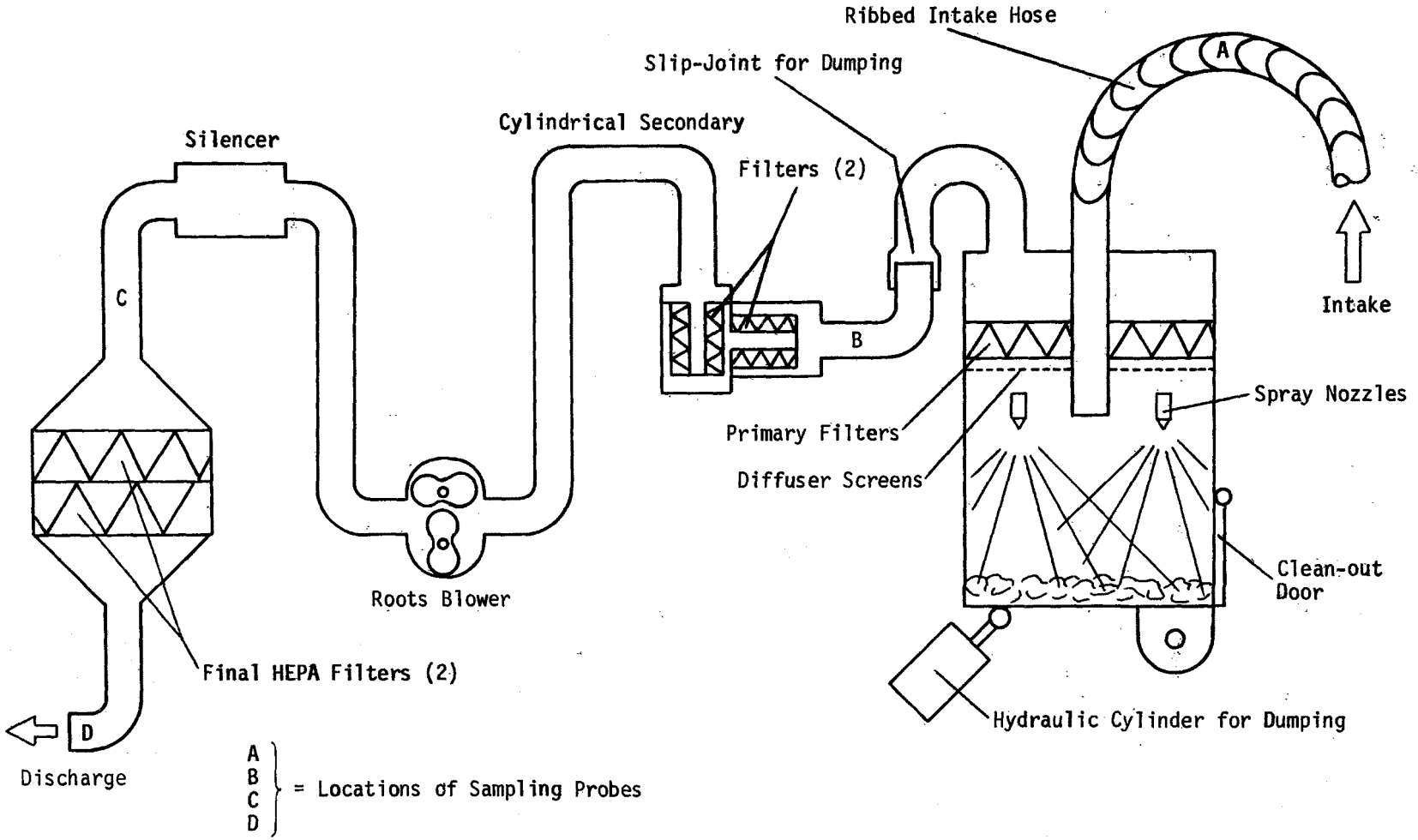


Figure 3. Schematic of truck-mounted vacuum system.

and primary filters located in the ceiling of the receiving chamber, through a gooseneck at the top front of the chamber, and through an O-ring sealed joint (used during the dumping operation). The air then passed through the secondary filter set, roots blower, silencer, and a pair of series-mounted HEPA filters, leaving the truck bed through a 15.2 cm i.d. plenum. With the exception of the gooseneck joint, all pipe connections were welded or bolted.

During normal operation the vacuum system is controlled automatically and does not require the attention of an operator. The roots blower is under direct drive from the truck engine. Whenever the differential pressure across the primary filter exceeds a preset value, the engine speed is reduced to idle, slowing the blower. Alternatively, whenever the differential pressure falls, the engine speed increases, simultaneously increasing blower speed.

Should the primary filters become clogged, as indicated by too high a differential pressure, the engine speed would be reduced to idle and high-pressure air would be injected behind the primary filters to back-flush them.

The vacuum receiving chamber was arranged so that a door at the back of the chamber could be opened and the entire vacuum chamber could be canted backward by a hydraulic ram to facilitate dumping of the collected asbestos.

The points sampled isokinetically to characterize the filtration efficiency of the system are indicated in Figure 3. Sampling points were center line at least eight diameters downstream and two diameters upstream of all flow disturbances. Sampling point A was through the wall of the intake hose before the receiving chamber; point B was between the primary and secondary filters; point C was located downstream of the silencer and blower between the secondary and tertiary (HEPA) filters; and point D was located in the exhaust plenum downstream of the HEPA filters.

WET AND DRY REMOVAL METHODS

Dry removal of untreated friable asbestos material is generally not recommended, but where necessary can be accomplished with specific EPA approval.[2] As shown in Table 1, dry removal can result in airborne fiber counts that can exceed 100 f/cm^3.[3] Asbestos removal following application of water without a wetting agent usually gives higher fiber counts because of the poor wettability and reduced penetration of the ceiling material. The addition of a wetting agent to water, or amended water, improves the wettability and penetration. Correctly applied amended water wet removal methods, however, generally result in significantly lower fiber concentrations.

---

[2] IBID, p.II-4-1.

[3] IBID, p.II-2-3.

TABLE 1. AIRBORNE FIBER CONCENTRATIONS DURING WET AND DRY REMOVAL METHODS[3]

Removal Method	Concentration* f/cm^3	Number of Samples	
Dry	82.2	11	-----
Dry	>100	N.A	-----
Wet	23.1	6	No wetting agent used; heavy water run-off
Wet	2.8	56	Amended water treatment
Wet	18.4	12	Amended water treatment; water inadequately applied; dry patches seen
Wet	0.5	5	Amended water treatment; cementitious material delaminates in sheets; chunks intact

* Fiber concentrations were determined by NIOSH standard microscope methods.

[3] IBID, p. II-2-3.

SECTION 5

METHODS

Four techniques of asbestos removal were characterized during the field sampling survey. Background samples of air and environmental surfaces were obtained before removing any asbestos. Asbestos emissions during operation, disassembly, and dumping were observed. Sampling was expedited by using the FAM which had previously been laboratory calibrated against the NIOSH microscope methods. The following sections detail the removal methods characterized.

BACKGROUND SAMPLING

Before removing the asbestos, background samples were taken to provide a base of comparison for the data collected on various removal techniques. The background samples taken from points indicated in Figure 4 consisted of five area samples collected at various indoor locations (one in a second floor hallway not shown in Figure 4, one in the stairwell landing between the first and second floor, and three inside the garage) and two bulk samples removed from the ceiling. High-volume air samples were collected upwind and downwind on the northeast side of the building where the vacuum system was to be parked.

Floor and wall wipes were taken in the garage. The wipes were obtained by vacuuming a designated area, usually one foot square, onto a Millipore^{TM}AA cellulose acetate membrane filter mounted in a preweighed, open-faced, 37 mm cassette with suction provided by a vacuum pump.

WET REMOVAL METHODS

Wet Removal I

The asbestos-coated ceiling on the northern corner of the garage was sprayed with amended water (Aquagrow from Aquatrols Corp. of America, Pennsauken, N.J.) from a distance of 3 to 4 feet using a portable garden pesticide sprayer. The ceiling was further wetted by a stream of water from a garden hose until the coating was thoroughly wet. The asbestos coating was scraped directly into the 15.2 cm intake duct of the vacuum with 10.2 cm putty knives. Three workers participated in the operation, each spending approximately equal time scraping asbestos, holding the vacuum hose or wetting down the ceiling, and policing fallen ceiling material from the floor area below the work platform. The samplers were situated as indicated in Figure 5.

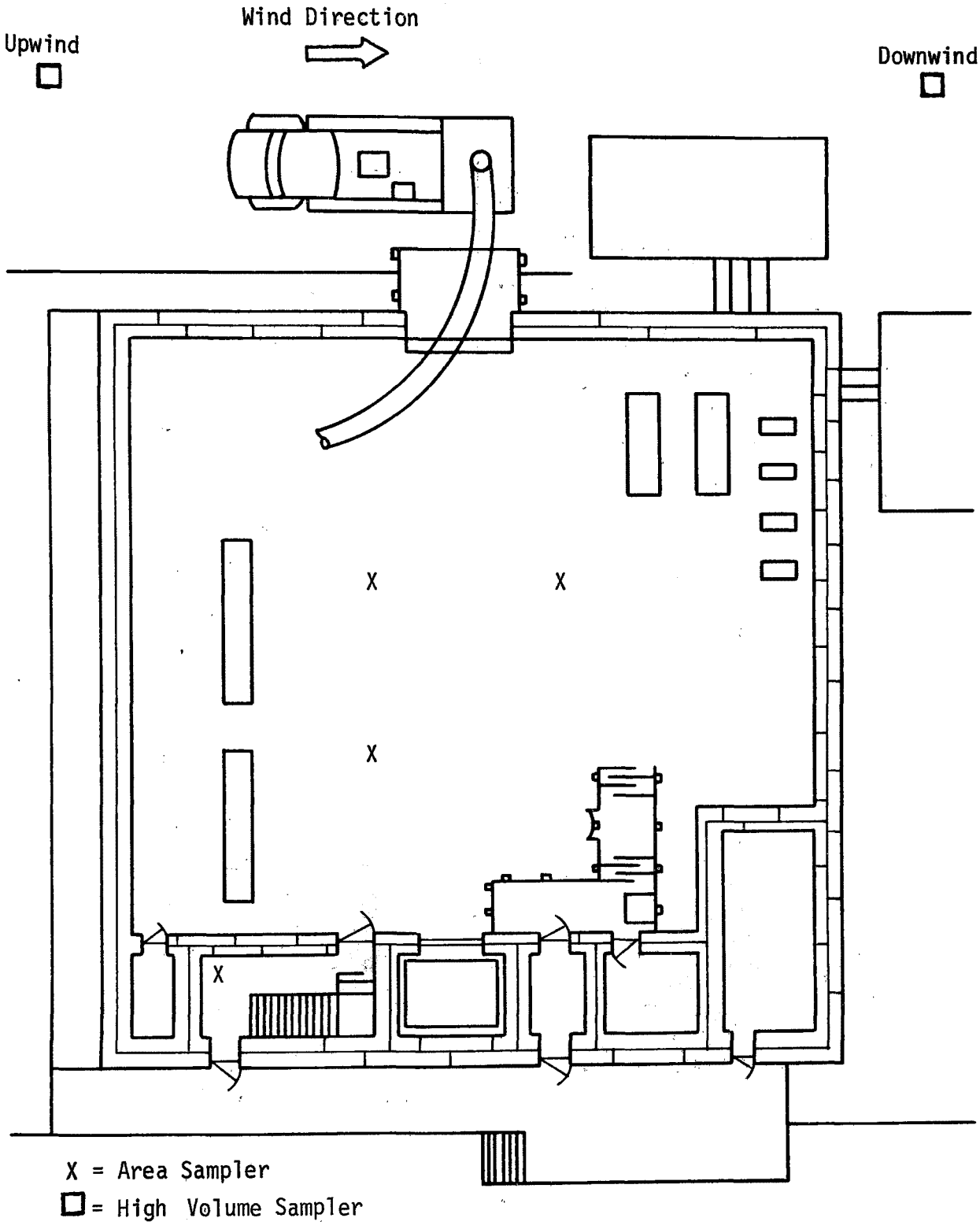


Figure 4. Background sampling locations.

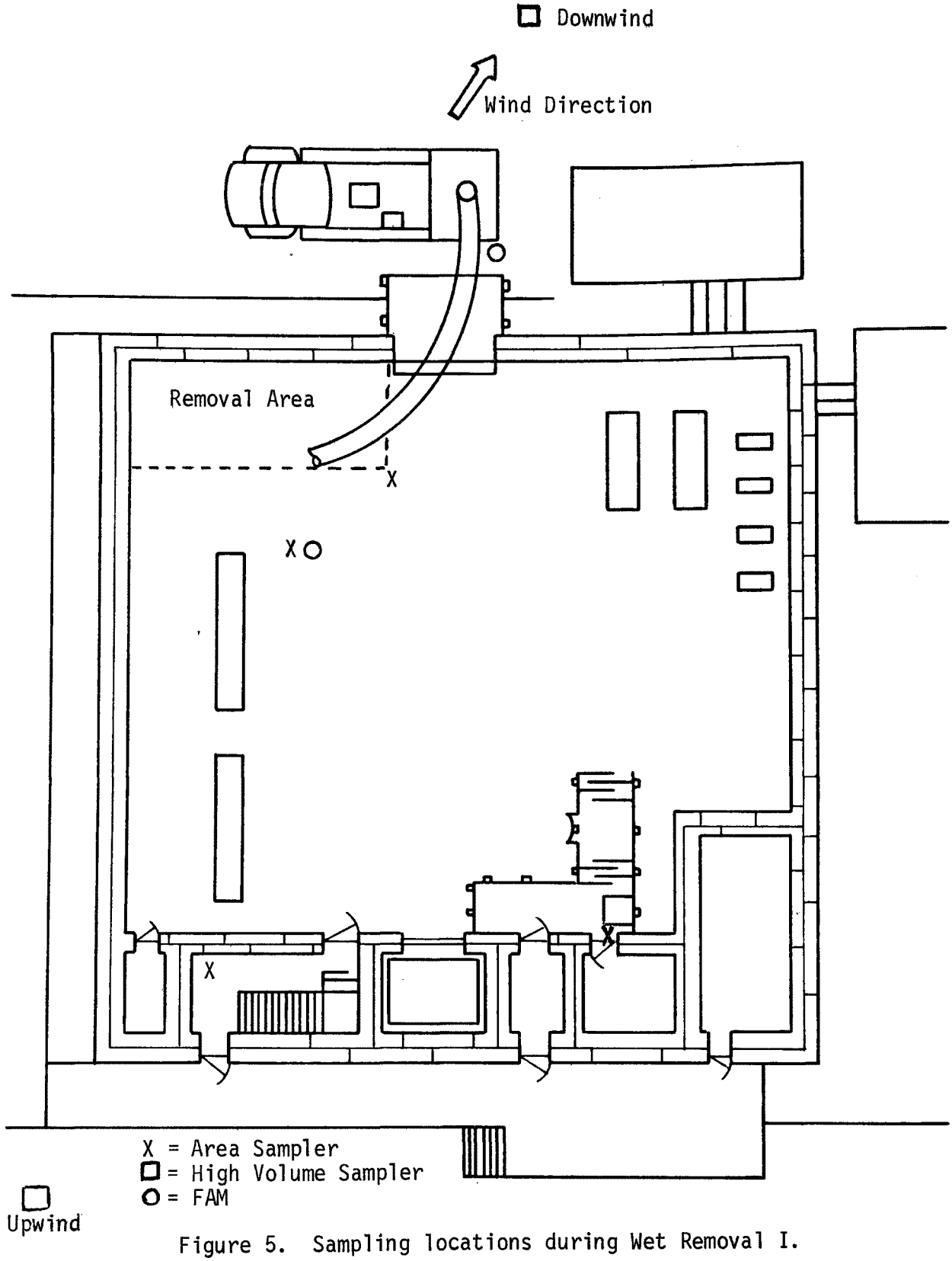


Figure 5. Sampling locations during Wet Removal I.

Wet Removal II

The asbestos coating was wetted, as in Wet Removal I, and then was scraped from the ceiling and allowed to fall to the floor. The third man in the crew vacuumed the asbestos from the floor. Again, the workmen alternated duties of scraping, vacuuming, and wetting, each spending approximately equal time on each activity. The samplers were located as indicated in Figure 6.

DRY REMOVAL METHODS

Dry Removal I

During Dry Removal I, no water or amended water was applied to the ceiling. The ceiling material was scraped using various tools and techniques and deposited into the vacuum hose, either with or without a variety of nozzles. The following techniques and equipment were used during dry removal:

A. Asbestos was scraped from the ceiling by two men, each using 10.2 cm wide paint scrapers; the ceiling materials were deposited in chunks into a single 15.2 cm diameter vacuum hose. In this technique, the scraper frees a chunk of asbestos material large enough to be held between the hand and the scraper. The material can be bent to break it away from the ceiling. The resulting chunk is placed into the vacuum by hand.

B. Asbestos was scraped by one man using a 10.2 cm paint scraper; a second man caught the scrapings in a 38.1 cm long, 20.3 cm wide, 15.2 cm deep rectangular box nozzle attached to the end of the vacuum hose. As a variation, scraping was accomplished by a pneumatically actuated paint scraper; the second man still collected the scrapings.

C. Asbestos was scraped by one man using the rectangular box attached to the 15.2 cm vacuum hose.

D. A Y-adaptor was fitted to the end of the 15.2 cm vacuum hose to which two 10.2 cm diameter hoses were attached. Each workman scraped the ceiling using a 10.2 cm paint scraper held in one hand and caught scrapings with the 10.2 cm vacuum hose held in the other hand. A scraper and knife-equipped prismatic nozzle was used on one 10.2 cm hose during part of Dry Removal I.

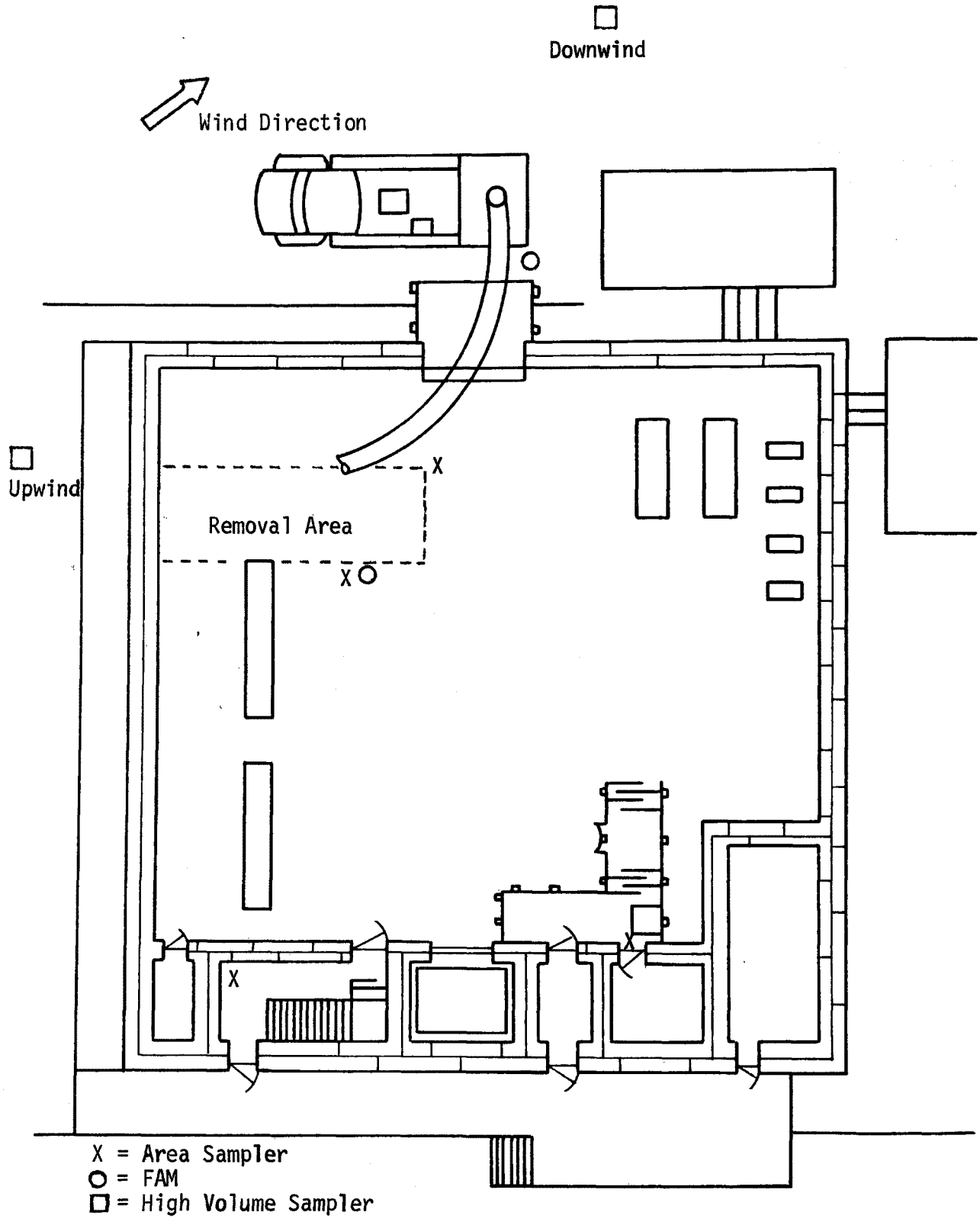


Figure 6. Sampling locations during Wet Removal II.

Sampling locations during Dry Removal I are illustrated in Figure 7.

Dry Removal II

Dry Removal II was a brief session of dry scraping the asbestos ceiling and permitting the scraped material to drop to the floor. The vacuum system was not used during this session. This test represents a worst case method of removal. Sampling locations are as indicated in Figure 8.

SYSTEM DISASSEMBLY AND ASBESTOS DISPOSAL

After wet asbestos removal was completed, the vacuum system was shut off and partially disassembled for transport by truck to the disposal site. Shutoff was accomplished by disengaging engine power from the roots blower and allowing the vacuum system to come to atmospheric pressure. The 15.2 cm vacuum hose was uncoupled from the top-center entry port on the receiving chamber.

The disposal site, located in a swampy area of the Machiasport, Maine dump, was a water-filled pit approximately 3 m square and more than 1 m deep. The texture of the ground prevented the vacuum truck backing to the pit and dumping the asbestos load directly into the pit. Therefore, the load was dumped in front of the pit and pushed into the pit by a small bulldozer. The asbestos load was released by unlatching the 2.4 m x 0.8 m door of the reservoir and then tipping the reservoir by means of a hydraulic ram. The door, hinged at the top, canted out of the way as the asbestos spilled out. Figure 9 illustrates the truck in the dump position. After dumping, the driver flushed the asbestos-contaminated reservoir and outside surfaces of the truck with a pressurized water spray. Sampling locations are indicated in Figure 10.

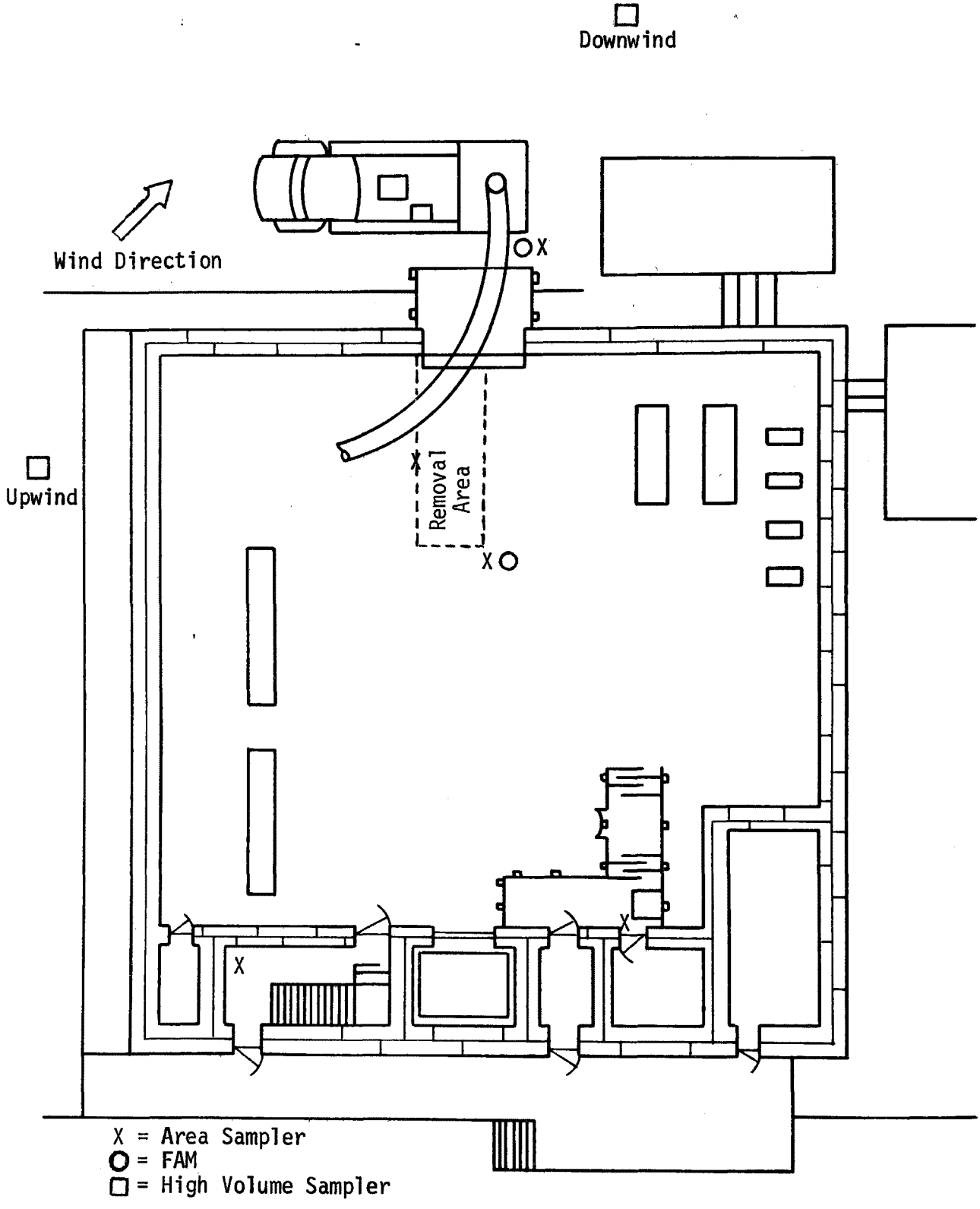


Figure 7. Sampling locations during Dry Removal I.

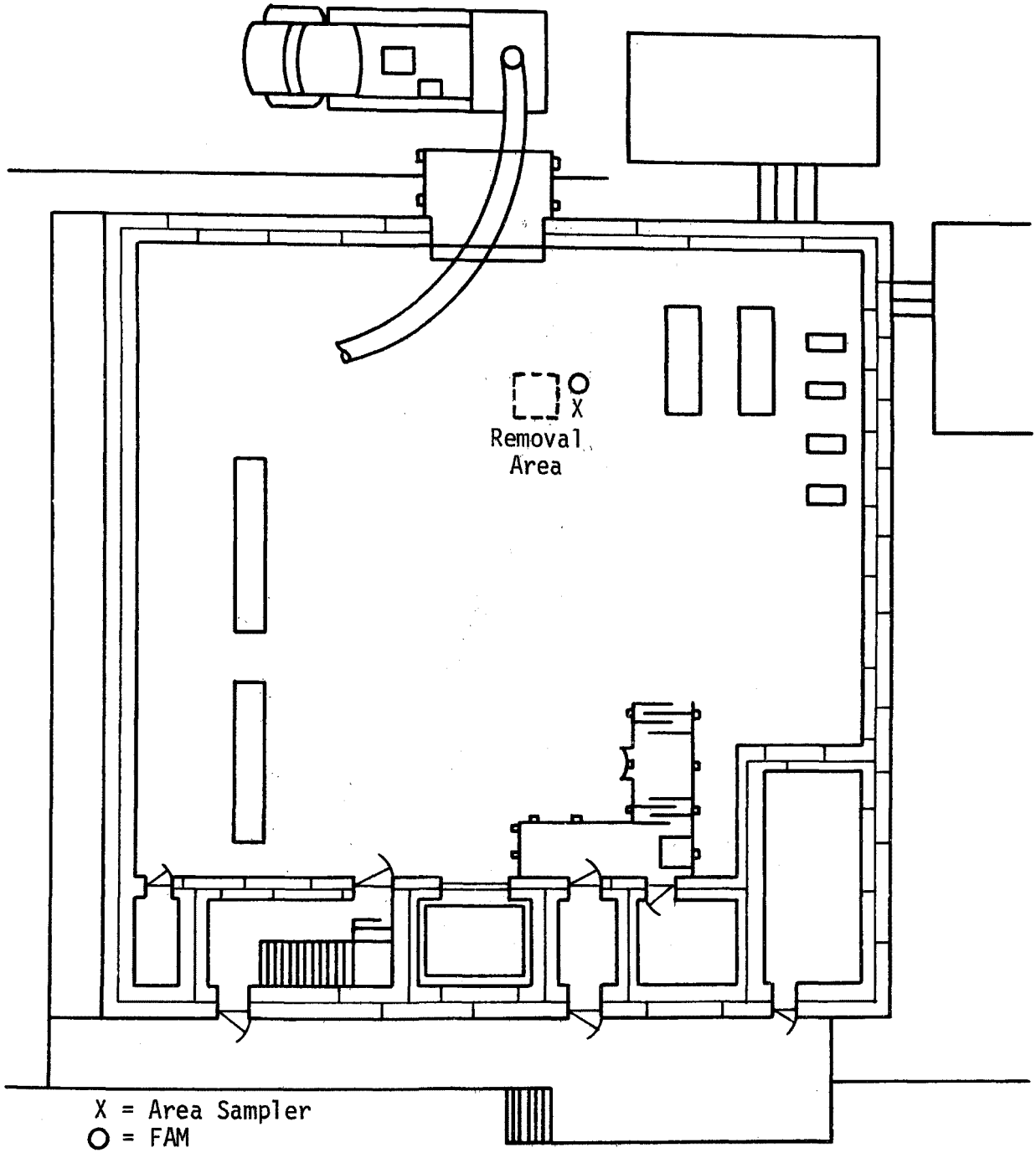


Figure 8. Sampling locations during Dry Removal II.

Figure 9. Photo of truck in dumping position.

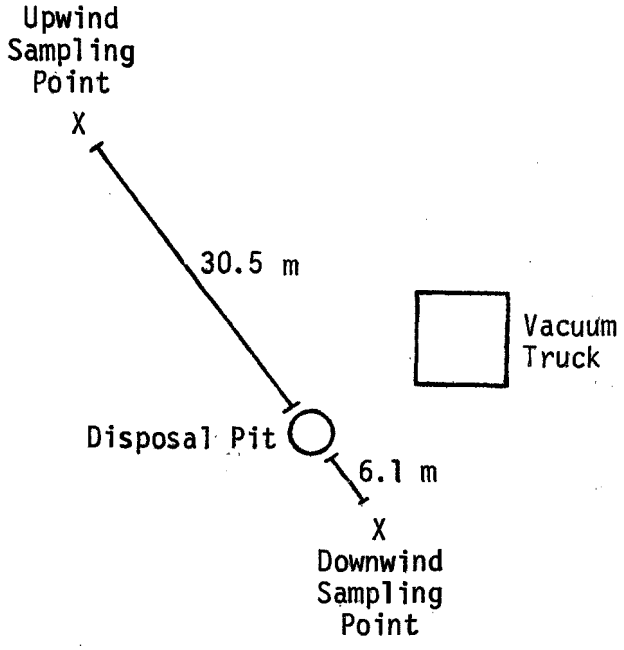


Figure 10. Sampling locations during asbestos disposal.

SECTION 6

SAMPLING AND ANALYSIS PROCEDURES

SAMPLING

Vacuum Truck Sampling

Prior to each asbestos removal, the vacuum system was instrumented with 0.18 cm i.d. probes connected to 37 mm diameter, 0.45 μm pore size cellulose acetate membrane filters mounted in tared filter cassettes. Suction was provided by rotary vane vacuum pumps with flow controlled by 4.9 lpm critical orifices. The probes were inserted into the ribbed intake hose, the suction header just ahead of the secondary filter set, in between the silencer and the HEPA filter (high efficiency particulate air), and in the HEPA filter discharge hose, as illustrated in Figure 3.

The flow rate through the sampling train was checked with a calibrated rotameter and determined to be 4.0 lpm.

Since difficulty was anticipated while sampling in the ribbed vacuum hose, an alternate procedure was used to estimate the mass input to the vacuum system. Unit samples of wet and dry asbestos were removed from measured areas of the ceiling in the work area. These were dried and weighed in the laboratory to determine the mass of ceiling coating removed per unit area. After sampling was completed during a removal method, the area of ceiling cleaned was measured to estimate the mass input during each sampling period. Filter cassettes were dried to constant weight in a dessicator. Mass accumulated during sampling was used to determine filtration efficiency of the vacuum system on a mass basis.

Bulk Samples and Area Wipes

Two bulk samples of the friable ceiling material were taken for subsequent characterization by polarized light microscopy and x-ray diffraction. These procedures are detailed in Appendix B. The composition of area wipes was determined by polarized light microscopy.

Personal, Area, and High-Volume Sampling

Personal samples were collected on a 0.8 μm pore size cellulose acetate membrane filters mounted in open-faced 37 mm diameter cassettes using MSA Model G personal sampling pumps at 1.7 lpm. The sample pumps were attached to the coveralls of the workers by means of duct tape straps around the waist

and over the shoulders, as shown in Figure 11. The cassette filter holders were attached as close to the breathing zone as possible. Personal samples were taken to assess the extent of individual exposure attributable to each method of asbestos removal.

Area samples were taken on 0.8 μm pore size 37 mm diameter cellulose acetate filters mounted in open cassettes at approximately 2.0 lpm. Flow was measured at the beginning and end of each test period by means of a calibrated rotameter. Area samples were taken 152 cm above floor level to determine the extent of contamination at that particular location.

High-volume air samples were collected on 0.8 μm pore size 20.3 cm x 25.4 cellulose acetate and 0.45 μm pore size 20.3 cm x 25.4 cm polycarbonate membrane filters upwind and downwind of the site. The high-volume samplers had previously been calibrated using a universal high-volume calibrator. Sampling flow rates were measured at the beginning and end of each sampling period. High-volume samples were taken to assess contamination to the environment attributable to the asbestos removal operation.

Fibrous aerosol concentration in the removal area and the high-volume samples collected on cellulose acetate membrane filters were analyzed by phase-contrast microscopy as discussed below. Electron microscopy was used to evaluate fibers collected on high-volume polycarbonate membrane filters and to confirm identification of asbestos fibers counted by phase-contrast microscopy in selected area samples. Electron microscopy methods are described below.

ANALYSIS

Phase-Contract Microscopy

Phase-contrast microscopy (PCM) was used to assess airborne fiber concentrations in accordance with NIOSH Analytical Method P&CAM 239.[4]

A portion of the filter--from the midsection to the outer edge--was mounted on a glass slide and cleared in a refractive index fluid, using a technique that is a variation of P&CAM 239.[5] This method allows the slides to be retained for re-examination and comparison for a longer period of time than the standard method. A description of this technique is given in Appendix C.

---

[4] Leidel, N.A., S.G. Bayer, R.D. Zumwalde, and K.A. Busch. USPHS/NIOSH Membrane Filter Method for Evaluating Airborne Asbestos Fibers. DHEW (NIOSH) No. 79-127. National Institute of Occupational Safety and Health, Cincinnati, Ohio, 1979. 21pp.

[5] Millipore Corporation Technical Brief: Procedure for Rendering MF-Millipore and Celotate Membrane Filters Transparent. Bedford, Massachusetts, 1975. 2pp.

Figure 11. Photo of personal sampling pump attached to worker.

The fiber concentration on each filter was analyzed using phase-contrast microscopy and observing counting rules recommended by NIOSH.

Polarized Light Microscopy

Polarized light microscopy (PLM) was used to identify the composition of the bulk samples and floor wipes and determine the type and percentage of materials present. A Zeiss light microscope with rotary stage, polarizer and analyzer, multiple objectives, and immersion oils with several different indices of refraction were used to make the identifications. In some cases, specific fibers were teased from the bulk specimen and remounted for further study. A detailed description of this method is given in Appendix C.

Electron Microscopy

Electron microscopy for asbestos analysis was conducted in accordance with the EPA's provisional methodology.[6] A grid opening was selected at random for critical examination at a magnification of 20,000X. The fibers observed in this opening were counted and measured. Each fiber was examined by selected area electron diffraction; the resulting pattern was used to identify the fiber as either serpentine, amphibole, not asbestos, or no pattern. In some cases, fiber identity was further confirmed using energy dispersive x-ray analysis for trace metals content.

X-Ray Diffraction

The bulk sample of ceiling material was separated into two fractions: the outer layer (termed "white") and the inner layer (termed "brown"). Both layers were analyzed by x-ray diffraction in two states: one was a nearly raw state after minimal crushing; the other was produced by grinding in a Wig-L-Bug (Crescent Dental Manufacturing Company). Four different samples were analyzed: white-raw, white-ground, brown-raw, and brown-ground. Each of the four samples was packed into a standard sample holder until it was flush with the plane of the holder. Pressure was applied to the two ground forms so no material would be lost in the x-ray diffraction unit.

The diffraction pattern of the brown portion was measured over the range 5° to 75°. Thirty-five major lines were observed and used for identification. An automated search of the JCPDS (Joint Committee on Powder Diffraction Sandards) mineral file provided a list of candidate identifications which were evaluated using chemical data and line-by-line comparisons. The diffraction pattern of the "white" portion was also measured over the angular range of 5° to 75°. Twenty-two major lines were observed and used for identification. A computer search of the JCPDS file was again used to generate a list of matching patterns.

---

[6] Samudra, A.V., C.F. Harwood, and J.D. Stockham. Electron Microscope Measurement of Airborne Asbestos Concentrations: A Provisional Methodology Manual. EPA-600/2-77-178. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, 1978. 57 pp.

Fibrous Aerosol Monitor

A primary consideration for using the fibrous aeresol monitor (FAM) was to obtain better defined evaluation of its design and use, provide a calibration, and monitor the asbestos removal activities. A brief description of the FAM and its operating principles and procedures are included in Appendix D.

Two well-characterized asbestos samples were used to calibrate the FAM. Table 2 summarizes the length and diameter distributions of the chrysotile and amosite used; Table 3 summarizes manufacturer's suggested FAM operating conditions for various fiber types. Chrysotile, a member of the serpentine group of asbestos minerals, was selected for calibration because 95% of the asbestos commercially consumed has been chrysotile; accordingly, it is more likely to be encountered than any other asbestos form. Amosite, a commercial name for South African amphibole asbestiforms usually of the cummingtonite-grunerite type, was selected because the manufacturer calibrates the FAM in the factory using amosite. This provided a reference check of FAM performance.

Calibration asbestos aerosols were generated by pneumatically spraying asbestos slurries into a stirred 14.5 m^3 chamber. Samples were collected for 30 min. from adjacent points using the FAM and open-faced filters. Filter sampling and analysis was done in accordance with NIOSH P&CAM 239 using the modified filter clearing procedure.

The calibrated FAM was then used to optimize filter loading for area sampling, to identify sources of fiber contamination during removal, and to assist the removal workforce in optimizing removal techniques.

TABLE 2. STATISTICS OF THE ASBESTOS MATERIALS USED FOR FAM CALIBRATION

	Intermediate Range Chrysotile			Amosite		
	Length (μm)	Diameter (μm)	Aspect Ratio	Length (μm)	Diameter (μm)	Aspect Ratio
Mean	1.25	0.11	11.48	12.54	1.09	10.12
Geo. Standard Deviation*	6.44	0.17	9.41	28.59	1.13	11.75
Minimum	0.10	0.02	3.00	0.85	0.06	3.00
Maximum	783.39	11.55	340.65	994.79	12.36	227.94
Median	0.82	0.09	8.44	4.37	0.72	6.42
10th Percentile	0.32	0.04	4.28	1.73	0.27	3.51
20th Percentile	0.40	0.06	5.28	2.31	0.34	4.09
30th Percentile	0.50	0.06	6.21	2.62	0.43	4.70
40th Percentile	0.65	0.07	7.17	3.01	0.54	5.56
50th Percentile	0.82	0.09	8.44	4.37	0.72	6.42
60th Percentile	1.02	0.10	9.91	5.84	0.85	7.59
70th Percentile	1.27	0.12	12.18	7.58	1.08	9.39
80th Percentile	1.61	0.14	15.70	12.92	1.47	12.43
90th Percentile	2.15	0.20	22.51	31.63	2.90	20.48
95th Percentile	2.54	0.21	---	---	---	---
99th Percentile	3.07	0.32	---	---	---	---
99.9th Percentile	76.9	0.69	---	---	---	---

* unitless

TABLE 3. RECOMMENDED FAM CONTROL SETTINGS FOR KNOWN ASBESTIFORM FIBER TYPES[7]

Fiber Types	Ratio Setting	Amplitude Setting	Discrimination Mode Setting	Comments
Amosite	5.0	0.5	Ratio plus amplitude	Factory calibrated for these these conditions
Crocidolite	5.0	0.5	Ratio plus amplitude	-----
Chrysotile	5.0	0.1	Ratio plus amplitude	See alternate below
Chrysotile (alternate)	---	see comments	Amplitude	Ratio sensing disabled. Determine correct amplitude setting by comparison with microscope filter count.

[7] GCA Environmental Instruments, GCA Fibrous Aerosol Monitor Model FAM-1 User's Manual. FAM-79-100. Bedford, Massachusetts, 1979. 69pp.

SECTION 7

RESULTS AND DISCUSSION

Background contamination levels and the analysis of bulk samples are presented first to identify baseline levels and the ceiling materials of interest. Each of the three major objectives is then presented: personal, area, and environmental exposures to asbestos resulting from the filtration efficiency of the removal system, system disassembly, and asbestos disposal. Additional miscellaneous results and observations are presented last, including comments on the fibrous aerosol monitor.

BACKGROUND SAMPLING AND BULK MATERIAL ANALYSIS

Bulk Material Analysis

The garage ceiling was coated relatively uniformly with two layers of asbestos-containing material. The total thickness of the coating was about 3 cm. The coating consisted of an outer white layer and an underlying brown layer. Paint had been applied to the surface of the white layer. Large areas of the outer layer had delaminated, as evident in Figure 1. Two samples of ceiling material were submitted for analysis of the bulk material and found to be identical. Material analysis by PLM (summarized in Table 4) indicated the white layer contained 49% chrysotile and 18% amosite; the brown layer contained 11% chrysotile and 56% amosite.

X-ray diffraction analysis confirmed the identifications provided by PLM. The diffraction pattern of the white portion, measured over the angular range of 5° to 75°, contained twenty-two major lines. The three major components--chrysotile (monoclinic), calcite, and aragonite--accounted for 20 of the observed lines. The patterns of the "ground" and "raw" samples were essentially alike, except that the raw white sample showed strong evidence of preferred orientation of the chrysotile crystals. This is common with chrysotile.

The diffraction pattern of the brown portions was measured over the range 5° to 75°. Thirty-five major lines were used for identification. Two major components--calcite and grunerite--accounted for 23 of the lines. Cummingtonite, whose pattern is very similar to grunerite, may be present. Manganese was detected in the sample using x-ray fluorescence. A minor amount of quartz was also present and accounted for four additional lines.

Background Sample Analysis

Table 5 summarizes the concentrations of background airborne fibers

TABLE 4. BULK MATERIAL ANALYSIS OF CEILING MATERIAL BY PLM

	Surface Layer	Underlying Layer
COLOR:	White	Brown
COMPOSITION:		
Chrysotile	49%	11%
Amosite (fibrous grunerite contaminated with anthophyllite)	18%	56%
Plaster, Mortar, Iron Oxide, Hornblende, and other trace components	33%	33%

TABLE 5. BACKGROUND FIBER CONCENTRATIONS

Location		Sampler Type	Sample Time	Analytical Method*	Fiber Concentration (f/cm^3)
Outdoor:	Upwind	High-Volume	420 min.	PCM	<0.005
	"	"	"	TEM	0.000
	Downwind	High-Volume	420 min.	PCM	<0.005
	"	"	"	TEM	0.000
Indoor:	Hallway	Area, 2.0 lpm	240 min.	PCM	<0.005
	4th Floor	" "	120 min.	PCM	0.020
	Stairwell	" "	240 min.	PCM	0.014
	Garage	" "	240 min.	PCM	0.029
	"	" "	240 min.	PCM	0.009
	"	" "	32 min.	PCM	<0.005

* PCM is NIOSH Phase Contrast optical microscopy, reference 4.
TEM is EPA provisional electron microscopy method, reference 7.

sampled by area and high-volume samplers within and around the FAA facility before asbestos removal operations. Outdoor fiber concentrations before asbestos removal were lower than the resolution limit for phase-contrast microscopy; no fibers were observed by electron microscopy. The time-weighted average indoor concentration for all samples was 0.014 fibers/cm^3.

Table 6 summarizes environmental surface contamination as revealed by polarized light microscopy of surface wipes. Asbestos was a major component only in the garage vertical I-beam samples. Amphibole (grunerite) predominated in the wipe samples even though it is a minor component of the outer ceiling layer. Further, most of the chrysotile was coated or encapsulated with paint.

PERSONAL, AREA, AND ENVIRONMENTAL ASBESTOS CONCENTRATIONS

Personal exposure to airborne fibers was determined by open-faced filter sampling and the NIOSH standard microscope method during each method of asbestos removal (Table 7). Time-weighted average personal exposure, in f/cm^3, was greatest during Wet Removal II, in which the asbestos ceiling material dropped to the floor and then was vacuumed. Some drying and resuspension of asbestos may have occurred during this mode of operation to elevate the fiber concentration. Personal sampler fiber concentrations observed for Dry Removal I, in which dry asbestos ceiling material was deposited directly into the vacuum hose, are surprisingly low compared with typical values for other dry removal techniques.

Indoor and outdoor area concentrations attributable to each removal method were determined by phase-contrast microscopy or the TEM provisional method (Table 8). As with personal samples, the highest fiber concentrations in the work area were collected during Wet Removal II. The highest concentration was 1.4 f/cm^3. The various techniques utilized during Dry Removal I did not last for a period of time long enough to obtain accurate measurements. However, the FAM detected slight changes in fiber concentration.

The partitioning of the work area successfully minimized contamination of the other areas within the FAA facility. The highest non-work area concentration was 0.33 f/cm^3, found in the shower during Wet Removal II. Small, but measurable, outdoor fiber concentrations were recorded; the maximum concentration was 0.02 f/cm^3.

The evaluation of outdoor fiber concentrations is difficult for several reasons. Some cross-contamination of upwind and downwind samples probably resulted from the irregular wind directions and complex air flow patterns around the radar facility. In addition, all of the fibers found on the high-volume filters may not have necessarily come from the vacuum truck during removal. The operator periodically left the work area through the roll door access opening to service the vacuum system. The FAM was especially useful here, as it detected the fibers shed from his work clothes during these service excursions. Finally, some contamination undoubtedly occurred during disassembly (discussed below).

TABLE 6. ANALYSIS OF AREA WIPE SAMPLES BY POLARIZED LIGHT MICROSCOPE

	Location				
	Garage Floor Near A/C Pumps	Garage Floor Near Boiler Room	Top Surface of Air Conditioner	Outer Wall of Garage (1.5 m level)	Vertical Surface of Ceiling Support
Surface load, g/ft^2	0.130	0.073	0.012	0.006	0.004
Primary Components >25%	Quartz Textile fibers Paper fibers	Quartz Paint flakes Paint spheres	Quartz	Plaster Mortar Quartz	Paper fibers Wood fibers
Major Components 5 to 25%	Micas Paint spheres Paint flakes Iron oxides	Carbonates Plaster Mortar Partial combustion products Wood fibers Iron oxides Hornblende Iron silicates	Paper fibers Textile fibers Partial combustion products Paint flakes Paint spheres Plaster Mortar Hornblende Other non-silicates	Wood Fibers Paint spheres Paint flakes Metal fragments Iron oxides Aluminum oxides	Amphibole asbestos Plaster Paint flakes Paint spheres Textile fibers Quartz Micas
Minor Components 0.5 to 5%	Amphibole asbestos Chrysotile asbestos Metal fragments Clay Humus Carbonates Wood fibers Cement Partial combustion products Aluminum oxides	Mica Paper fibers Textile fibers Clays Humus Metal flakes	Amphibole asbestos Mica Iron oxides Carbonates Clays Humus Vermiculite Metal flakes Wood fibers Other minerals	Paper fibers Textile fibers Micas Hornblende Iron silicates Carbonates Partial combustion products Cement Clays Humus	Chrysotile asbestos Iron oxides Metal flakes Partial combustion products Clays Humus Asphaltic matter
Trace Components <0.5%	Fiberglass Rubber tire fragments Vehicle exhaust Plant parts Insect parts Starch Rodent hairs Human hairs Skin flakes Grinding abrasives (silicon carbide) Diatoms	Amphibole asbestos Chrysotile asbestos Fiberglass (organic bound) Grinding abrasives (silicon carbide) Plant parts Insect parts Pollen Spores Rubber tire fragments Vehicle exhaust Human hair	Chrysotile asbestos Fiberglass (organic resin coat) Insect parts Plant parts Pollens Spores Rodent hair Skin flakes Rubber tire fragments Vehicle exhaust Human hair	Amphibole asbestos Chrysotile asbestos Fiberglass (organic bound) Grinding abrasives (silicon carbide) Pollens Spores Plant parts Insect parts Human hair Rodent hair Rubber tire fragments	Fiberglass Rubber tire fragments Vehicle exhaust Insect parts Pollens Spores Plant tissue Skin flakes Human hair Plant parts

TABLE 7. PERSONNEL EXPOSURE DURING ASBESTOS REMOVAL

Removal Method	Wet I		Wet II		Dry I	
	time,min.	f/cm^3	time,min.	f/cm^3	time,min.	f/cm^3
Sampler #24	185	4.16			22	2.23
	35	1.79	40	34.47	81	1.30
Sampler #25	185	3.77	43	9.10	86	1.12
	41	1.07				
Sampler #82	186	1.12	46	4.06	22	2.57
	35	1.11				
TIME WEIGHTED AVERAGE		2.73		15.17		1.46

Exposure was determined by the NIOSH standard method.

TABLE 8. INDOOR AND OUTDOOR AREA CONCENTRATIONS DURING ASBESTOS REMOVAL OPERATIONS

Removal Method		Wet I		Wet II		Dry I		Dry II	
		Time, min.	Conc., f/cm^3	Time, min.	Conc., f/cm^3	Time, min.	Conc., f/cm^3	Time, min.	Conc., f/cm^3
LOCATION:									
Outdoor:	Upwind	375	0.02 (TEM)	---	---	330	0.007 (TEM)	---	---
	Downwind	375	0.01 (TEM)	---	---	330	<0.005 0.007 (TEM)	---	---
Indoor:	Hallway	372	0.01	243	0.005	333	0.013	---	---
	Stairwell	374	<0.005	245	<0.005	363	0.008	---	---
	Shower	253	0.185	250	0.326	281	0.046	---	---
	Garage	185	0.025	255	1.40	342	0.12	90	1.49
	"	119	0.95	255	1.27	342	0.09		
	"	120	0.76						

All concentrations were determined by phase-contrast microscopy or by the TEM provisional method for Dry Removal II which was determined by the FAM.

VACUUM SYSTEM COLLECTION EFFICIENCY

The collection efficiency of the vacuum system was determined on a mass basis using the following technique. The mass input to the vacuum was estimated by obtaining the dry weight of friable ceiling material removed from a known surface area of ceiling and then computing the total mass removed by estimating the area of ceiling cleaned. The mass downstream of each filter element was obtained by differential mass accumulated on the membrane filters collecting through isokinetic sampling probes. The HEPA filter discharge was additionally monitored by the FAM and in Dry Removal I, by adjacent area sampling.

Mass input and mass accumulation after each stage of filtration was measured for each of the three removal methods employing the vacuum system (Table 9). The mass input term is probably correct within ±25%. The mass input term was measured by estimating the ceiling area cleaned during each method. The filtration efficiency of the system exceeded 99.99% on a mass basis. The HEPA discharge of 0.02 ppm by weight indicates that during operation the vacuum system is unlikely to be a significant source of environmental contamination.

TABLE 9. VACUUM SYSTEM FILTRATION EFFICIENCY

Removal Method	Mass in kg	Filter Discharge Values		
		Primary mg	Secondary mg	HEPA mg
Wet I	31 ± 8	2.4 ± 0.2	1.9 ± 0.2	0.7 ± 0.2
Wet II	61 ± 15	13.6 ± 0.2	1.2 ± 0.2	0.4 ± 0.2
Dry I	47 ± 12	6.3 ± 0.2	105.9 ± 0.2	0.7 ± 0.2

WET VERSUS DRY REMOVAL

Personal, area, and ambient concentrations of asbestos fibers measured during Wet Removal methods I and II in this study were comparable to those previously summarized in Table 1. That is, during Wet Removal I, personal exposures averaged 2.7 f/cm^3, work area concentrations averaged 0.5 f/cm^3, and ambient concentrations were less than 0.1 f/cm^3. During Wet Removal II, personal exposures averaged 15.2 f/cm^3, work area concentrations averaged 1.3 f/cm^3, and ambient concentrations were again less than 0.1 f/cm^3. Other studies measured asbestos concentrations over the range 0.5 to 23.1 f/cm^3 during wet removal.

By way of comparison, during dry removal with the vacuum system, personal exposures averaged 1.5 f/cm^3, work area concentrations averaged 0.1 f/cm^3, and ambient air concentrations were again less than 0.1 f/cm^3. As measured in this study, through the utilization of a properly filtered vacuum system, asbestos can be removed dry from building interior surfaces with airborne fiber concentrations comparable to those observed during standard Wet Removal procedures.

SYSTEM DISASSEMBLY AND ASBESTOS DISPOSAL

System disassembly and asbestos disposal are the two activities most likely to release significant amounts of asbestos into the environment. After the vacuum was shut off, accumulated water in the receiving chamber poured out of the receiving chamber door, leaving a foamy puddle on the pavement beneath the truck. Since the surfaces of the door gasket and mating flange were smooth and clean, leakage was evidently caused by slight warpage in the door and insufficient clamping force.

After the vacuum was shut off, the vacuum hose was uncoupled from the receiving chamber pipe by the operator and soggy asbestos ceiling material was violently spewed out by the force of the uncoupling. Upon inspection, the interior of the vacuum hose revealed significant asbestos contamination. The amount of asbestos contamination was probably increased by the presence of water from the wet removal tests. Dry asbestos residue inside a dry hose would probably be significantly less, though this has not been formally evaluated.

The vacuum truck is shown in the dumping position during asbestos disposal in Figure 9. The sources of airborne asbestos during dumping are numerous. A puff of aerosol was observed as the receiving chamber was canted. After dumping, the back surfaces of the truck were significantly contaminated with the asbestos-water slurry. The operator sprayed the truck with water in an attempt to remove the asbestos contamination. A visible aerosol was formed by the jet of water impinging on the truck surface; some asbestos undoubtedly was carried away by this spraying procedure. A heavy mist of water would probably produce less impingement aerosol and be more effective in decontamination. A wipe sample was taken of the outside surface of the door following decontamination. Analysis by PLM of this sample revealed asbestos fibers which had not been removed during washdown.

The upwind area sampler indicated background asbestos concentrations were below the lower detection limit for PCM; i.e., 0.005 f/cm^3. In fact, no fibers were visible on the filter. The personal exposure of the truck operator was 0.067 f/cm^3. The downwind sampler measured 0.116 f/cm^3.

ADDITIONAL OBSERVATIONS

Table 10 summarizes the results of laboratory calibration of the FAM using chrysotile and amosite aerosols. The percentage of statistical accuracy, % SA, for sampling is given by:[8]

$$\% \text{ SA} = \frac{\pm 200}{\sqrt{10 \cdot t \cdot n}}$$

where t = the sampling time in minutes

n = the fiber concentration determined by the NIOSH microscope method in f/cm^3.

The % SA cannot account for the shortfall in fiber counts for chrysotile reported by the FAM. Instrumental malfunction is not indicated since amosite concentrations are in reasonable agreement with those obtained by the NIOSH method.

Operating procedures for chrysotile suggested by the manufacturers were briefly evaluated. Operating the FAM in the amplitude-only mode with an amplitude setting of 0.1 resulted in significant background counts for nonfibrous aerosols. Further, fiber counts by FAM were not significantly different from background counts previously obtained in the test chamber with no chrysotile; hence, this procedure is not recommended for ambient asbestos sampling.

The FAM was used during asbestos removal to identify sources of contamination that might otherwise escape notice. For example, in the last step in site preparation, the few remaining boxes and equipment were removed from the work area and stored temporarily near the shower. The FAM indicated average fiber concentrations in this area of 0.1 f/cm^3. By comparison, concentrations of 0.01 f/cm^3 were obtained in the work area. The source of the high fiber counts was identified as residue clinging to the boxes and tracked into the shower when the boxes were transferred. After the area was mopped down, FAM counts dropped to 0.01 f/cm^3. The area sampler indicated 0.185 f/cm^3 prevailed in the shower.

---

[8] Lilienfeld, P., and P.B. Elterman. Development and Fabrication of a Prototype Fibrous Aerosol Monitor (FAM). EPA-600/7-77-147. U.S. Environmental Protection Agency, Washington, D.C., 1977. 71pp.

TABLE 10. COMPARATIVE NIOSH METHOD AND FAM FIBER CONCENTRATIONS*

Fiber Type	FAM Ser.No.	NIOSH method, f/cm³	FAM f/cm³	Time, min.	%SA	Notes
Chrysotile	2003	0.33	0.00	30	20%	
	2003	6.7	1.20	7	9%	
	2003	17.0	2.6	24	3%	
	2003	36.7	1.98	13	3%	FAM gain 9
	2003	36.7	3.9	11	3%	FAM gain 10
	2003	67	0.36	28	1%	
Amosite	1004	0.84	0.53	30	13%	
	2003	0.84	1.08	30	13%	

* FAM operating conditions. Ratio 5. Amplitude 0.5. Ratio plus amplitude.

It was possible to identify specific activities which resulted in high fiber concentrations by using the FAM during removal operations. During dry removal with no vacuum the FAM immediately indicated that fiber concentrations were greater than those recommended when using the half-face respirators worn by the work force; the workers left the area immediately. Dropping the wet asbestos directly on the floor for subsequent vacuuming during Wet Removal II gave 2.1 f/cm³, compared with 0.45 f/cm³ obtained during Wet Removal I. These counts parallel results obtained by area samplers.

The lack of experience in asbestos removal on the part of the vacuum system operator and work crew appears to have a direct bearing on the results obtained in this study. For any removal technique utilized, fiber concentrations detected by the FAM were highest at the beginning. As the work crew became more adept at the technique, fiber concentrations were observed to decrease.

Several malfunctions occurred in the vacuum system which limited progress with asbestos removal. Most of these were associated with the spraying system in the receiving chamber. The sprayers stopped functioning just before the dumping operation. The water supply line for the sprayers froze overnight and shattered the supply line rotameter.

The third malfunction apparently resulted from excessive water carryover from the receiving chamber into the filter elements. Water or ice accumulation on the filter elements caused an excessive pressure drop in the vacuum line; simultaneously, the vacuum available at the inlet hose was inadequate to allow removal to continue. The automatic primary filter backflush system was unable to correct the problem, and the operator subsequently shut the system down.

APPENDIX A

VACUUM SYSTEM DESCRIPTION

Diversified Vacuum Systems Inc.

671 Frelinghuysen Avenue
Newark, N. J. 07114
(201) 242-7002

551 Post Road
Greenwich, Conn. 06830
(203) 622-0493

October 5, 1979

Mr. John D. Stockham
Manager
Fine Particles Research
IIT Research Institute
10 West 35th Street
Chicago, Illinois 60616

Dear John,

As per our meeting on October 4, 1979. We will equip the test vehicle with (4) four monitoring ports. Tentatively, the locations would be on 90° elbows with 1/4" female couplings installed at the centerlines, (subject to your approval).

As we have discussed, the line velocity will be a maximum of 20,000 F.P.M. on the 4" air line to a maximum of 5000 F.P.M. on the 8" lines. Maximum vacuum will be 200" H_2O, (adjustable to a lower setting if necessary). The line velocity is also adjustable if required. Keep us appraised of any particular requirement you may have, if possible we will comply. Within the next few weeks we will forward a description of the equipment.

Very truly yours,

Robert De Mane

Robert De Mane

RD/kw

Diversified Vacuum Systems Inc.

671 Frelinghuysen Avenue
Newark, N. J. 07114
(201) 242-7002

551 Post Road
Greenwich, Conn. 06830
(203) 622-0493

November 30, 1979

Mr. Roger Hancock
IIT Research Institute
10 West 35th Street
Chicago, Illinois 60616

Dear Roger,

Enclosed is a description of the Model AS-10 Vacuum Loader, as modified for asbestos handling. Of particular importance in the design of the unit is the filtration system and operating parameters. The AS-10 is unique in that substantially all filtration is handled directly in the main vacuum receiving section. Asbestos dust and fiber is regenerated directly in this chamber. This eliminates the necessity for a bag house and separate dust conveying equipment. The primary problem with all other truck mounted vacuum loaders has been: 1] Inability to filter particulate sizes smaller than 1-2 micron. 2] No back up or safety filtration to protect against bag failure. 3] No positive sensing or electronic control system, and, 4] Bag house contamination. Once the bag house has been contaminated by asbestos, it is impossible to totally clean. The mechanism and apparatus which conveys the dust from the bag house back to the body is inaccessible, and cannot be cleaned. When this type of truck is returned to regular vacuum service, it inevitably will generate asbestos pollution.

The AS-10 is equipped with three major filtration sections. Material enters the main vacuum receiving chamber. It is diffused and baffled. Within this chamber there are multiple filtration elements in a parallel configuration. All flow then travels from the body section through a split flange with an "O" ring seal, to the truck chassis. At the base of the split flange, after the first 90° bend, we provided test port location No. 1. Air flows through a straight section for approximately 3', at this point, port No. 2 is located. From port No. 2, all air passes through the second major filtration section. This consists of a compound element - a major and minor section. Air flows straight for approximately 4 1/2', at the end of this run, on the 90° elbow, is test port No. 3. The air then passes through a three lobed, positive displacement blower. After the blower exhaust silencer, is test port No. 4. All flow then passes through

the blower safety output filter. This is a multiple section, specially coated, absolute filter material, with estimated efficiency of 99.99%.

Test ports No. 1 and No. 2 essentially see the same quality of air. The two locations were provided in order to provide different air flow patters for the sampling probes. Test ports No. 3 and No. 4 also see the same quality of air. However, No. 3 is on the vacuum side of the blower and No. 4 is on the positive side.

The storage section of the vacuum body is internally equipped with multiple water misting devices. The truck chassis has a 100 gallon water tank for storage of amended water.

All vacuum truck functions are operated by two main control panels. The primary logic is handled by a 12 Volt, D.C., electronic control circuit. To insure maximum reliability and safety, the circuit is fail-safe. Redundant back-up is utilized for the secondary and safety sections. L.E.D.'s indicate the status of operating conditions. The upper control panel interfaces electrical signals to air logic. All air signals originate from this panel. Dual selectors allow the truck operator to monitor each individual section of air flow pattern within the vacuum systems.

We are naturally, extremely interested in all test information gathered from the project. We would appreciate copies of any reports relative to the project.

During the test, we did not have the opportunity to evaluate any mechanical devices for physically removing the asbestos from the wall and ceiling surfaces. We hope that these devices will further reduce fiber count within the work area. The fully refined tools would be mounted within the vacuum wand. This should provide consistently lower fiber counts. We will keep you appraised as to tool developement.

If we may be of further service, please feel free to contact us.

Very truly yours,

Robert De Mane

Robert De Mane

RD/kw
cc: Dr. Robert Sawyer
Tucker Deming
file (2)

ADVANCED
SERVICE SYSTEMS INC.

661 - 671 FRELINGHUYSEN AVENUE
NEWARK, NEW JERSEY 07114
(201) 344-2400

TRUCK MOUNTED VACUUM LOADER

MODEL AS-10

General Description

The Model AS-10 is a truck mounted mobil vacuum loader. The unit utilizes a heavy duty, reinforced vacuum receiving chamber. The vacuum loader truck is capable of vacuuming materials such as; dusts, sludges, slurries, gravel, catalyst and oil spills. Various materials can be air conveyed at distances up to 700'.

Body Assembly

Body construction consists of one, 10 cu. yd., heavy duty reinforced vacuum chamber. Chamber is fabricated from 3/16" steel plate, braced internally and externally with structural channel.

Blower

One heavy duty positive displacement, roots type blower. Consisting of two figure eight impellers, rotating in opposite directions to move entrapped air around the case to the port outlet.

AS-10

ADVANCED
SERVICE SYSTEMS INC.

661 - 671 FRELINGHUYSEN AVENUE
NEWARK, NEW JERSEY 07114
(201) 344-2400

Filtration

Primary filtration centrifugal type seperators. 50 micron and larger to 90% efficiency. Secondary filtration, high performance cyclones with spin out and high velocity section. 15 micron and larger to 95% efficiency. Final filtration, dry element 99.50% all particle size 3 micron and larger. Safety element built in to final filtration section.

Special Filtration and Modification

Filtration

Three stage, heavy duty, dry type system. Primary filtration stage, multiple element sections in parallel. Nominal efficiancy, 99.50%. Secondary filtration, two stage, heavy duty high efficiency in series, nominal efficiency 99.95%. Third stage, positive pressure side of blower, special modified and coated type element, nominal efficiency, 99.99%.

Control Circuit Protection and Controls

Complete air control circuitry, fail safe type with redundant back-up. Each stage of filtration is differentially sensed and protected by electronic cells. Automatic system shut down will occur at any time pressure drop reaches 25% of maximum safe value. Equipment shut-off is a two stage operation. Blower R.P.M. is dropped to minimum operating speed. System vents and blower speed are brought to idle, after a pre-set interval, complete shut down occurs. L.E.D. fault indicating lights identify reason for system shut-off.

ADVANCED
SERVICE SYSTEMS INC.

661 - 671 FRELINGHUYSEN AVENUE
NEWARK, NEW JERSEY 07114
(201) 344-2400

Engine and Blower Protection

Diesel engine is protected by automatic low water shut-off, low oil pressure, and over temperature watch guard system.

Blowers and body are protected against:

- Maximum vacuum level
- Blower exhaust temperature
- Differential final filtration pressure
- Full body level
- Out phase fault shut-off
- Blower P.T.O. interlock
- Locked blower shut-down
- Pre-filter warning

Instrumentation

- Blower Vacuum 0-30" Hg.
- Filter differential pressure
- Oil pressure
- Ampmeter
- Water tank pressure
- L.E.D. status lights

Instrumentation - Additional for Asbestos

- 0-30" Hg. Vacuum gage, glycerin filled and pulsation dampened
- 2-12 Gal./min. water flow
- 0-100" W.C. differential gage with dual 12 position selectors
- 0-100 P.S.I. Primary air pressure
- 0-100 Secondary air pressure
- 0-75 Water tank pressure
- 100-250°F. Primary air temperature
- 150-350°F. Secondary air temperature
- 0-3600 R.P.M. Indicator
- 1500-3000 P.S.I. Hydraulic pressure gage.
- Full body depth sensor, R.F. type
- Liquid level - Mechanical type

ADVANCED
SERVICE SYSTEMS INC.

661 - 671 FRELINGHUYSEN AVENUE
NEWARK, NEW JERSEY 07114
(201) 344-2400

Hydraulic System

P.T.O. drive continuous duty 420 Vickers pump. Three bank manual control valve with built in pressure relief. Full return line filter, 10 micron rating.

Paint

Cab and chassis, Imron Silver. Body and pipe racks, Imron Blue.

Diversified Vacuum Systems Inc.

671 Frelinghuysen Avenue
Newark, N. J. 07114
(201) 242 7002

551 Post Road
Greenwich, Conn. 06830
(203) 622-0493

October 29, 1979

Mr. Dennis F. Finn
Environmental Engineer
IIT Research Institute
10 West 35th Street
Chicago, Illinois 60616

Dear Dennis,

Regarding our conversation for air sampling at the Bucks Harbor facility. We have finalized on an optimum air flow for this job. Subject to any requirements by you to the contrary, the line velocities would be; 4" Dia. tube, 19,500 F.P.M., 6" Dia. tube, 8680 F.P.M., 8" Dia. tube, 4870 F.P.M. An interesting area for monitoring will be checking the ongoing filter efficiency between the primary air filters and secondary air filters. We suspect that efficiency should improve as the filters "load".

Look forward to hearing from you soon.

Very truly yours,

Robert De Mane

RD/kw

APPENDIX B

BULK SAMPLE AND WIPE SAMPLE ANALYSIS PROCEDURES: POLARIZED LIGHT MICROSCOPY AND X-RAY DIFFRACTION

BULK SAMPLE POLARIZED LIGHT MICROSCOPY ANALYSIS METHODS

Clumps of the distinctly different phases, and bundles of obvious fibers were plucked from each sample and mounted in standard immersion oil (n_D = 1.515). The samples were examined by polarized light microscopy to determine other phases present and what additional sample preparation steps would be required in order to complete the analysis.

The polarized light microscopical analysis revealed the presence of obvious chrysotile asbestos, an amphibolic asbestos type, abundant plaster-mortar material (calcium sulphates and carbonates), and minor quantities of asbestos gangue minerals.

To simplify the asbestos quantification, the plaster material was dissolved away in dilute acetic acid. A weighed portion of each sample was digested in warmed, dilute acid for 1 hour. Frequent stirring insured dissolution of all the plaster material. The non-soluble portion of the suspension was recovered on a tared membrane filter and was thoroughly washed with filtered, deionized water. The dried residue was then weighed, and the percent weight lost, which represented the dissolved plaster-mortar material, was calculated.

Concentrations of each asbestos type present in the distinctly different colored phases were estimated microscopically.

The amosite (more accurately termed fibrous grunerite) identification was made by mounting some of the amphibole fibers in n_D = 1.660 standard refractive index liquid. The refractive indices of the amphibole fibers were found to correspond most closely to those reported for grunerite.[1]

---

[1] Hurlbut, C.S., Jr., and C. Klein. Manual of Mineralogy. John Wiley & Sons, New York, 1977. 532pp.

ANALYSIS OF ASBESTOS IN INSULATION

ID NUMBER: 4-1

CONTACT NAME _____ PHONE _____

AGENCY _____

AGENCY ADDRESS _____

BUILDING NAME _____

BUILDING ADDRESS _____

ROOM (HALL) _____

SAMPLED FROM _____

SAMPLED BY _____ ON _____

FRIABILITY _____

SHIPPED ON _____ RECEIVED _____

ANALYSIS RESULTS

ANALYST JLG ANALYSIS DATE 12/1/79

PLM INSTRUMENT 2

SUPPLEMENTARY ANALYSES --

SAMPLE DESCRIPTION Light-brownish overall; clump of light-grayish material interspersed; fibers obvious--more fibrous than the 16-1 and 16-2 samples.

ASBESTOS TYPE Chrysotile and amosite (anthophyllite contaminants in amosite)

ASBESTOS CONCENTRATION Total ~62% asbestos: brownish material-- ~85% amosite, ~~15% chrysotile; grayish material-- 65% chrysotile,35%amosite~~

OTHER FIBROUS COMPONENTS	MASS PER CENT	FIBER DIAMETERS, μm RANGE	MEAN
fiber glass	<<1		
rock, slag wool	<<1		
cellulose	<<1		
other	--		

NONFIBROUS COMPONENTS

plaster,mortar	~36%	prismatic amphiboles		
iron oxides		non-fibrous serpentine		
hornblende		clays		

REPORT BY _____ REPORT DATE _____

ANALYSIS OF ASBESTOS IN INSULATION

ID NUMBER
16-1

CONTACT NAME _____ PHONE _____
AGENCY _____
AGENCY ADDRESS _____
_____
_____
BUILDING NAME _____
BUILDING ADDRESS _____
_____
ROOM (HALL) _____
SAMPLED FROM _____
SAMPLED BY _____ ON _____
FRIABILITY _____
SHIPPED ON _____ RECEIVED _____

ANALYSIS RESULTS

ANALYST JLG ANALYSIS DATE 12/1/79
PLM INSTRUMENT 2
SUPPLEMENTARY ANALYSES --
SAMPLE DESCRIPTION Light-grayish overall, with clumps of light brown material; fibers very obvious.

ASBESTOS TYPE Chrysotile and amosite (anthophyllite contaminants in amosite)
ASBESTOS CONCENTRATION Total ∿65%: grayish material--75% chrysotile, 25% amosite; ~~brownish material--80% amosite, 20% chrysotile.~~

OTHER FIBROUS COMPONENTS	MASS PER CENT	FIBER DIAMETERS, µm RANGE	MEAN
fiber glass	<<1		
rock, slag wool	<<1		
cellulose	<<1		
other	--		

NONFIBROUS COMPONENTS

plaster, mortar	33%	prismatic amphiboles	
iron oxides		non-fibrous serpentine	
hornblende		clays	

REPORT BY _____ REPORT DATE _____

ANALYSIS OF ASBESTOS IN INSULATION

ID NUMBER 16-2

CONTACT NAME _____ PHONE _____

AGENCY _____

AGENCY ADDRESS _____

BUILDING NAME _____

BUILDING ADDRESS _____

ROOM (HALL) _____

SAMPLED FROM _____

SAMPLED BY _____ ON _____

FRIABILITY _____

SHIPPED ON _____ RECEIVED _____

ANALYSIS RESULTS

ANALYST JLG ANALYSIS DATE 12/1/79

PLM INSTRUMENT 2

SUPPLEMENTARY ANALYSES --

SAMPLE DESCRIPTION Light-grayish overall; clumps of light-brownish and whiter material evident; fibers obvious.

ASBESTOS TYPE Chrysotile and amosite

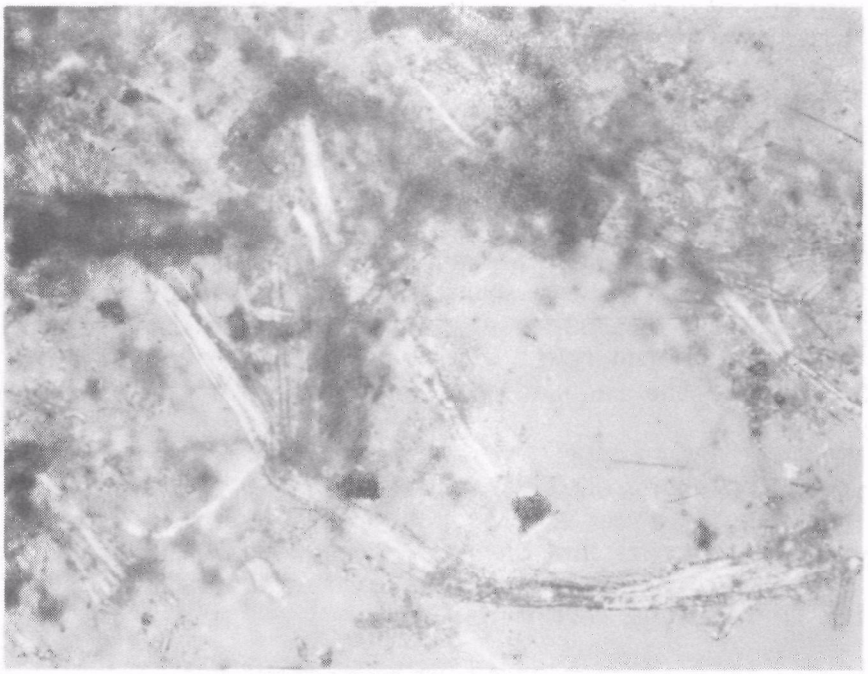
ASBESTOS CONCENTRATION Total ~65% asbestos: brownish material--85% amosite, ~~15% chrysotile; grayish material--80% chrysotile, 20% amosite~~

OTHER FIBROUS COMPONENTS	MASS PER CENT	FIBER DIAMETERS, μm RANGE	MEAN
fiber glass	<<1		
rock, slag wool	<<1		
cellulose	<<1		
other	--		

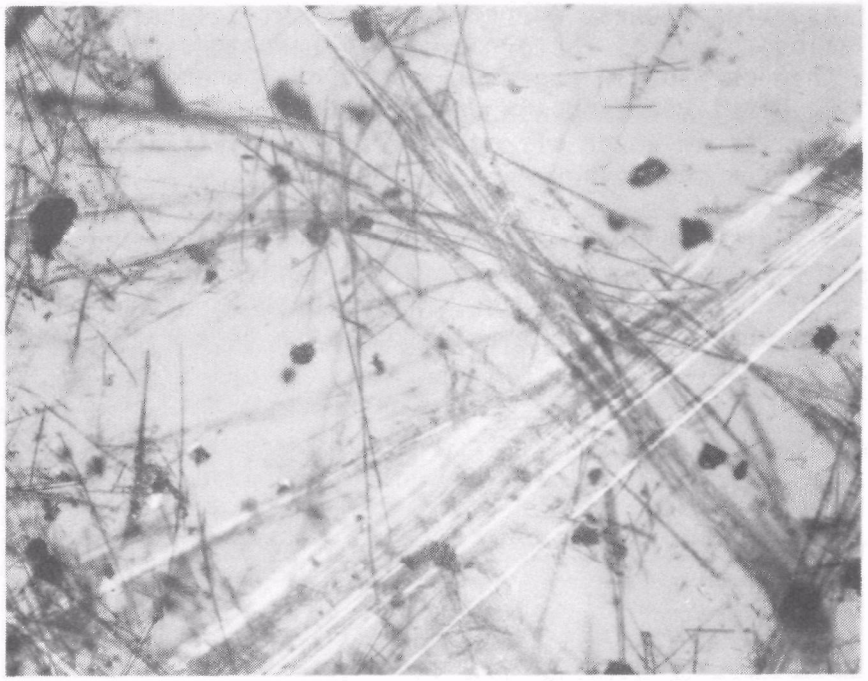
NONFIBROUS COMPONENTS

plaster,mortar	~33%	prismatic amphibole	
iron oxides		non-fibrous serpentine	
hornblende		clays	

REPORT BY _____ REPORT DATE _____



Bundles of chrysotile fibers coated with plaster-mortar; slightly uncrossed polars; 82X.



Bundles of the harsher amosite (grunerite) asbestos fibers coated with plaster-mortar; slightly uncrossed polars; 82X.

POLARIZED LIGHT MICROSCOPIC ANALYSIS OF WIPE AND VACUUM SWEEP SAMPLES

Seven aerosol filter sampling cassettes and one towel wiping sample were submitted for polarized light microscopic analysis. The samples represented sweepings of dust from various floor and structural surfaces.

Since the membrane filters in the aerosol sampling cassettes were so loaded with large particles that a loose, removable dust was visible, the loose dust rather than the membranes were mounted for microscopic analysis. In all samples, clumps of fibers were present as "lint balls," in addition to a loose, free-flowing fine dust. Tweezers were used to remove samples of the "lint balls," while a spatula was used to remove samples of the loose dust for mounting. Materials were mounted on glass slides in standard immersion oil (n_D = 1.515) for microscopic analysis. The sample for microsopic analysis was removed from the towel wiping by scraping the visible dust deposit with a scalpel; the removed dust was mounted in the same manner as the other samples.

The prepared samples were examined with a polarized light microscope at magnifications ranging from 62X through 400X. Particle types observed were identified from optical and physical properties. Concentrations were estimated from the relative number abundance of each particle type after size and density corrections were made.

The attached tables list the components noted in each sample and their relative abundance. Photomicrographs of each sample are also included. Arrows indicate the asbestos fibers (amphibole, in most cases).

In most samples, the amphibole asbestos fibers were more abundant than the chrysotile asbestos fibers, even though chrysotile was in the outermost layer of insulation. Several factors probably resulted in the release of more amphibole than chrysotile asbestos. Most of the chrysotile detected in the samples was heavily coated with, and actually encapsulated by, paint. The paint probably served as an effective coating which minimized release of the chrysotile. It should be mentioned that in several samples the chrysotile concentration could be higher than that listed; the paint coatings hindered and probably prevented detection of all chrysotile fiber bundles. The amphibole asbestos is much more friable, in terms of both fiber length and bundle width, than chrysotile asbestos. Therefore, more small fibers and fiber bundles of amphibole would be released, with less disturbing force, than chrysotile fibers.

TABLE B-1. GARAGE FLOOR NEAR AIR-CONDITIONING PUMPS

Primary Components

quartz
textile, paper fibers

Major Components

micas
paint spheres, flakes
iron oxides

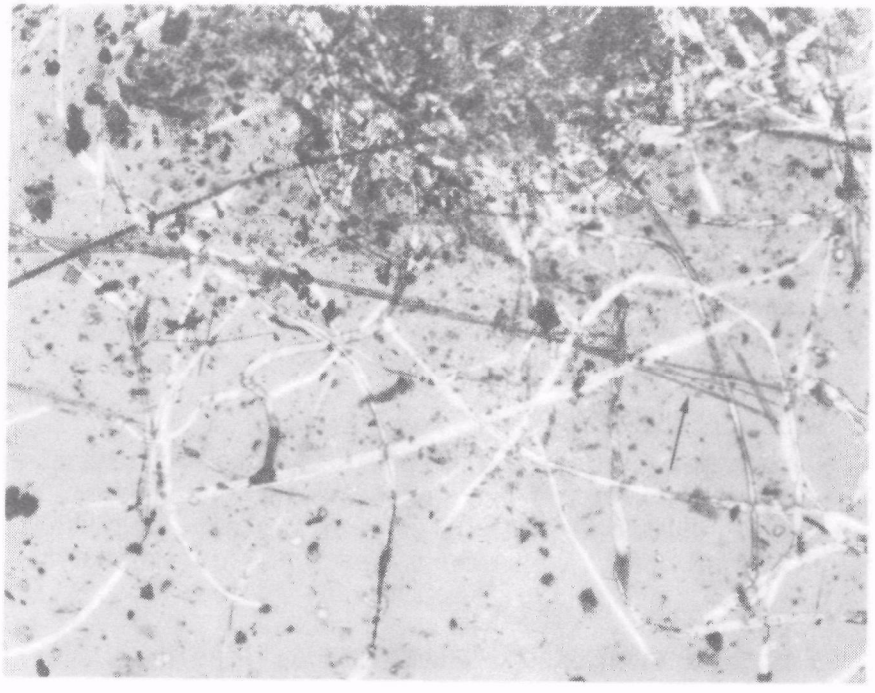
Minor Components

amphibole asbestos (<1-1220 μm, mean ∿20 μm)
metal fragments
clay, humus
carbonates
wood fibers
cement
partial combustion fragments
aluminum oxides

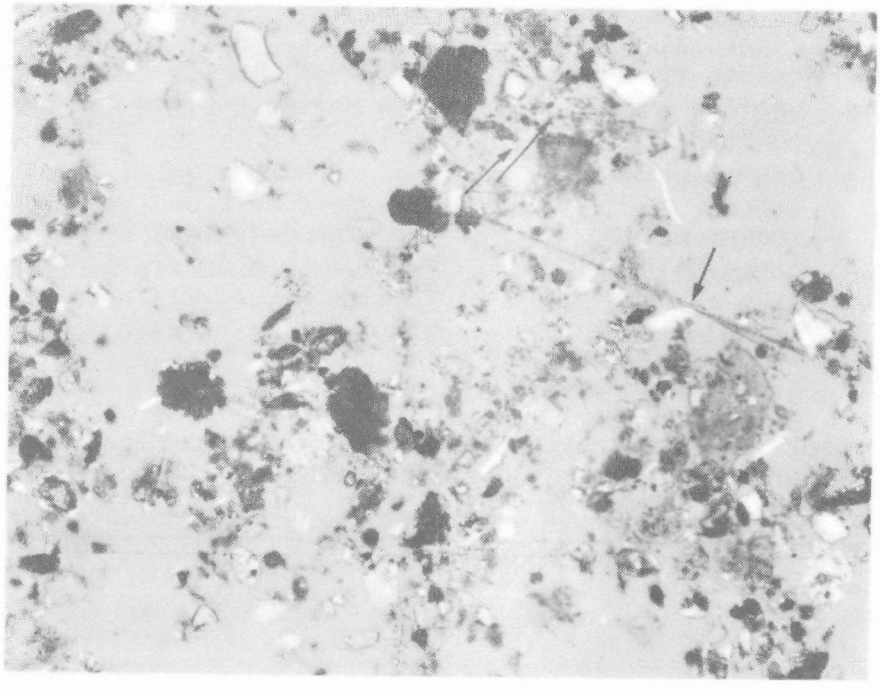
Trace Components

chrysotile asbestos (∿1-360 μm)
fiberglass
rubber tire fragments
vehicle exhaust
plant parts
insect parts
starch
rodent hairs
human hairs
skin flakes
grinding abrasives
diatoms

Chrysotile concentration could possibly approach 1%; some chrysotile was noted encapsulated in paint.



Lint ball; 82X.



Fine dust; 208X.

TABLE B-2. GARAGE INTERIOR WALL WIPE SAMPLE
(150 cm from floor)

Primary Components

plaster, mortar
quartz

Major Components

wood fibers
paint spheres, flakes
metal fragments
iron oxides
aluminum oxides

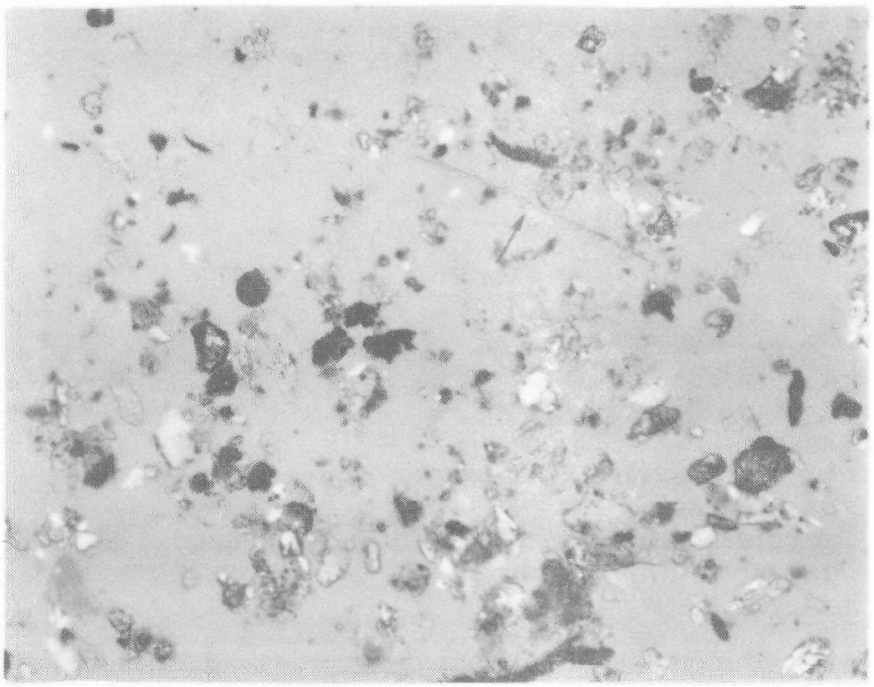
Minor Components

paper fibers
textile fibers
micas
hornblende, iron silicates
carbonates
partial combustion fragments
cement
clays, humus

Trace Components

amphibole asbestos (<1-440 μm, mean ∿24 μm)
chrysotile asbestos (<1-500 μm)
fiberglass (organic bound)
grinding abrasives
pollens, spores
plant parts
insect parts
human hair
rodent hair
rubber tire fragments
glassy flyash

GARAGE INTERIOR WALL WIPE SAMPLE
(150 cm above floor)



Fine dust; 208X.

TABLE B-3. VERTICAL SURFACE OF WIDE FLANGE OF I-BEAM (150 cm above garage floor)

Primary Components

paper, wood fibers

Major Components

amphibole asbestos (<1-1700 μm, mean ∿35 μm)
plaster
paint flakes, spheres
textile fibers
quartz
micas

Minor Components

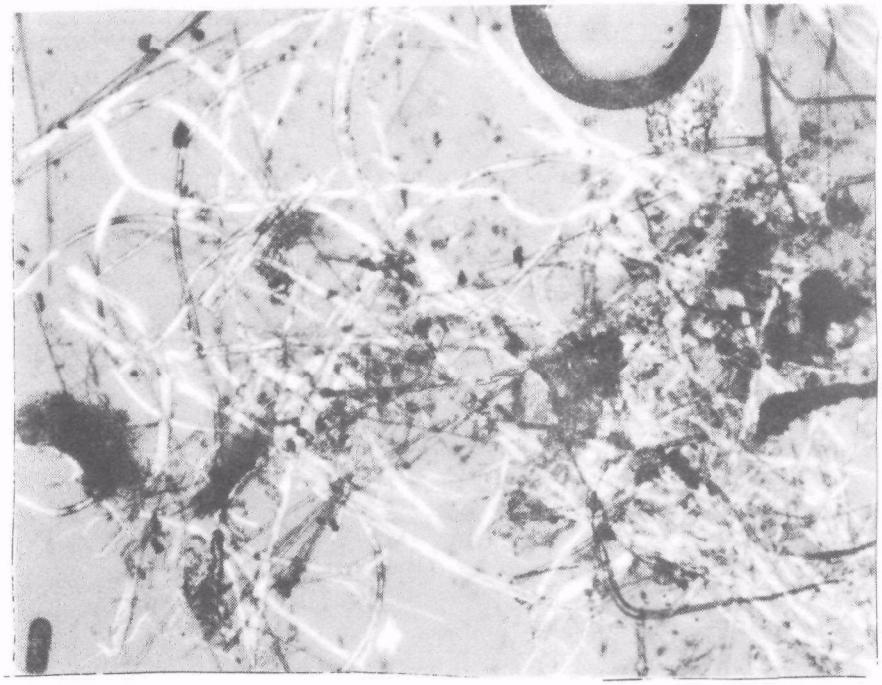
chrysotile asbestos (1-600 μm) other minerals
iron oxides
metal oxides
partial combustion fragments
clays, humus
asphaltic material

Trace Components

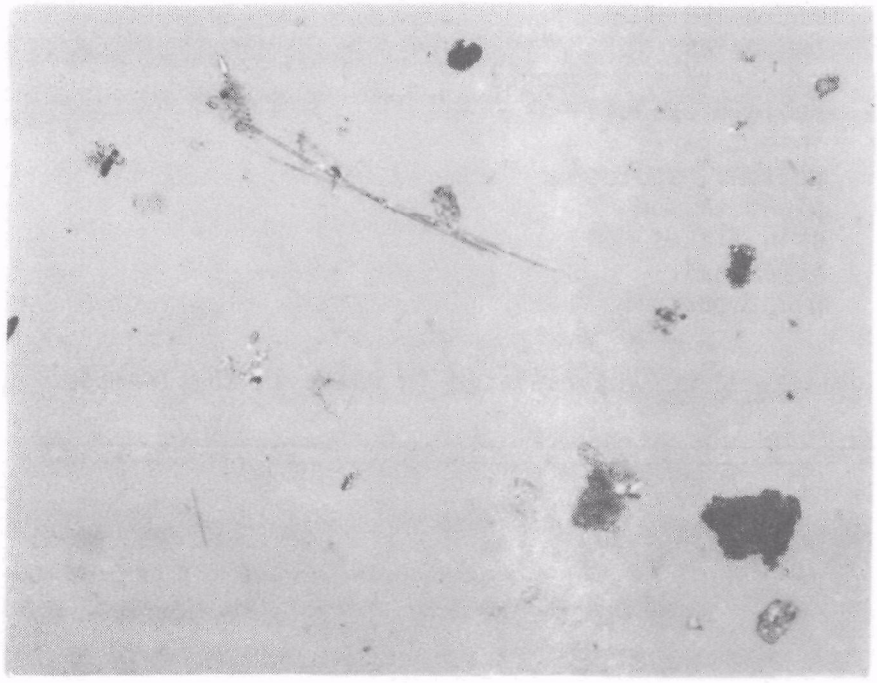
fiberglass (organic bound)
rubber tire fragments
vehicle exhaust
insect parts
pollens, spores
plant tissue
skin flakes
human hair
plant parts

Chrysotile was not encapsulated in paint in this sample.

VERTICAL SURFACE OF WIDE FLANGE I-BEAM
(150 cm above garage floor)



Lint ball; 82X; straight dark fibers are amphibole asbestos bundles.



Fine dust; 208X; fibrous particles are amphibole asbestos.

TABLE B-4. GARAGE FLOOR NEAR BOILER ROOM

Primary Components

quartz
paint flakes, spheres

Major Components

carbonates
plaster, mortar
partial combustion fragments
wood fibers
iron oxides
hornblende and other iron-silicates

Minor Components

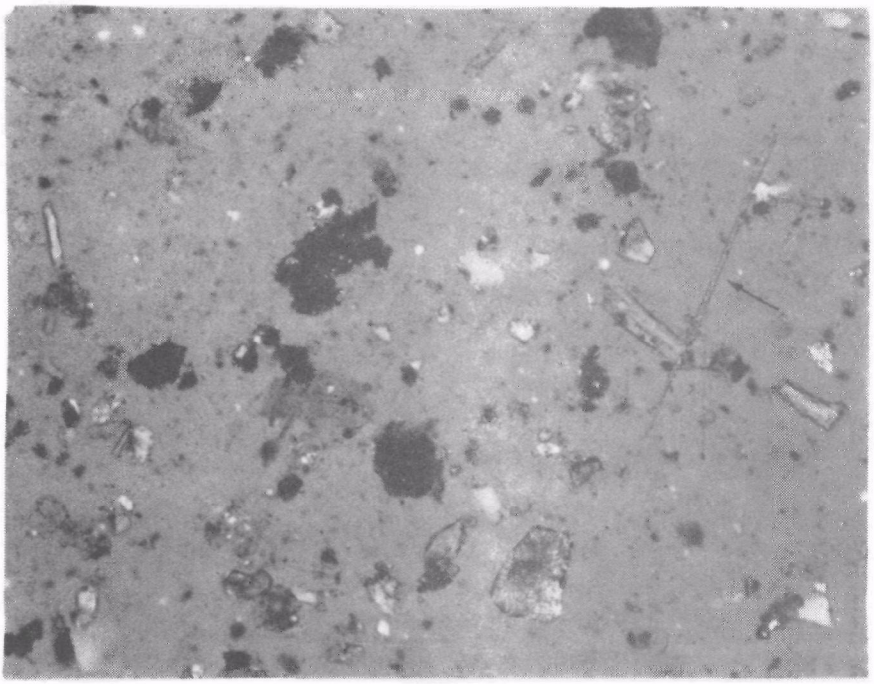
mica
paper fibers
textile fibers
clays, humus
metal flakes

Trace Components

amphibole asbestos (<1-820 μm, mean ∿30 μm)
chrysotile asbestos (<1-1000 μm, mean ∿18 μm)
fiberglass (organic bound)
grinding abrasives (corundum, silicon carbide)
plant parts
insect parts
pollens, spores
rubber tire fragments
vehicle exhaust
human hair
diatoms

Chrysotile was not detected as an encapsulated phase in this sample. Number concentrations of amphibole fibers were only slightly greater than chrysotile fiber concentrations.

GARAGE FLOOR NEAR BOILER ROOM



Fine dust; 208X.

TABLE B-5. TOP HORIZONTAL SURFACE OF GARAGE LEVEL AIR-CONDITIONERS

Primary Components

quartz

Major Components

paper fibers
textile fibers
partial combustion fragments
paint flakes
paint spheres
plaster, mortar
horneblende and other iron-silicates

Minor Components

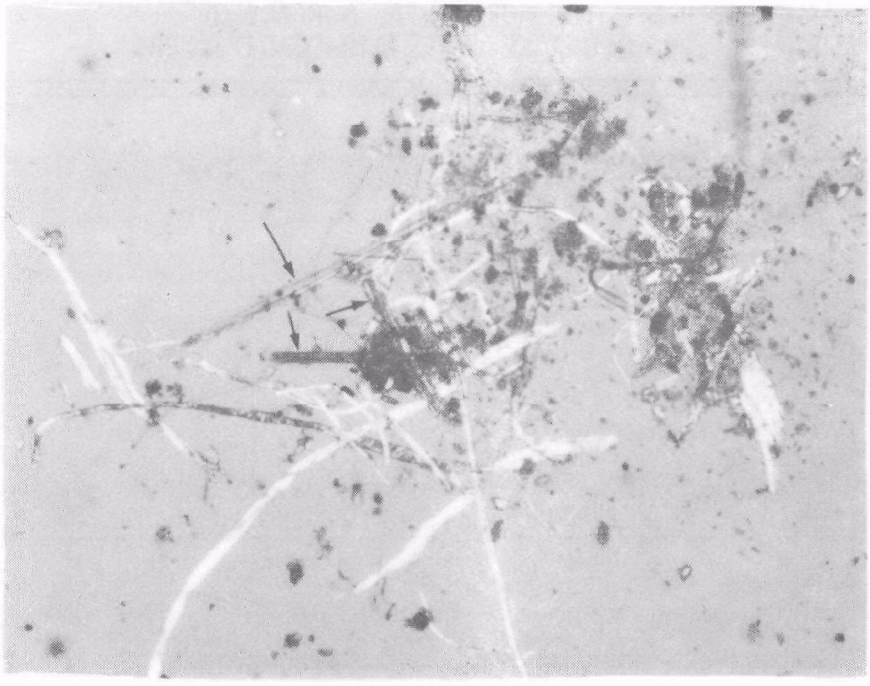
amphibole asbestos (<1-1000 μm, mean ∿20 μm)
mica
iron oxides
carbonates
clays, humus
vermiculite
other minerals
metal flakes
wood fibers

Trace Components

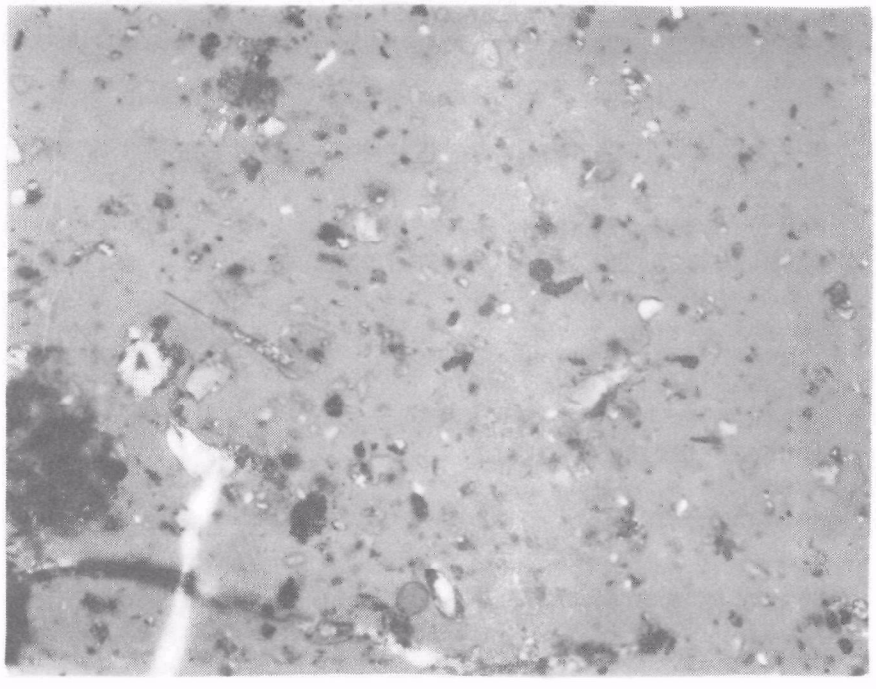
chrysotile asbestos (<1-680 μm)
fiberglass (organic resin coating)
insect parts
plant parts
pollens, spores
rodent hairs
skin flakes
rubber tire fragments
vehicle exhaust
human hair

Conceivably there could be up to 1% chrysotile. Chrysotile was detected encapsulated in some of the paint flakes.

TOP SURFACE OF GARAGE LEVEL AIR-CONDITIONERS



Lint ball; 82X.



Fine dust; 208X.

TABLE B-6. WIPE SAMPLE OF RECEIVING RESERVOIR DOOR AFTER DUMP AND DECONTAMINATION

Primary Components (>25% by mass)

quartz

Major Components (5-25% by mass)

hornblende and other iron silicates
micas
iron oxides

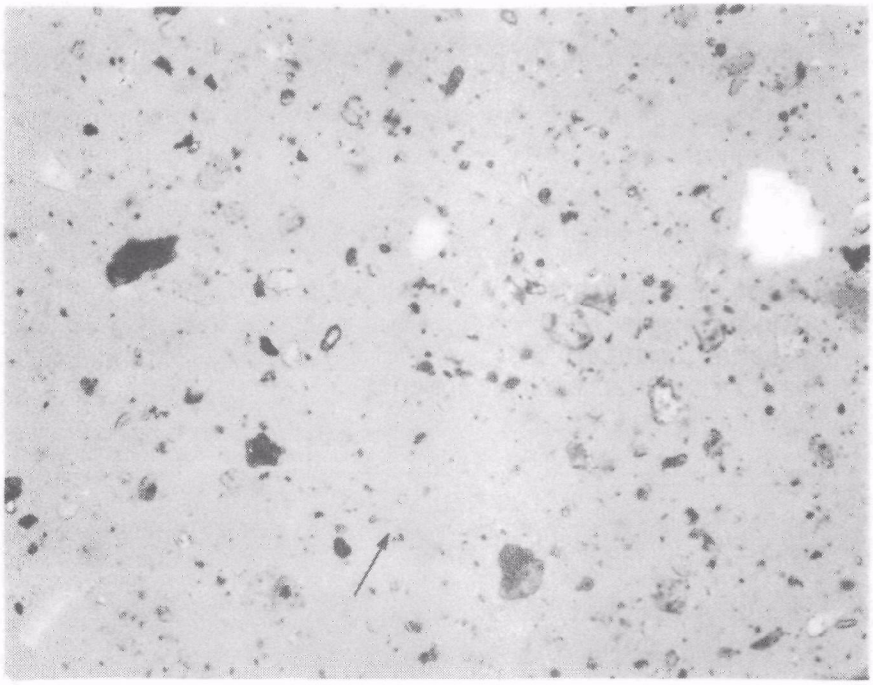
Minor Components (0.5-5% by mass)

rubber tire fragments
paper fibers
textile fibers
metal fragments
carbonates
asphalt
paint fragments
clays, humus
plaster, mortar
partial combustion fragments

Trace Components (<0.5% by mass)

chrysotile asbestos
amphibole asbestos
fiberglass
vehicle exhaust
grinding abrasives
plant parts
insect parts
wood fibers
flyash spheres

WIPE SAMPLE OF RESERVOIR DOOR AFTER
DUMP AND DECONTAMINATION



GENERAL DESCRIPTION OF X-RAY DIFFRACTION TECHNIQUE AND INSTRUMENT SPECIFICATIONS

The basic process utilized in x-ray diffraction is the interaction or interference of any crystalline structure on a focused beam of x-rays. The interference results in a splitting of the incident beam into multiple parts with varying intensity. The direction and intensity of the individual components provide a unique signiture or spectrum which can be used to identify the crystal. Generally, only one or a few compounds can be simultaneously analyzed since the patterns can be individually complex. If more than one species of a crystal is present, a superimposition of complex spectra can occur which complicates the analysis.

The features which make x-ray diffraction analysis useful include the following:

- The technique is one of the very few which provide structure, i.e., molecular information, rather than merely elemental content.
- The technique is broadly applicable--the unique diffraction signatures for over 25,000 organic and inorganic compounds have been catalogued for use in manual or computerized search files.
- The technique is non-destructive--samples which must be preserved or examined by other techniques are not destroyed.
- Sample preparation is minimal--typically, a thin layer sample may be examined directly.

The general level of the detectability for chrysotile (serpentine asbestos), a mineral of interest found in dust for which x-ray diffraction is an attractive analytical technique, is about 10 μg.

The probable analysis procedure for chrysotile and other major minerals would involve the following steps:

1) Collect the sample. Mount each clearly different material in a suitable holder.
2) Make a preliminary 2θ scan of the raw, as-collected material over a wide angular range (5° to 75°) to obtain qualitative estimates of composition, analytical interferences, and interference-free regions for use as an internal standard.
3) Add an internal standard, if necessary (e.g., CaF_2 is commonly used if there are no interferences), and mix (using ultrasonic agitation) with the sample using a wetting agent. Dry.
4) Remount specimen with internal reference standard.

5) Measure peak areas of interest (e.g., at 4.26 A for α-quartz, 405 A cristobalite, and 3.15 A for calcium fluoride).

6) Convert to absolute mass units using the internal standard.

MAJOR SPECIFICATIONS FOR THE RIGAKU 12 KW HIGH BRILLIANCE ROTATING ANODE DIFFRACTOMETER AND ASSOCIATED EQUIPMENT

Hardware Specifications

Generator Power	12 kilowatt x-ray tube with rotating copper anode.
Source Dimensions	Source dimensions of 0.5 x 10 mm on the anode gives 0.05 mm x 10 mm line source; can be modified to give 0.1 x 1 mm on the anode for 0.1 x 0.1 mm effective spot.
Sample Holders	Automatic 43 sample changer accepting power, plate, or paper filter samples. (Filter holder also interchanges into x-ray fluorescence spectrometer.)
Goniometer	Vertical wide-angle goniometer (185 mm radius) with complete computer control of data acquisition in either step or continuous mode.
Goniometer Scanning Speed	11 programmable scanning speeds of 32, 16, 8, 4, 2, 1, 1/2, 1/4, 1/8, 1/6, 1/32°/min.
Goniometer step size (2θ)	8 programmable step sizes (2θ) or (0.001°, 0.002°, 0.1°) x (1, 2, 5).
Goniometer Range (2θ)	Programmable step sizes (2θ) is -5° to +130° (2θ).
Monochromator	A curved graphite monochromator with 22.4 cm radius is available to isolate the copper K alpha and enhance the signal to noise ratio.
Data Computer System	Digital Equipment Corporation 11/03 computer with 32 k memory, LA-36 terminal/printer, RX02 dual floppy mass storage, and LA-180 line printer. The operating system is RT-11 CLASS (RT-11 Fortran in preparation).

Major Software Specifications

Diffractometer Software	Step Scan. Step scan through specified angular range with linear background correction based on endpoint values.

Printout gives 2θ, gross counts, net-counts, and background.

Continuous Scan. Continuous scan through specified angular range. Printout gives 2θ and gives counts in successive time intervals.

Search. Continuous scan through specified angular range followed by peak detection and tabulation of 25 most intense peaks. Normalizes, sorts, and prints d-spacing for most intense lines.

APPENDIX C

PERSONAL, AREA, AND HIGH-VOLUME SAMPLE ANALYSIS PROCEDURES

MILLIPORE: RECOMMENDED PRACTICE

Procedure for rendering MF-Millipore (mixed esters of cellulose) and Celotate (cellulose acetate) membrane filters transparent.

Scope

This procedure provides a chemical clearing technique that yields a transparent membrane permanently affixed to a glass slide and because of the nature of the clearing procedure, the contamination is also permanently affixed to the membrane resulting in a permanent sample.

Outline of Method

Contaminants must be collected on a MF-Millipore (white or black plain) or Celotate membrane disc where vacuum has been used to impinge the particles upon the surface of the filter. The filter disc is rendered transparent by dissolution, thus, the particles can be observed using transmitted light microscopy.

Apparatus

- Glass slides 5.1 cm x 7.6 cm (for 37 and 47 mm filters)
  Millipore Catalog # XX10 076 15
- Filter forceps, stainless, smooth-tip
  Millipore Catalog # XX62 000 06
- Eyedroppers with rubber bulbs
- Watchglass (diameter greater than 47 mm)
- Glass syringe (50-100 ml)
- Micro-syringe, Luer inlet, 25 mm
  Millipore Catalog # XX30 025 00
- Fluoropore membrane filters (pore size 0.2 µm)
  Millipore Catalog # FGLP 025 00
- Large diameter petri dishes

Reagents

- Clearing Solution A: 33 ml Hexane, Technical Grade
  33 ml 1,2-Dichloroethane, Technical Grade
  33 ml 1,4-Dioxane, Technical Grade
- Clearing Solution B: Acetone, Technical Grade

Filter Clearing Procedure

1) Filter Clearing Solution A using FGLP (0.2 μm pore size) filter into pre-cleaned container.

2) Using an eyedropper, freshly rinsed with a filter solvent (Freon® TF is recommended), dispense sufficient Clearing Solution A to thoroughly wet a cleaned 5.1 cm x 7.6 cm microscope slide.

3) Carefully roll the dry test filter particle side up, onto the pre-wetted glass slide. (Caution: Do not release membrane on this slide.) Immediately roll the wet filter onto a clean, dry glass slide and cover the glass petri dish.

4) After 30 seconds, remove the glass petri dish and invert the sample over a watch glass half filled with acetone. Allow the sample to become completely transparent (2 to 5 minutes exposure time to the acetone vapors).

5) Remove the sample from the watch glass and place on a level surface, covering it with the petri dish.

6) Allow the filter to dry 2 to 5 minutes at room temperature. Filter is now ready for analysis.

ASBESTOS ANALYSIS BY ELECTRON MICROSCOPY (EM)

Selected filter samples of the work area, upwind ambient air, and downwind ambient air were analyzed by electron microscopy to assess and/or verify the asbestos concentration. A JEOL 100C transmission, scanning electron microscope (EM) with chemical elemental analytical capability (energy dispersive x-ray spectrometer) was used for the fiber counting and identification. This analytical EM provides electron diffraction analysis and x-ray elemental analysis in addition to the observation and photographing of micro-images.

The coded filter samples were examined for asbestos concentration in accordance with the EPA's provisional methodology (ref. Samudra, et al., EPA 600/2-77-178 revised June 1978) and outlined below.

Sample Preparation

A portion of the sample collected on Nuclepore filter was cut and mounted on a clean glass slide. The mounted membrane section was coated

with a carbon film (∿0.40 nm in thickness) in a JEOL JEE-4C vacuum evaporator. Samples collected on Millipore filters did not require a carbon film coating.

A modified Jaffe Wick Washer was used to dissolve the filter membrane. In a Class 100 clean bench, a small section of filter membrane (∿3 mm diameter) was placed on a 200 mesh carbon-coated copper electron microscope grid. The EM grid and filter membrane pane was placed on a 200 mesh stainless steel screen which was on a stack of filter paper in a glass petri dish. Enough solvent was added to the petri dish to soak the filter paper stack and thus enable the wicking action to gently dissolve the filter membrane and leave the particles on the carbon-coated substrate of the EM grid.

Chloroform was used for dissolving the Nuclepore membrane and acetone was used for Millipore filters. The petri dish was kept covered for approximately 24-48 hours, except for periodic addition of solvent. After the specified wetting period, the stainless steel mesh plus grid was placed on a clean filter paper to allow the solvent to evaporate. The grid was then placed in a covered grid box for EM analysis.

Analytical Method

The prepared grid was examined at low magnification (250X and 1000X) for film integrity, extraneous particle concentration, and uniformity of deposition. A grid opening was selected at random for critical examination at an instrument magnification of 20,000X. The grid opening was scanned by a back and forth traverse and each fiber (defined as a particulate with a minimum of 3:1 length to width aspect ratio and with relatively parallel sides) was counted, the width and length measured, and a selected area electron diffraction (SAED) pattern observed, if possible. Since observation of morphology, measurements, and SAED identification were conducted at 0° tilt angle, additional SAED analyses were conducted at a 40° tilt angle for selected fibers. A 40° tilt angle facilitated x-ray analysis of the fiber by the energy dispersive spectrometer for elemental identification. Photographs were taken of selected fibers and their SAED pattern at 0° and 40° tilt angles. Their corresponding x-ray spectra were also photographed.

Approximately 100 fibers were to be counted or a minimum of ten (10) grid openings (approximately 3000 fields) were to be examined.

APPENDIX D

FIBROUS AEROSOL MONITOR DESCRIPTION AND OPERATION

PRINCIPLE OF OPERATION

Aerosol particles are sampled at 2.0 lpm through an inverted U-duct which prevents the direct access of large dust particles into the flow-direction tube. The aerosol then enters a horizontal tube in which a laminar profile is attained.

Fibers are induced to rotate rapidly by application of a rotating high-intensity electric field. Fibers rotating along the centerline of the tube are simultaneously illuminated by a continuous HeNe laser. A photomultiplier tube detects light scattered perpendicular to the axis of illumination. Maximum intensity of light scattered from fibers occurs in the plane perpendicular to the fiber axis, which contains the axis of illumination. The frequency of light scattering pulses produced by the fibers and detected by the PMT is thus determined by the frequency of the rotating field. Synchronous detection then permits enhanced discrimination of light pulses from fibers versus light pulses from nonfibrous aerosols. Fiber length discrimination is achieved by pulse shape and amplitude discrimination.

Particle pulses which meet the selection criteria necessary to identify them as fibers greater than 5 μm long are counted. At the end of the operator preselected sampling period, fiber counts are automatically converted into fiber concentration and displayed.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-600/2-80-088		

4. TITLE AND SUBTITLE	5. REPORT DATE
Evaluation of a Commercial Vacuum System for the Removal of Asbestos	May 1980
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
R. W. Welker, D. F. Finn, J. D. Stockham, and R. P. Hancock	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
IIT Research Institute 10 West 35th Street Chicago, Illinois 60616	C1Y-L1B
	11. CONTRACT/GRANT NO.
	68-02-2617, Task 10
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
EPA, Office of Research and Development Industrial Environmental Research Laboratory Research Triangle Park, NC 27711	Task Final; 10-12/79
	14. SPONSORING AGENCY CODE
	EPA/600/13

15. SUPPLEMENTARY NOTES IERL-RTP project officer is David C. Sanchez, Mail Drop 62, 919/541-2547.

16. ABSTRACT The report gives results of a brief field study that included measurement of personal, area, and environmental asbestos exposures resulting from wet and dry asbestos removal using a commercial vacuum system. Personal and area (indoor) asbestos concentrations during dry removal were less than 1 fiber/cu cm, as measured by NIOSH P and CAM 239 when the vacuum system was used. Asbestos released to the environment from the vacuum system's three-stage exhaust filter was negligible. Asbestos was released from the operator's protective garments when he exited the work area to service the vacuum system. Sources of asbestos fiber release associated with vacuum system operation were identified; these occurred during operation, disassembly, and asbestos disposal. Following vacuum shutdown, liquid drained from the collection reservoir due to inadequate door seals. During vacuum hose disassembly, bulk losses of asbestos-containing materials occurred. During disposal, the exterior of the vacuum truck became contaminated as the reservoir was emptied. Additional dry removal testing is required.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Pollution Control	13B
Asbestos	Stationary Sources	11E
Vacuum Cleaners		13G
Vacuum Filters		13K
Vacuum Filtration		07A

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
Release to Public	Unclassified	79
	20. SECURITY CLASS *(This page)*	22. PRICE
	Unclassified	

EPA Form 2220-1 (9-73)