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Asbestos Control Program for Institutional Facilities[a]

By Mark D. Ryckman,[1] A. M. ASCE, DeVere W. Ryckman,[2] F. ASCE, and Jeffrey L. Peters[3]

Abstract: Asbestos-containing materials have been used in 20%-50% of the institutions in this country for ceiling, boiler and pipe insulation, acoustical treatment, and fireproofing. Medical criteria indicates that there is no limiting dose relating relationship between asbestos exposures and the various cancers it may cause that are either fatal or difficult to treat. The Environmental Protection Agency estimates that between 100 and 6,800 people may be expected to die prematurely of cancers due to non-peak asbestos exposure at the prevailing levels in schools. Total environmental health impacts may be considerably higher due to peak exposures created by maintenance, renovation, and other activities. The purpose of this treatise is to present state-of-the-art asbestos environmental health auditing procedures, corrective action program design and implementation, and liability/risk control considerations to reduce the projected environmental health impacts. Special emphasis is placed on the use of decontamination air-lock chambers, personnel protective measures, removal methodologies, medical surveillance/environmental monitoring procedures, waste packaging and disposal practices.

Background

The Environmental Protection Agency (EPA) estimates that since the beginning of this century, over 30,000,000 tons (2.7×10^{10} kg) of asbestos fibers have been used in the United States, at an average annual usage rate of 750,000 tons (6.8×10^8 kg). Two-thirds of this amount has been utilized by the construction industry for the manufacturing of insulating and fireproofing materials. The popularity of asbestos as a construction material is due to the excellent resilient properties toward heat, sound reflection, and a variety of chemicals (Table 1). However, these resilient and other physicochemical properties also make asbestos an important priority pollutant of severe pathological consequence (Fig. 1).

Over 15% of all cancer related deaths during the next 25 yr will be linked to exposure of asbestos dust. Exposure to asbestos dust increases the risk of asbestosis (a fibrotic disease of the lung whereby embedded dust fibers are surrounded by scar tissue), lung cancer, mesothelioma (a cancer of the membrane lining of the chest and abdomen), and other cancers of the gastrointestinal tract (Table 1). These diseases exhibit a characteristic 15–40 yr latency period between exposure and symptom development.

One of the principal areas of concern for exposure to asbestos is maintenance personnel and building occupants in structures where ceiling materials contain asbestos. Of special interest are primary and secondary educational institutions, where spray-on insulation materials containing asbestos were used widely in construction. In these institutions alone, the EPA estimates that 3,000,000 students, 250,000 faculty members, and 23,000 maintenance workers have been exposed to asbestos fiber containing material. It is in these facilities that individuals are exposed to asbestos fibers on a daily basis for many years. Current projections indicate that as many as 6,800 of these individuals may be expected to die prematurely of cancers at prevailing exposure levels in schools.

Primary exposure mechanisms (Fig. 2) include loss of adhesive or cohesive properties of the matrix, structural vibration, water damage, matrix impaction, and facility modification. Secondary exposure may be caused by resuspension of fiber particles due to air movements or cleaning activities, and the ability of particles to cling to the hair or clothing of individuals, and become resuspended at another time. The tendency for asbestos particles to remain suspended in the air allows them to be easily inhaled or ingested.

Government agencies such as the National Institute for Occupational Safety and Health (NIOSH) and the Occupational Safety and Health Administration (OSHA) are directing attention to the hazards of asbes-

TABLE 1.—Physicochemical/Toxicological Properties of Asbestos

Property (1)	Description (2)
	(*a*) Physicochemical
Fibrous silicate minerals	Serpentine—chrysotile Amphiboles—amosite, anthophyllite, crocidolite, tremolite, actinolite
General characteristics	Incombustible, high tensile strength, thermal and electrical insulator, high tensile strength, good chemical resistance, good acoustical properties, hydrophobic, low settling velocities
Fiber length	0.03 to 30 microns
Fiber diameter	100 to 250 Å
Morphology	Long tubular shape
	(*b*) Toxicological
Physical effects	Skin and eye irritant Asbestosis—inhibits oxygen exchange to blood in lungs
Cancer agent	Mesothelioma, lung cancer, and cancer of esophagus, stomach, colon and rectum

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[1]Vice President of Engrg., D. W. Ryckman and Assoc., Inc., St. Louis, Mo. 63141.

[2]President, D. W. Ryckman and Assoc., Inc., St. Louis, Mo. 63141.

[3]Mgr. Research and Development, D. W. Ryckman and Assoc., Inc., St. Louis, Mo. 63141.

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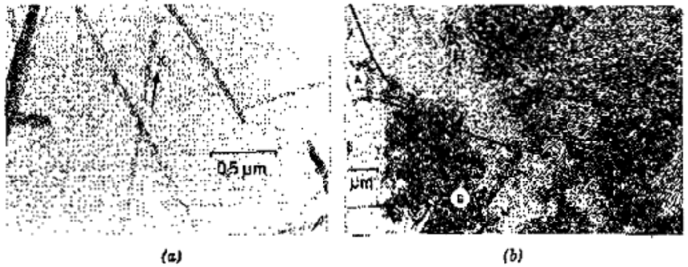
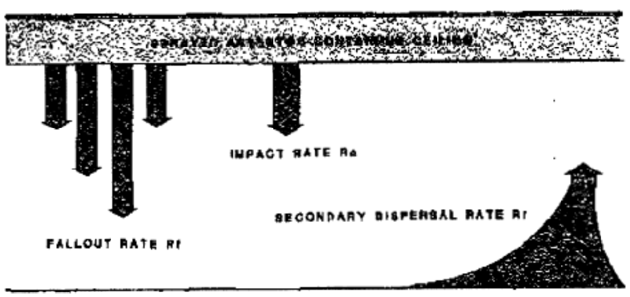


FIG. 1.—Electron Micrographs of Asbestos Fibers: (*a*) Thin Chrysotile Fibers, A, and Thicker Amosite Fibers, B, with Magnesite Filler (Nonfibrous) in Typical Insulation Material; and (*b*) High Magnification Micrograph of Chrysotile Showing Typical Tubular Morphology

tos exposure through more stringent proposed regulations. Current OSHA standards limit asbestos exposures to two fibers per cubic centimeter (2f/cc) over an 8-hr time weighted average (TWA) period, with a 15-min ceiling limit of 10f/cc. The existing standard is based on counts of fibers five microns or longer in length, using Phase Contrast Microscopy to analyze air samples collected from the breathing zone. NIOSH has proposed standards that would limit exposures to 0.1f/cc for an 8-hr TWA and a 0.5f/cc ceiling limit.

Unfortunately, current and proposed air standards do not effectively address the full scope of the problem. When asbestos-containing ceiling matrices are handled abrasively, asbestos fibers break into extremely small particles and are dispersed into the air. As can be seen in Fig. 3, 65% of all fiber particles released are smaller than five microns in length.



MODE	CAUSES	FREQUENCY	RATE
FALLOUT	AIR MOVEMENT, VIBRATION, MATRIX DETERIORATION, WATER DAMAGE	CONSTANT	LOW (Rf)
IMPACT	MAINTENANCE, ACCIDENTAL IMPACT, RENOVATION, VANDALISM	OCCASIONAL	HIGH (Re)
SECONDARY DISPERSAL	PERSONNEL MOVEMENT, CUSTODIAL SERVICE	FREQUENT	LOW TO HIGH (Rr)

FIG. 2.—Modes and Rates of Asbestos Fiber Dispersal

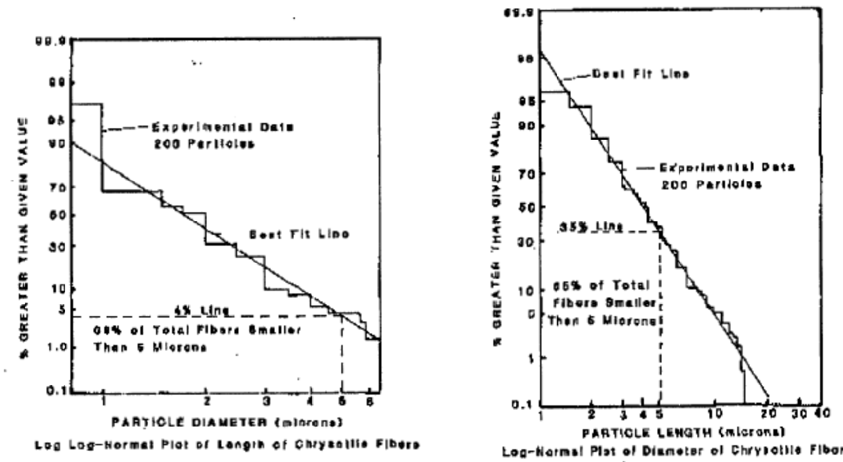


FIG. 3.—Typical Asbestos Particle Size Distribution by Diameter and Length Created during Dry Removal Operations: 65%–95% of Total Fibers Unregulated

More importantly, current research indicates that asbestos fibers may enter the lung much like a javelin, thereby making diameter the critical dimension. Fig. 3 indicates that 96% of all fibers released into the air are smaller than 5 microns in diameter. Size distribution analysis of airborne asbestos fibers (Table 2) indicate that the majority of fibers deposited in the lungs have lengths of 3.3 microns or less, with particles ranging in size from 0.01 microns to 3.3 microns being responsible for the most tissue damage to the lungs.

From the data presented in Fig. 3, it may be deduced that current air sampling methodologies for asbestos may be missing 65%–96% of the total number of airborne fibers. (The writers, in addition, are concerned about the adequacy of OSHA and NIOSH asbestos-approved respirators and their effectiveness in removing these small fibers.) To compound the problem, current medical research suggests that exposure periods for as short as one month are responsible for a significant number of reported cases of asbestosis. Consequently, the medical community has adopted a "zero risk/zero exposure" criteria for asbestos exposures in buildings.

Introduction

The purpose of this treatise is to present the state-of-the-art asbestos environmental health auditing procedures, corrective action program design and implementation, and liability/risk control considerations. The writers hope that the information contained herein will assist engineers, architects, and institution officials to better cope with implementing effective asbestos control programs.

Material pertaining to auditing procedures and program design have been developed by the writers and employed on facilities containing over 1,500,000 (139,500 m^2) of asbestos-containing matrices. Much of the ma-

TABLE 2.—Asbestos Fibers Less Than 3.3 Microns in Length are Deposited in Lungs

Length, in micrometers (1)	Disposition (2)
Over 10	Fibers are deposited in the mucous layer of the bronchi (upper respiratory tract)
5–10	Fibers are removed in the bronchi
3–5	Fibers will possibly pass deep into the lungs, but not in any appreciable quantity
0.8–3	Most fibers are deposited at the alveoli (air sacks). Although this size distribution is too small to be seen by the unaided eye, it is the size which causes injury in the lungs
0.4–0.5	Fewer fibers are deposited; 80% are exhaled; fiber behavior similar to Brownian molecular motion
Under 0.2	Electrostatic forces cause combination of these extremely fine particles and alveoli deposition is again high

terial pertaining to program implementation is reproduced with the permission of officials of the University of Maryland. This project received an "Engineering Excellence Award—Honorable Mention" from the Missouri Consulting Engineers Council in May, 1981.

Program Design

Asbestos Environmental Health Audit.—An environmental health audit is conducted to determine the extent of the problem and the viable alternatives for corrective action. An algorithm (Fig. 4) has been developed to aid in selecting the appropriate methodology for problem resolution. The algorithm was designed to aid experienced engineers in appropriately defining the concentration of asbestos, total effective area of contamination, and the physical condition of the ceiling material to determine potential modes for release or dispersal of fibers or both. From this, various corrective action alternatives such as entombment, encapsulation, and removal could be defined and evaluated.

To adequately define matrix composition with heterogeneous matrices, a minimum of one bulk sample per 5,000 sq ft (465 m^2) of effective area, or three bulk samples per sample area should be taken. A sample area is defined as a given matrix area within a building having the same properties. All bulk samples must be analyzed using Polarized Light Microscopy as presented in "Interim Method for the Determination of Asbestiform Minerals in Bulk Insulation Samples." Supplementary analysis including Polarized Light Microscopy with dispersion staining, scanning election microscopy, x-ray diffraction, and energy dispersive analysis may be necessary to obtain a correct matrix characterization.

For matrices found to contain greater than 1% asbestos by weight, a confirming audit and pilot program should be conducted to ensure correct matrix characterization and selection of the appropriate corrective

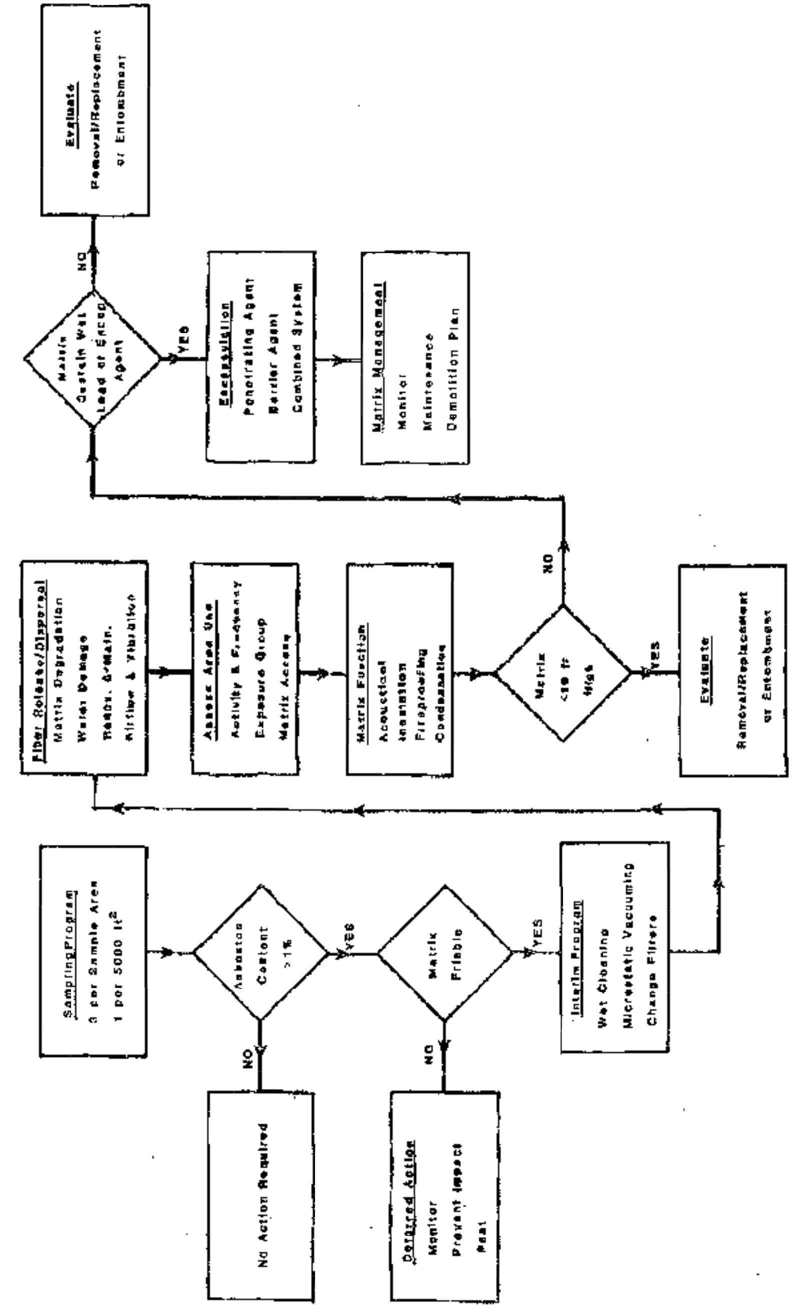


FIG. 4.—Environmental Health Asbestos Audit Algorithm for Selecting Corrective Action Methodology

action methodology. Numerous cases of removing sprayed-on matrices not containing asbestos or applying an encapsulant to a ceiling matrix that failed during application could have been avoided if representative sampling, evaluation, and selection of an appropriate program had been conducted by competent and experienced professionals.

When a friable matrix containing asbestos is discovered during an audit, an interim cleaning and control program should be implemented to minimize asbestos exposure. Amended wet cleaning techniques and high efficiency microstatic vacuum systems prevent resuspension and propagation of asbestos fibers in the contaminated area. In addition, contaminated air handling filters should be replaced and packaged, labeled, and disposed of as an asbestos containing waste.

Contractor Specifications.—Suggested specification elements for engineering removal contractors to control liabilities and risks are presented in Table 3. These specifications outline criteria a contractor should meet concerning qualifications and experience, and the steps to be followed to ensure that all work is performed in accordance with good environmental health practices. Project supervision and certification by registered professional engineers experienced in environmental health or certified industrial hygienists will ensure conformance with good environmental health practices.

TABLE 3.—Suggested Specification Elements for Engineering Contractors to Control Liabilities and Risks

Element (1)	Description (2)
Experience requirement	Work conducted under registered professional environmental engineers or certified industrial hygienists supervision
Past work completed	Completed three jobs of equal size and can substantiate fibers of all sizes inside and outside the work area controlled below 0.1 fibers per cubic centimeter (NIOSH recommended standard)
Medical surveillance requirement	Produce evidence that all employees are in good health and have complied with medical examination requirements of 29CFR1910. 1001(j)
Corrective action implemented	Require conformance with good environmental health practices for removal, encapsulation, and entombment. Encapsulation and entombment of matrices containing asbestos require the same personal protection and dust control systems as for removal
Personnel protection requirement	Disposable hoods, coveralls, gloves, boots, umbilical cord or self-contained breathing systems or radionuclide respirators (only if dust counts in work area kept below 0.1 fibers/cc)
Project certification requirement	Asbestos removal, confinement, and residue disposition completed in accordance with good environmental health practices certified by professional engineer or certified industrial hygienist

Program Implementation

In June, 1980, the University of Maryland contacted REACT to implement a decontamination program for the Student Union Bowling Alley. The deteriorated ceiling insulation was sprayed on 22,000 sq ft (2,046 m^2) of concrete waffle ceiling located behind a suspended ceiling track system as depicted in Fig. 5. Bulk sample analysis determined that the matrix contained 30%–60% chrysotile asbestos.

Two control strategies were considered by the University of Maryland. The first alternative was to encapsulate the ceiling matrix using a combined system of a penetrating and a barrier agent. The ceiling matrix is first sprayed with a penetrating agent to enhance the adhesive and cohesive properties of the matrix, and then sprayed with an elastomeric barrier agent to minimize damage from impaction. The second alternative was removal of the insulation matrix and replacement with a nontoxic material with comparable accoustical properties.

Addressing only capital costs, encapsulation is generally less expensive, \$3–\$10/sq ft, (\$0.28–\$0.93/m^2), than removal costs, \$4–\$20/sq ft (\$0.37–\$1.86/m^2). However, long-range operational and deferred capital costs associated with encapsulation far exceed removal costs. With encapsulation, routine inspection, maintenance, and demolition costs must be included to determine total program costs.

The University of Maryland selected removal over encapsulation because tests showed that the matrix had degraded to the point that it could not support the wet load of encapsulating agents. It was discovered that the insulation would not have to be replaced since the suspended ceiling system would provide the desired acoustical properties for noise control in the bowling alley.

Personnel Protection.—Prior to beginning removal operations, several factors regarding health and safety were considered. Precautions were

FIG. 5.—Deteriorated Ceiling Insulation at University of Maryland Student Union Bowling Alley

taken to prevent asbestos fiber exposure to removal personnel and confine dust propagation to the work area.

The first concern was the safety of removal personnel since these individuals potentially would be exposed to the highest concentration of fibers. A respirator cartridge, designed for use in environments containing low levels of dusts, mists, fumes, and radionuclide daughters was chosen because of its high efficiency of 99.98% particle removal down to sizes of 0.3 microns. The writers recommend using umbilical cord or self-contained breathing systems if there is any concern over holding all particle sizes below 0.1 fibers per cubic centimeter in the work area.

To prevent propagation of fibers from the work area via worker transport, disposable protective coveralls, hoods, and booties were worn. These protective garments were disposed of in the vacuum area adjacent to the work area and packaged and labeled as asbestos-containing residues.

Asbestos Control Zones.—Four separate control zones were defined to prevent dust propagation outside the contaminated area. The work zone isolated the decontamination operations from the rest of the building. The entire work area was sealed off and covered with 6-mil polyethylene plastic to prevent dust fibers from contaminating furniture, carpeting, and other articles in the work zone. In addition, all openings in the work area including heating, ventilating, and air conditioning system ducts were sealed off to prevent dust propagation via the plenum.

The next three zones consisted of the vacuum zone, shower and wet cleaning zone, and clean room. Each of the three zones was constructed as an airlock, with 6-mil double flap plastic sheets to prevent air currents from passing asbestos fibers from one zone to the next. Personnel, equipment, and packaged residues leaving the work zone were cleaned in the vacuum zone employing microstatic vacuum equipment. Disposable clothing was removed and placed in containers. Personnel still wearing their respirators proceeded to the shower zone where fibers adsorbed to respirators and skin were rinsed off. Contaminated shower water was collected in the shower basin and pumped through a two-stage cartridge filtration system consisting of a 75-micron primary filter and a 5-micron secondary filter prior to discharge into the sewer system. Packaged residues and equipment were wet cleaned with an amended solution containing polyethylene ester and polyoxyethylene ether and water. Contaiminated liquid residues from the wet cleaning zone were treated through the same filtration system as shower water. Street clothes, new disposable personal protective equipment, clean equipment, and supplies were staged in the clean room. Rest room and eating activities were restricted to the clean room or area outside the clean room. As can be seen in Table 4, the use of a four zone control system confined asbestos fibers generated during removal to the work area.

Removal Operations.—After construction of the four control zones, the decontamination program was initiated by removal of the suspended ceiling system below the sprayed-on insulation. Fallout from the insulation had contaminated the reverse side of the ceiling panels and suspension tracks. Each panel and the associated track system was wetted to control dust propagation and vacuumed with microstatic vacuums. Microstatic vacuums were used because tests indicating comparable dust removal efficiencies to High-Efficiency Particulate Aerosol (HEPA) Sys-

TABLE 4.—Control Zones Confine Fiber Levels Generated During Removal Process To Work Area and Below NIOSH Proposed Standards

Sample number (1)	Activity and location (2)	Fiber concentration, in Fibers per Cubic Centimeter (3)
524.3	Ambient concentration during bulk removal in bowling alley	none
524.5	Work area during removal	0.042
524.9	Vacuum zone during removal	0.024
524.20	Shower zone during removal	none
524.11	Clean room during removal	none
524.FD1	Final dust count in work area following asbestos decontamination	0.001

Note: Original percentage of asbestos in the ceiling matrix was 30%. Air analysis by phase contrast microscopy.

tems (Table 5), and because microstats do not fail under wet conditions as do HEPA Systems. The efficiency of the microstatic vacuums under wet conditions permitted the ceiling panels and track systems to be disposed of as noncontaminated wastes, resulting in a considerable cost savings to the client.

To minimize propagation of asbestos fibers at the work surface, the wetting agent and water solution was used to fully saturate the insulation matrix. Application of the wetting solution decreased the surface tension of water on the hydrophobic asbestos fibers permitting the formation of a coalesced wetted matrix. Periodic misting of the air prevented the resuspension of particles and kept the dust counts in the work area below the proposed NIOSH standard of 0.1f/cc (Table 4).

Environmental Health Monitoring.—Air monitoring instruments were employed to periodically sample asbestos air concentrations. Four air samples were taken every 24 hr during removal operations as follows: two inside the work area, one in the vacuum zone, and one ambient sample outside the building. The monitoring devices consisted of an air pump with a cartridge cassette holding a membrane filter. Personal monitors were calibrated at sampling rates of two liters per minute. Minimum sampling periods of 2 hr (240 L) for ambient and clean room samples and 1 hr (120 L) for work area and vacuum zone samples were utilized to collect representative samples and to ensure accountability with the NIOSH proposed asbestos standard.

Dehumidification Systems.—Removing asbestos-containing insulation from a bowling alley presented several unique problems. By sealing the work zone with polyethylene plastic, a "dead" airspace was created causing thermal gradients and "sweating" between the plastic and bowling lanes. Wetting the matrix with the wetting agent solution, along with periodic misting of the air created high humidity levels. A dehumidification system was designed to prevent water damage to the bowling alleys, pin setting machines, and electronic scoring equipment. Calcium

TABLE 5.—Microstatic Vacuum and Air Cleaner Performance Meet NIOSH Proposed Asbestos Standards of 0.1f/cc and Do Not Fall under Wet Operating Conditions

Sample number (1)	Activity and location (2)	Fiber concentration, in fibers per milliliter (3)
321-0	Transformer room prior to isolation and microstatic decontamination	4.9[b]
321.100	Transformer room after isolation and microstatic air cleaning	0.00712[a]
321-M	Ambient air sample prior to isolation and microstatic air cleaning	0.8[b]
335.2	Ambient air sample following isolation and microstatic air cleaning	0.005[a]
321-N	Hallway first floor prior to isolation and decontamination	0.8[b]
321.200	Hallway first floor after isolation and decontamination	0.000855[a]

[a]Analysis by scanning electron microscopy.

[b]Analysis by polarized light microscopy.

Note: Spray-on fireproofing containing asbestos ranged from 30% to 50% amosite and 2% to 3% chrysotile. HVAC filter media prior to decontamination contained 2% to 10% amosite asbestos.

chloride desiccators and a three-stage microstatic air filtration system exchanged air in the work zone, thereby controlling humidity and fiber levels.

Trace Fiber Fixation and Encapsulation.—Following bulk removal operations from the ceiling, removal personnel utilized fine wire brushes to remove residual asbestos fibers from the ceiling surface. Trace asbestos fibers were fixed to the ceiling using a polyvinyl acetate copolymer (PAC) bonding agent. Spray-on insulation material behind ducts and other inaccessible areas was encapsulated and labeled as asbestos-contaminated to deter future impact.

Residue Packaging and Disposition.—One hundred and thirty cubic yards (99 m^3) of asbestos residues from removal operations were packaged while wet in 6-mil polyethylene bags, sealed, labeled, and loaded into 40-cu-yd (31-m^3) closed skips for transport and ultimate disposition at a licensed hazardous waste disposal site. Contaminated protective clothing, filter cartridges, and contaminated air handling filters were treated as asbestos containing residues. Thirty-five cubic yards (27 m^3) of decontaminated suspended ceiling material were disposed of at a sanitary landfill resulting in a substantial cost saving to the client.

Conclusions and Recommendations

Asbestos materials in institutions can be identified and controlled by utilizing experienced and knowledgable professional environmental health

personnel. To avoid compounding asbestos exposure problems under existing inadequate laws, it is suggested that programs be designed, supervised, and certified by Certified Industrial Hygienists or Registered Professional Engineers experienced in asbestos control strategies.

Asbestos control programs—whether they involve removal, encapsulation, or entombment—should follow the same fiber control strategies as presented herein to protect workers and public health and welfare. Gross fiber contamination problems have resulted in entire facility shutdowns for periods of one to twelve weeks when corrective action programs were not supervised in accordance with good environmental health practices for all modes of corrective action.

State-of-the-art removal practices can be implemented in a cost-efficient manner. The Maryland program involved over 28,000 sq ft (2,600 m^2) of contaminated ceiling matrix removal from the bowling alley, lecture hall, and mechanical and electrical vaults. This project was completed for $176,000 which was $48,000 below removal costs estimated by the National Institute of Environmental Health Services. Microstatic air cleaning and vacuum equipment used in conjunction with dust misting systems will control dust levels below NIOSH proposed standards and save 30%–50% over the cost of traditional HEPA systems.

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