United States
Environmental Protection
Agency

Water Engineering
Research Laboratory
Cincinnati OH 45268

Research and Development

EPA/600/S2-86/070 Jan. 1987

EPA

Project Summary

Assessment of Assay Methods for Evaluating Asbestos Abatement Technology at the Corvallis Environmental Research Laboratory

Mark A. Karaffa, Robert S. Amick, Ann Crone, and Charles Zimmer

Two analytical methods and two sampling techniques were evaluated for their effectiveness in a project to remove air-entrainable asbestos from the Corvallis Environmental Research Laboratory in Corvallis, Oregon. The two analytical methods were phase contrast microscopy (PCM) and transmission electron microscopy (TEM). The sampling techniques included a static (nonaggressive) method and an aggressive one using a blower.

Air sampling was conducted at an EPA office building that had undergone an amosite asbestos abatement program. The aggressive sampling technique revealed that air-entrainable asbestos remained in work areas after completion of abatement actions. Results also confirm that under similar sampling conditions, TEM analysis detects more fibers than PCM because of the former's better resolving capability. Because PCM does not discriminate between asbestos and other fibers and cannot resolve fibers thinner than about 0.2 μm, this method may not accurately reflect the true hazard potential.

TEM coupled with aggressive sampling should be recommended as the analytical method of choice for final post-abatement clearance testing.

This Project Summary was developed by EPA's Water Engineering Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Background

The Technical Assistance Program of the Office of Pesticides and Toxic Substances of the U.S. Environmental Protection Agency (EPA) provides guidance and information on the identification of asbestos-containing materials in buildings and on the correction of potential asbestos hazards. Four EPA Guidance Documents contain much of the existing technical information about asbestos in nonindustrial settings.[1-4] These documents describe how to establish an asbestos identification and control program, provide background information and direction to school officials and building owners on exposure assessment, and give instruction on how to develop and implement an asbestos abatement program. The most recent asbestos guidance from EPA not only emphasizes recent experience and new information on asbestos control but also introduces and discusses criteria for developing an appropriate asbestos control plan.

Considerable scientific uncertainty still surrounds the effectiveness of specific abatement actions in reducing the risk of exposure to airborne asbestos. One critical concern among those responsible for asbestos abatement is how clean the contractor leaves a building (or building area) after removing the asbestos material or after completing work that could have disturbed an asbestos-containing material (e.g., encapsulation, enclosure, or special maintenance operations). The two criteria recommended by the EPA guidance (1983)[3] that was in effect at the outset of this study were visual inspection of the worksite and air monitoring after completion of the project. Visual inspection should detect incomplete removal, damage caused by abatement activity, and (most important) the presence of debris or dust left by inadequate cleanup of the work area. Air monitoring by the membrane filter collection technique and phase-contrast microscopic (PCM) analysis are recommended to supplement the visual inspection and to determine whether elevated levels of airborne fibers generated during the removal process have been sufficiently reduced. This currently recommended optical microscopic technique is one of two methods specified by the National Institute for Occupational Safety and Health (NIOSH) to determine airborne fiber concentrations; it is used by the Occupational Safety and Health Administration (OSHA) to measure total airborne fibers in occupational environments.

The EPA-recommended air-monitoring methodology for determining abatement completion (NIOSH Method No. P&CAM 239) was as follows:

> Air sampling should begin after the project has been completed and all surfaces in the abatement site have been cleaned, preferably within 48 hours after abatement work is finished. A minimum of three air monitors per worksite and at least one per room is recommended. Air is drawn through a membrane filter for about 8 hours at a flow rate of approximately 2 L/min. A total air volume of approximately 1,000 liters collected at the specified flow rate should be sampled. After the sampling, a section of the filter is mounted on a microscope slide and treated to form a transparent, optically homogeneous gel. The fibers are sized and counted by using a phase-contrast microscope at 400 to 450X magnification. For counting purposes, a fiber is defined as a particle with a physical dimension longer than 5 micrometers and a length-to-diameter ratio of 3 to 1 or greater.[3]

This method is intended to give an index of the airborne concentration of fibers of specified dimensions in an atmosphere known or suspected to contain asbestos; it is not designed to count fibers less than 5 μm long or to differentiate asbestos fibers from other fibrous particulates.

The most significant limitation of the PCM method compared with transmission electron microscopy (TEM) and scanning electron microscopy (SEM) is that PCM is limited in the detection of fine particles (i.e., those with submicron diameters or lengths less than 5 μm) that may be toxicologically significant. For example, in glove-box tests of simulated industrial mechanical operations on asbestos-containing products (drilling, sawing, and sanding), the PCM method counted fewer than 1 percent of the fibers counted by TEM.[5] Although conditions of this glove box study were obviously different from asbestos abatement activities, some concern existed about the relative merits and capabilities of the different analytical methods used to determine representative fiber concentrations. Another study estimated that small asbestos fibers (i.e., fibers less than 0.2-μm wide and 5-μm long that are not detected by the PCM method) were present at 50 to 100 times the concentration of the larger, optically visible fibers.[6]

Study Objective

The objective of this research project was to identify and quantify the airborne amosite asbestos fibers present in building atmospheres after an asbestos remedial activity was completed and the building was reoccupied. The project focused on the adequacy of EPA's previously recommended PCM method of analysis and static sample collection technique. The PCM method was compared with TEM methods, and the feasibility of an alternative aggressive sampling technique was investigated. The results of this study established the advantages and limitations of applying PCM and TEM analytical methods, both separately and in conjunction with an aggressive sampling technique, to the evaluation of air quality following asbestos abatement.

Reliable methods of air sampling and analysis permit the use of monitoring results to be included in evaluating the efficacy of asbestos abatement methods and in developing better technical guidance for abatement contractors, building owners, and other parties directly responsible for remedial asbestos programs. Active or recently completed abatement sites were selected for monitoring because they provided an excellent opportunity to collect real-world data, and because the monitoring tasks could be arranged with minimum lead time and coordination.

The conditions in a work area while the final air samples are collected can greatly influence the results of a postabatement assessment. After an abatement action, the air is usually sampled under static conditions—that is while the area is sealed off, before ventilation is restored, and after at least a 24-hour settling period following the final wet cleaning. Consequently, this monitoring technique may fail to detect residual fibers that have settled on horizontal surfaces or that were missed by the cleaning.

Residual asbestos fibers constitute a potential exposure hazard because they could be reentrained later, when the air in the area is agitated by personnel traffic, air flow from ventilation systems, and custodial activities. Thus, for more accurate characterization of postabatement fiber concentrations, the work area should experience appreciable air movement to simulate actual use conditions during air monitoring.

The introduction of air turbulence into the work area during the collection of stationary air samples is termed "aggressive sampling." This method entails the creation of air movement by the use of blowers, fans, brooms, or compressed air streams to entrain any particulate matter that may be present. The advantages of the aggressive sampling technique over the static (or nonaggressive) sampling are that the former reflects worst-case conditions and that the testing requires a relatively short period. The disadvantages are that this technique is not readily standardized or reproducible, nor does it reflect normal exposure levels to occupants. As with the static sampling method, no criteria have been established to define an acceptable or safe level of fibers in a nonoccupational environment. The research on fiber concentration levels using the PCM and TEM methods is continuing so that the before-, during-, and after-abatement criteria can be developed within the next 2 years.

Project Description

Site Selection

Air monitoring was conducted at two selected sites from which friable asbestos building materials had been removed: Site 1, Columbus East High School, Columbus, Indiana; and Site 2, the EPA Environmental Research Laboratory in Corvallis, Oregon.

This report describes only the results of the air monitoring survey conducted at Site 2. The monitoring data from Site 1 and the significance of these data are the subject of a separate report (Assessment of Assay Methods for Evaluating Asbestos Abatement Technology: Columbus East High School, Columbus, Indiana, EPA/600/2-86/053). These selected sites met the following criteria:

- The abatement plan involved the removal of friable, spray-applied, asbestos-containing material.
- The contractors carried out the work area preparation, removal, and decontamination in accordance with EPA-recommended specifications and requirements.[1]
- Multiple work areas containing homogeneous asbestos material were available for monitoring.
- The building owner and abatement contractor agreed to cooperate with EPA and to provide access to selected areas of the building.

Building Description

The Corvallis Environmental Research Laboratory (CERL) is housed in a two-story, reinforced-concrete structure built in 1966. The building contains a total gross area of approximately 465 m^2 (45,000 ft^2). A single-pass heating, ventilating, and air conditioning (HVAC) system supplies the occupied building areas with 100 percent outside air. The outside air enters through intakes on the roof, is tempered by heating or chilling coils, and is distributed by a closed-duct system to ceiling-mounted diffusers in all rooms and laboratories. Air flows through louvers in the bottom of interior doors and passes into the hallways (which serve as air plenums to the outside), or it is exhausted through laboratory fume hoods.

Asbestos-containing Materials

Asbestos-containing insulation had been spray-applied and tamped on to the concrete ceiling (beams and deck) of four rooms (Rooms 146, 155, 157, and 159) and the penthouse in the main CERL facility and on beams in the boiler room (Room 163). The large air intakes located under the building, which supply ventilating air to the boiler and chiller room, were also lined with asbestos. The insulation material on the ceilings of Rooms 155, 157, and 159 and in the air ducts had been removed in 1984 during a controlled abatement program. The asbestos-containing insulation in Room 146 (deionizer room), the boiler room, and the penthouse was still in place.

Samples collected from Room 146 and the penthouse were analyzed by polarized light microscopy and dispersion staining. The results indicated 80 percent amosite asbestos in each of the two bulk samples analyzed. At the time of the survey, the remaining insulation material was characterized as highly friable, loosely packed, and showing some signs of deterioration (loose, hanging pieces were visible).

Methods and Procedures

The sampling procedures and analytical methods are outlined briefly here. They are described fully in the full report and in the project summary for Site 1 (Assessment of Assay Methods for Evaluating Asbestos Abatement Technology: Columbus East High School, Columbus, Indiana, EPA/600/2-86/053).

Abatement Program

The asbestos-containing insulation in Rooms 155, 157, and 159 and in the air intakes was removed between May 21 and July 2, 1984. The abatement plan and schedule prepared by the contractor and submitted to CERL were reviewed and approved by EPA before work was begun. The work plan was in accordance with the then-current EPA guidelines and EPA and OSHA asbestos regulations for asbestos removal and decontamination. On completion of the abatement effort, CERL personnel surveyed the work performed by the abatement contractor, performed additional cleaning of the work areas, and made arrangements for the painting of all ceiling surfaces from which the asbestos insulation had been removed.

According to CERL accounts, each work area was isolated from the rest of the building by temporary barriers. Ventilation ducts and openings to the outside or to adjacent rooms were sealed. Walls and floors were covered with plastic sheeting. Fully protected abatement workers first wetted the insulation with amended water and then scraped it off. The asbestos-containing debris was placed in sealable plastic bags and disposed of at a local EPA-approved sanitary landfill. Each work area was cleaned three times, and a settling period of 24 hours was allowed between cleanings. The ceiling surfaces were painted to bond any residual fibers not removed by the scraping, brushing, and wet-cleaning.

Monitoring Approach

The sampling strategy for this study was to collect representative samples for PCM and TEM analysis from (1) rooms where friable asbestos-containing insulation had been removed, (2) rooms that were never treated with asbestos-containing materials, and (3) outdoors. Samples for subsequent PCM and TEM analyses were collected from two or three representative locations in each room approximately 6 weeks after completion of all abatement activities. Two of the three monitored rooms from which asbestos insulation had been removed had been reoccupied. (Room 159 was vacant at the time of the survey.) Both static and aggressive sampling techniques were used in each room. The static sampling was conducted first during regular working hours while the facility was occupied. The aggressive sampling was conducted on a Saturday when the sampling areas were unoccupied. Filter holders containing either 0.8-μm Millipore* mixed-cellulose ester (PCM) or 0.4-μm Nuclepore polycarbonate filters (TEM) were positioned 1.3 to 1.5 m (4 to 5 ft) above the floor at arbitrary locations. Battery-powered sampling pumps were used to draw air through the filters. The constant-flow pumps were calibrated to 2.5 L/min and were operated for 8 hour per test. Samples were collected concurrently at outdoor locations during each monitoring period.

On completion of each monitoring survey, samples were submitted to the appropriate laboratory for preparation and analysis. The Nuclepore filters were carbon-coated before they were transported to the laboratory for TEM analysis.

Overview of Air Sampling Strategy

Samples designated for PCM and TEM analysis were collected with both

*Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

static and aggressive methods in six different rooms. Samples were also collected in the surrounding environment outside the building. The areas sampled included three rooms that had been treated previously with asbestos insulation and have since been abated and rooms that have never been treated with asbestos. Representative samples for PCM and TEM analysis were collected approximately 6 weeks after all abatement activities had been completed. Outdoor air samples were collected concurrently with indoor samples on the roof of the building or at ground level in the open field west of the main building.

Side-by-side samples (one for PCM, one for TEM) were collected in each room under static and aggressive sampling conditions. The number of samples per room was not specified by the study design, but three of each type of sample were collected within each room. The static sampling was performed first during regular working hours with the building occupied and the HVAC system operating. The aggressive sampling was performed on a Saturday while the sampling areas were unoccupied and the HVAC system was not operating. Placement of the sampling equipment within each work area was the same during both static and aggressive sampling.

Results

Air Monitoring Results

Table 1 presents a detailed listing of the results of PCM and TEM analysis of samples collected under aggressive and static sampling conditions after abatement. With one exception, all concentrations of asbestos fibers and total structures under aggressive sampling conditions were higher than the corresponding measurements made under static sampling conditions. The exception involved two samples with differences that were considered negligible because they were below the limit of reliable quantitation for the analytical method.

Comparisons of PCM and TEM analyses of samples collected under static and aggressive sampling conditions are presented graphically in Figure 1, which is based on the data results presented in Table 1.

Statistical Comparisons

Statistical Method of Analysis

The Mann-Whitney test was used to determine whether the observed differences in analytical methods and sampling conditions were statistically significant.[7] Use of the Mann-Whitney test required no prior assumption regarding the nature of the underlying probability distribution function of measurements of asbestos fiber concentrations.

Analytical Methods

Tables 2 and 3 compare the geometric averages of fiber concentrations determined by PCM and TEM analyses under static and aggressive sampling conditions. Table 4 summarizes these results. Based on the application of the Mann-Whitney test and the assumption that the fiber/volume concentrations are comparable, the difference between PCM and TEM results is statistically significant (i.e., $p < 0.03$) for samples collected outdoors and indoors in abated areas under static conditions. The difference between PCM and TEM results from indoor sampling of nonasbestos areas was also statistically significant ($p < 0.10$) under static sampling conditions; however, this conclusion was based on a small sample size ($n = 3$). The ratios of TEM/PCM concentrations for static sampling were 3.0 for ambient samples, 3.3 for indoor abated-area samples, and 7.5 for indoor nonasbestos-area samples. The difference between PCM and TEM results is not statistically significant (i.e., $p > 0.005$) for indoor samples from both abated and nonasbestos areas under aggressive sampling conditions. For aggressive sampling in abated areas, the ratio of TEM/PCM was 1.8. For aggressive sampling in nonasbestos areas, the ratio of TEM/PCM was 1.9.

Sampling Conditions

Table 2 also compares static and aggressive sampling conditions for PCM and TEM analyses in both abated and nonasbestos areas. The difference between the geometric average fiber concentrations under static and aggressive sampling conditions was statistically significant (i.e., $p < 0.002$) for both PCM and TEM in abated areas. For PCM analyses, the ratio of aggressive to static fiber concentrations was 7.0; for TEM analyses, the ratio was 3.7. For sampling conducted in nonasbestos areas, the difference between the geometric average fiber concentrations under static and aggressive sampling conditions was statistically significant for PCM analyses (i.e., $p < 0.002$) but not statistically significant for TEM analyses (i.e., $p > 0.04$). For nonasbestos areas, the ratio of aggressive to static fiber concentrations for PCM analyses was 8.0; for TEM analyses, the ratio was 2.0.

Comparison of Indoor Abated Samples and Ambient Samples

Also included in Tables 2, 3, and 4 are the PCM and TEM analyses of samples collected in the ambient atmosphere and in indoor abated areas.

The difference between asbestos concentrations measured under aggressive sampling conditions in indoor abated areas and those measured in ambient samples was statistically significant ($p < 0.02$). The ratio of asbestos concentrations measured by TEM under aggressive sampling conditions in indoor abated areas to ambient TEM concentrations was 6.2.

Comparison of Indoor Nonasbestos Samples and Ambient Samples

For samples analyzed by PCM, the geometric mean asbestos concentration for indoor samples collected statically in nonasbestos areas was below the detection limit of the analytical method, as were the ambient PCM samples. Consequently, no meaningful comparisons can be made. For PCM samples collected aggressively, the geometric mean concentration was 0.016×10^6 fibers/m^3 compared with lower than 0.002×10^6 fibers/m^3 for ambient samples, a ratio of 16.0 (if a concentration of 0.001×10^6 fibers/m^3 for ambient samples is assumed). This observed difference was statistically significant ($p > 0.01$). One nonasbestos area (Room 152, the instrumentation laboratory) was extremely dusty, so the aggressive sampling procedure entrained large quantities of house dust that had accumulated on shelf and cabinet tops over many years. This fact accounted for the relatively high PCM fiber counts.

For TEM samples collected inside nonasbestos areas under static conditions, the geometric mean asbestos fiber concentration was 0.015×10^6 fibers/m^3 compared with 0.006×10^6 fibers/m^3 for TEM ambient samples, a ratio of 2.5. This observed difference

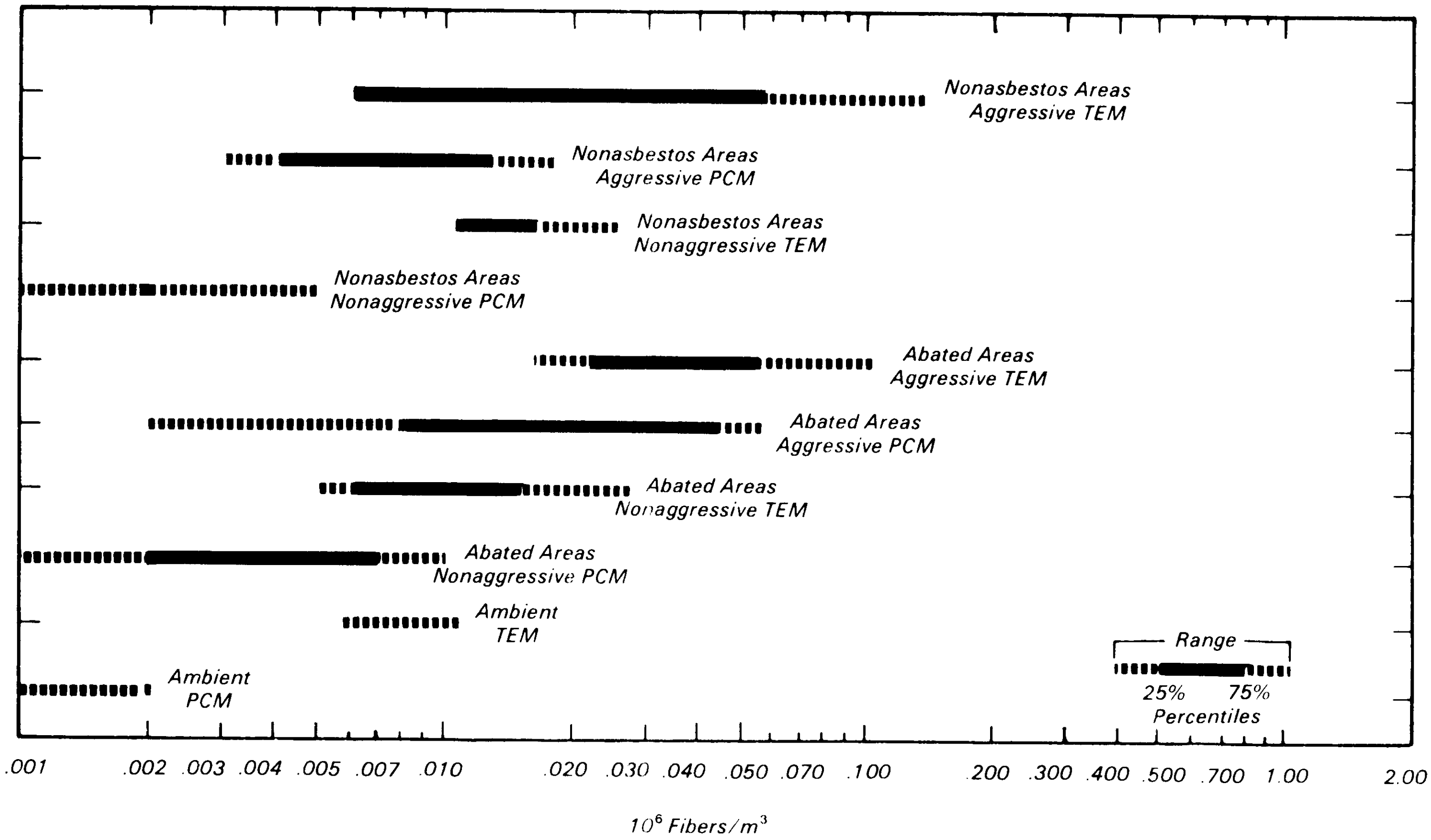

Figure 1. Comparison of airborne fiber concentrations for PCM and TEM under static (nonaggressive) and aggressive conditions.

was not statistically significant (i.e., $p > 0.10$), nor was it significant under aggressive sampling conditions (i.e., $p > 0.10$), where the ratio was 5.0. Because the comparisons of fiber concentrations for TEM samples in nonasbestos areas and ambient samples are based on very small sample sizes ($n = 3$ and $n = 2$, respectively), the observed differences are not statistically significant at a probability level of >0.05.

Comparison of Samples From Indoor Abated and Nonasbestos Areas

For all PCM samples (aggressive and static), the observed differences in fiber concentrations in indoor abated and nonasbestos areas were not statistically significant ($p > 0.08$ for static conditions and $p > 0.05$ for aggressive conditions). For PCM samples collected under static conditions, the ratio of fiber concentrations in abated areas to nonasbestos areas was 3.0 (a concentration of 0.001×10^6 fibers/m^3). For PCM samples collected under aggressive conditions, the ratio was 1.3.

For all samples analyzed by TEM, the difference between abated and nonasbestos areas was also not statistically significant ($p > 0.10$ for static conditions). For TEM samples collected under static conditions, the ratio of asbestos fiber concentrations in abated to nonasbestos areas was 0.7. Under aggressive conditions, this ratio was 1.3 for asbestos structures, and 1.2 for asbestos fiber concentrations.

Conclusions

The following conclusions resulted from this study:

1. The aggressive sampling technique used in this problem-definition study revealed that air-entrainable asbestos fibers were present in previously abated areas. TEM analysis of aggressive samples from building areas that were never treated with asbestos insulation also revealed detectable levels of asbestos fibers.
2. Regardless of the analytical method used, the fiber concentrations measured under aggressive sampling conditions were significantly higher than those measured under static conditions. The ratios of aggressive to static PCM fiber concentrations in abated and nonasbestos areas were 7.0 and 8.0, respectively. By TEM analysis, these ratios were 3.7 and 2.0.
3. The study results clearly demonstrate that under similar sampling conditions, TEM analysis identifies more fibers than PCM. The ratio of TEM/PCM fiber concentrations for static sampling was 3.0 for ambient samples, 7.5 for indoor nonasbestos areas, and 3.3 for indoor abated samples. The ratios for aggressive sampling in indoor areas were about 2 to 1.
4. Asbestos concentrations determined by TEM in abated areas with

Table 1. *Results of PCM and TEM Analysis*

Sampling Location	Nonaggressive					Aggressive				
	PCM		TEM			PCM		TEM		
	Sample Number	10^6 Fibers/m^3	Sample Number	10^6 Asbestos* Fibers/m^3	10^6 Asbestos† Structures/m^3	Sample Number	10^6 Fibers/m^3	Sample Number	10^6 Asbestos* Fibers/m^3	10^6 Asbestos† Structures/m^3
Abated areas										
Room 155	COR-02	0.007‡	COR-N-02	0.006	0.006	COR-27	0.002‡	COR-N-27	0.017	0.022
	COR-03	0.002‡	COR-N-03	0.016	0.016	COR-25	0.01‡	COR-N-25	0.041	0.041
	COR-01	<0.002#	COR-N-01	0.010	0.010	COR-26	0.007‡	COR-N-26	0.024	0.024
Room 157	COR-04	0.008‡	COR-N-04	0.018	0.028	COR-28	0.032	COR-N-28	0.041	0.041
	COR-05	0.006‡	COR-N-05	0.017	0.017	COR-29	0.048	COR-N-29	0.104	0.104
	COR-06	0.01‡	COR-N-06	0.012	0.012	COR-30	0.035	COR-N-30	0.059	0.065
Room 159	COR-08	<0.002#	COR-N-08	<0.005§	<0.005§	COR-31	0.045	COR-N-31	0.060	0.066
	COR-07	<0.002#	COR-N-07	0.006	0.006	COR-46	0.045	COR-N-46	0.025	0.025
	COR-09	0.004‡	COR-N-09	0.011	0.011	COR-34	0.057	COR-N-34	0.022	0.028
Nonasbestos areas										
Room 173	COR-13	<0.002#	COR-N-13	0.011	0.011	COR-35	0.044‡	COR-N-35	0.006	0.006
	COR-14	0.002	COR-N-14	**	**	COR-36	0.003‡	COR-N-36	**	**
Room 152	COR-10	<0.002#	COR-N-10	0.012	0.012	COR-37	0.17	COR-N-37	0.135	0.149
	COR-16	0.002	COR-N-16	**	**	COR-38	0.18	COR-N-38	**	**
Room 205	COR-19	<0.002#	COR-N-19	0.024	0.024	COR-40	0.01‡	COR-N-40	0.032	0.032
	COR-11	<0.002#	COR-N-11	**	**	COR-39	0.008‡	COR-N-39	**	**
	COR-17	0.005‡	COR-N-17	**	**	COR-41	0.01‡	COR-N-41	**	**
Outdoors (ambient)										
Ground	COR-21	<0.002#	COR-N-21	<0.006§	<0.006§					
	COR-44	<0.002#	COR-N-44	**	**					
Roof	COR-43	<0.002#	COR-N-43	0.011	0.011					
	COR-18	<0.002#	COR-N-18	**	**					
	COR-42	<0.002#	COR-N-33	**	**					
Blanks	COR-45	0/100††	COR-N-60	0/20‡‡	0/20‡‡					
	COR-47	0/100††	COR-N-61	1/20##	1/20##					
	COR-48	0/100††								
	COR-49	0/100††								

*Fiber concentration based on the total number of asbestos fibers counted.
†Concentration based upon the total number of chrysotile and amphibole structures counted. These asbestos structures include asbestos fibers, asbestos matrices/debris, asbestos clusters/clumps, and asbestos bundles.
‡Less than 10 fibers in 100 fields were counted. Fiber concentration based on the actual number of fibers counted in 100 fields. Fiber concentration is below the reliable limit of quantitation (i.e., 10 fibers in 100 fields).[7]
#No fibers were detected in 100 fields. Below the detection limit (e.g., counting 0.5 fiber in 100 fields).
§Below detection limit (no fibers or structures counted in 20 grid openings).
**Sample collected but not analyzed.
††No fibers were detected in 100 fields.
‡‡No asbestos fibers or structures were detected in 20 grid openings.
##One asbestos fiber or structure was detected in 20 grid openings.

Table 2. *Comparison of Static and Aggressive Sampling Results for Postabatement Testing*

Samples Included in Comparison	Nonaggressive						Aggressive						PCM Aggressive Fibers,* $10^6/m^3$	TEM Aggressive/Static	
	PCM		TEM				PCM		TEM						
	No. of Samples	Fibers,* $10^6/m^3$	No. of Samples	Asbestos Fibers,* $10^6/m^3$	Asbestos Structures,* $10^6/m^3$	TEM PCM Fibers	No. of Samples	Fibers,* $10^6/m^3$	No. of Samples	Asbestos Fibers,* $10^6/m^3$	Asbestos Structures,* $10^6/m^3$	TEM PCM Fibers		Asbestos Fibers	Asbestos Structure
Abated areas	9	0.003	9	0.010	0.010	3.3	9	0.021	9	0.037	0.040	1.8	7.0	3.7	4.0
Nonasbestos areas	7	<0.002	3	0.015	0.015	7.5	7	0.016	3	0.030	0.031	1.9	8.0	2.0	2.1
Outdoors	5	<0.002	2	0.006	0.006	3.0	0	–	0	–	–	–	–	–	–

*All concentrations are geometric means.

aggressive sampling were significantly (6.2) times higher than ambient TEM concentrations. The TEM concentrations under aggressive conditions in the nonasbestos areas were 5 times higher than ambient TEM concentrations, but this difference was not statistically significant.

Recommendations

Although time-consuming and expensive, TEM should be recommended as the analytical method of choice for measuring airborne asbestos fiber concentrations for final clearance testing of work areas after asbestos abatement. After a standardized TEM protocol and an aggressive sampling procedure are incorporated into asbestos guidelines, a criterion should be established to define an acceptable asbestos fiber concentration in building areas after asbestos abatement. Continued research should focus on the development of a quicker, less expensive method for monitoring buildings after asbestos abatement and on more efficient abatement practices.

References

1. U.S. Environmental Protection Agency. Asbestos-Containing Materials in School Buildings: A Guidance Document, Part 1. Office of Toxic Substances, Washington, D.C. 20460. March 1979.
2. Sawyer, R.N., and D.M. Spooner. Asbestos Containing Materials in School Buildings: A Guidance Document, Part 2. Office of Toxic Substances, U.S. Environmental Protection Agency, Washington, D.C. 20460. March 1979.
3. U.S. Environmental Protection Agency. Guidance for Controlling Friable Asbestos-Containing Materials in Buildings. EPA/560/5-83-002, Office of Toxic Substances, Washington, D.C. 20460. March 1983.
4. U.S. Environmental Protection Agency. Guidance for Controlling Asbestos-Containing Materials in Buildings. EPA/560/5-85-024, Office of Toxic Substances, Washington, D.C. 20460. June 1985.
5. Falgout, D. Environmental Release of Asbestos From Commercial Product Shaping. EPA/600/2-85/044, Engineering-Science, Fairfax, Virginia. August 1985.
6. Chatfield, E.J. Measurement of Asbestos Fibre Concentrations in Ambient Atmospheres. Study No. 10, Ontario Research Foundation. 1983.
7. Mosteller, F., and R.E.K. Rourke. Sturdy Statistics: Nonparametrics and Order Statistics, Addison Wesley, Reading, Massachusetts. 1973.

The full report was submitted in fulfillment of Contract No. 68-03-3197 by PEI Associates, Inc., under the sponsorship of the U.S. Environmental Protection Agency.

Table 3. *Comparison of Sampling Results by Sample Location**

Samples Included in Comparison	*Sample Location Comparisons*		
	Indoor Abated/ Indoor Nonasbestos	*Indoor Abated/ Outdoors*	*Indoor Nonasbestos/ Outdoors*
PCM-Static	*3.0*	*3.0*	*1.0*
PCM-Aggressive	*1.3*	*3.5*	*16.0*
TEM-Static	*0.7 (0.7)†*	*1.7 (1.7)†*	*2.5 (2.5)†*
TEM-Aggressive	*1.2 (1.3)†*	*6.2 (6.7)†*	*5.0 (5.2)†*

**All quantities are ratios of the geometric mean fiber concentrations. For PCM samples, fiber concentrations include all fibers greater than 5 μm in length; for TEM samples, fiber concentrations include all asbestos fibers.*
†Ratio of geometric mean concentrations of asbestos structures.

Table 4. *Summary Comparison of PCM and TEM Analyses of Air Samples Collected During Static and Agressive Conditions**

Analytical Technique	*Outdoor (Ambient)*	*Nonasbestos Areas*		*Abated Areas*	
		Static	*Aggressive*	*Static*	*Aggressive*
PCM, fibers (>5 μm)/m³	*BDL†*	*BDL*	*BLRQ‡ (16,000)*	*BLRQ (3,000)*	*BLRQ (21,000)*
TEM, asbestos fibers/m³	*6,000§*	*15,000*	*30,000*	*10,000*	*37,000*
TEM, asbestos structures/m³	*6,000§*	*15,000*	*31,000*	*10,000*	*40,000*

**All values are geometric means.*
†BDL = Below detection limit (≅1,136 fibers/m³).
‡BLRQ = Below limit of reliable quantitation (≅22,720 fibers/m³).
§Geometric mean based on two sample values. One sample value was below the detection limit for TEM analysis (≅5,688 asbestos fibers or structures/m³).

Mark A. Karaffa, Robert S. Amick, Ann Crone, and Charles Zimmer are with PEI Associates, Inc., Cincinnati, OH 45246-0100.
***William C. Cain** is the EPA Project Officer (see below).*
The complete report, entitled "Assessment of Assay Methods for Evaluating Asbestos Abatement Technology at the Corvallis Environmental Research Laboratory," (Order No. PB 87-110 961/AS; Cost: $13.95, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
Water Engineering Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268

Official Business
Penalty for Private Use $300

EPA/600/S2-86/070