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Quantification of Fiber Releases for Various Floor Tile Removal Methods

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The risk of human exposure from asbestos-containing material is directly related to the condition of the material, custodial/maintenance activities, and the methods used to reduce the potential exposure to workers, bystander employees, and occupants of the area containing the asbestos. Many consider floor tile to be nonfriable, which is in accordance with the National Emission Standards for Hazardous Air Pollutants regulations, although there is some documentation of fiber releases from deterioration of such asbestos-containing materials during polishing, removal, or routine walking, due to the friction generated by such activities. This study evaluates several commonly used procedures for removal of floor tile and quantifies the fibers released during those procedures using data obtained by analyses from phase contrast microscopy and analytical transmission electron microscopy. These data document that fibers are released when floor tile is broken and/or abraded during removal procedures. Fiber levels vary with the aggressiveness of the procedures. A considerable percentage of the asbestos fibers identified by the analytical transmission electron microscopy methods specified in the Asbestos Hazard Emergency Response Act are below the size that can be detected by phase contrast microscopy and which are also the most easily respired due to their physical characteristics. CROSSMAN, JR., R.N.; WILLIAMS, JR., M.G.; LAUDERDALE, J.; SCHOSEK, K.; DODSON, R.F.: QUANTIFICATION OF FIBER RELEASES FOR VARIOUS FLOOR TILE REMOVAL METHODS. APPL. OCCUP. ENVIRON. HYG. 11(9):1113–1124; 1996.

The risk of human exposures from asbestos-containing building materials is considered to be directly related to the condition of the material, degree of friability of the material, the asbestos content (percent), and the fiber size distribution within the product. An effective management strategy for reducing the potential of exposure must therefore include a physical inspection made by an accredited inspector to evaluate factors such as air movement, accessibility, vibration, and potential for disturbance based on the type of material (surfacing, thermal, miscellaneous).[1,2]

Floor tile, which is classified as miscellaneous material, poses a particular challenge for proper management since any asbestos is often finely dispersed within the matrix, and thus difficult to assess as to percentage by standard techniques using polarized light microscopy (PLM). Many floor tiles do contain asbestos, usually chrysotile, at levels up to 25 percent, but which may be reported as 1 percent or less by PLM analysis.[3–5] Therefore, asbestos fibers, because of their potentially thin diameters, require analytical transmission electron microscopy (ATEM) as the method of choice for accurate quantitation in air samples and some bulk materials.[6] This is particularly important in chrysotile-containing products where many fibrils below the limit of detection by light microscopy may become airborne and thus inhalable.[7] While it may be considered that the asbestos fibers in products such as floor tiles are bound and not easily released unless broken or crushed, Sebastien *et al.*, found that even under normal conditions of weathering, asbestos fibers were released into the environment.[8]

Although levels of asbestos in public buildings may usually be low, elevated levels of airborne asbestos can be expected when asbestos-containing material (ACM), including floor tile, is in poor condition or is disturbed by occupants and maintenance activities.[9] The Environmental Protection Agency (EPA) has reported asbestos fiber release from floor tile spray buffing operations in 12 of 17 schools in New Jersey.[10] The Occupational Safety and Health Administration (OSHA)[11] requires polishing of asbestos-containing floor tile to be conducted using least abrasive pads and polishers operating at 300 rpm or less.[11]

Limited numbers of other studies have been carried out to ascertain what fiber release occurs when asbestos-containing floor tiles are removed by procedures not utilizing negative pressure containment and wet methods as required under the Asbestos Hazard Emergency Response Act (AHERA)[12] for asbestos abatement in public schools. Unfortunately, these data are usually collected for personal exposure compliance purposes and not as part of a protocol in a scientific project. The published data often fail to describe condition, age, type of material, asbestos type and content, sampling information (volume and collection rate), filter pore size, and analysis protocols.

The EPA has published a guidance advisory[3] specifying that floor tile should be analyzed by ATEM, if it is reported to contain 1 percent or less asbestos by PLM. The OSHA regulation 1926.1101[11] places all floor tile installed in 1980 or earlier in the presumed ACM category, unless rebutted by a bulk sample analysis by a technically feasible method. However, a final rule to phase out distribution of vinyl asbestos tile (VAT) in the United States was declared invalid by the U.S. Court of Appeals in New Orleans; therefore, the manufacture, distribution, and importation of VAT are not restricted.[13]

The issue of potential exposure from the removal of floor tiles in public buildings can be addressed by either total containment procedures or through one of several other procedures, such as the suggested work practices published by the Resilient Floor Covering Institute (RFCI).[14] When federal or state regulations permit, selection of the removal technique is left up to building owners or their consultants. The decision may be made on the perception that total containment procedures are the most costly, without considering the potential health risk and liability risk. Total containment controls emissions and residue, while noncontainment may result in exposure to workers during the project and to occupants through reentrainment by subsequent activities.

The authors established a joint research investigation with the Texas Department of Health, which was designed to assess fiber release during floor tile removal in public buildings by a series of available procedures, monitored by phase contrast (light) microscopy (PCM) and ATEM. These data were quantified to compare the merits of each method, as well as the level of fibers detected by PCM versus ATEM in actual work place environments.

The Texas Asbestos Health Protection Rules, September 1994, §295.36,[15] provide an exemption from licensing and registration for persons removing resilient floor covering materials in public buildings, if those persons received training in an 8-hour course covering the elements in the document titled, *Recommended Work Practices for the Removal of Resilient Floor Coverings*, published by the RFCI in 1990.[14]

Methods

Study Design

The following general criteria were established for all field investigations during this study:

1. Locations for investigative procedures were evaluated by a licensed asbestos inspector to rule out the potential for asbestos contamination caused by friable and/or damaged ACM in the work areas. No sites were used which had any friable ACM or damaged ACM present in the area.
2. Each site was cleaned by high efficiency particulate air (HEPA) vacuum and/or wet wiping prior to the collection of baseline samples and the beginning of any work that was part of the test procedures. The baseline air samples were collected and analyzed by PCM (NIOSH 7400, Rev. 3,A rules) and ATEM.[2,16]
3. Bulk samples of floor tile and mastic were analyzed by PLM.[17]
4. Bulk samples of floor tile were analyzed by ATEM via the Chatfield Method.[18]
5. Each work site had critical barriers installed and was under a differential pressure of −0.02 inches water column. Two of the sites had polyethylene wall covering while the third site had full inverted containment consisting of a single layer of 4 ml polyethylene on the walls and ceiling. (The type of containment will be noted under specific procedures.) All work sites had a minimum of four air changes per hour within the critical barriers. During each specific procedure, the work area within the negative pressure enclosure was sealed using double flap doors taped closed so there was no air circulation by suction or discharge from negative air machines. The air flow was checked using smoke tubes and there was no detectable flow observed. The exception for this is the full AHERA[2] procedure investigation, which was conducted with no restriction of flow through the work area. All locations had decontamination facilities.[11,19,20]
6. Three air samples were collected in the work area involved during each procedure. These were analyzed by PCM and ATEM. The relative location in each area was the same.
7. Outside samples were taken at negative air unit discharges and areas outside containment and were analyzed by both PCM and ATEM using the procedures cited in item 2 above.
8. Following the completion of the procedures being evaluated, each area was cleaned by HEPA vacuum/wet wiping and samples for clearance analysis were collected by aggressive methods.[2] These samples were also analyzed by PCM and ATEM.
9. After clearance was achieved, all remaining polyethylene was removed and disposed of as ACM and the areas were made available for reoccupancy following final cleaning.
10. All area air samples were collected on 0.45 μm pore size, mixed cellulose ester (MCE) filters with backup pads in 25-mm diameter conducting cassettes with 50-mm extension cowls. Staplex high volume pumps were used to collect the samples. The flow rates were 1 L/min to less than 10 L/min. Flow rates were checked at the start and end of each sampling period using an Asbestos Analytics rotameter, which was calibrated using a bubble burette as a primary standard.
11. All workers were EPA Model Accreditation Plan (MAP)[21] accredited and were experienced in asbestos abatement. The same workers were used at both sites of the urban school district and were employees of the school district. The workers conducting the procedures at the third site were furnished by another licensed asbestos contractor.
12. The Texas Department of Health is not an OSHA[11] enforcement agency and personal samples were not a part of this study. Personal samples were collected by the employer of the workers.

Abatement Methods

Removal of floor tile at the first site, designated as Room 10 (Figure 1), was conducted under AHERA[2] rules. This site, located inside a middle school building of a large urban school district, contained approximately 1000 square feet of floor tile, which was "flooded" each morning for 3 days preceding the removal. Gross removal was conducted using amended water and hand spud bars* to release the tiles from the floor. The 9 × 9 floor tiles had been installed 20 to 25 years before onto a concrete floor and were securely attached. Consequently, removal of the tiles required a great amount of force, which resulted in breakage of the tiles into many small pieces.

*A spud bar is a steel shaft approximately 2 inches in diameter, with a tapered, sharp end to work under the floor tile. Hand power may be used or the bar may be inserted in a pneumatic power unit, which causes the bar to operate in a hammerlike mode.

FIGURE 1. Urban middle school, room 10, AHERA removal.

FIGURE 3. Commercial building, room 8, dry ice removal.

There were three patterns of tile in Room 10. The predominant pattern was light blue-gray in color and occupied approximately 95 percent of the floor area in the room. Analysis by PLM of this tile showed an asbestos content of 4 to 6 percent; ATEM analysis found the amount of asbestos to be considerably higher, 16 to 23 percent. No asbestos was detected by ATEM analysis of the other two tile patterns. (See Table 1 for analytical results.)

The second site consisted of two rooms of an administrative building, which had previously been used as an elementary school, of the same urban school district. Room A (Figure 2) was approximately 1200 square feet and Room B was approximately 900 square feet. During this procedure, workers wore full personal protective equipment, which included Type C supplied air respirators. Personal samples were taken by the contractor in accordance with 40 CFR 763, Subpart G, Worker Protection.[20]

In Room A, floor tiles were removed initially using a hand-powered spud bar. Later, due to the difficulty in releasing the tile from the concrete floor, the pneumatic powered spud bar was used.

In Room B, floor tile was initially removed dry, using hand-held scrapers in accordance with the RFCI[14] work practices. This method for removal was extremely slow, and sufficient force to remove all pieces of the tile from the floor was not possible. Because the floor tiles were so firmly attached to the concrete floor, the procedures were changed and pneumatic powered spud bars were utilized for two sampling periods. Use of both the hand-held scraper and the pneumatic powered spud bar resulted in many very small sized pieces of detached floor tile. (Analytical results are in Table 2.)

The third location was in an unoccupied commercial building in East Texas, which contained approximately 1500 square feet. After this area was precleaned, critical barriers were erected, a single inverted polyethylene containment was erected for the walls and the ceiling, and differential pressure was established for the area. Work areas were separated and isolated from the air flow from the rest of the contained area by taped, double-flap doors. The approximate square footage of each work area was 175 to 220 square feet. At this site, methods for the removal of floor tile included heating, dry ice,

FIGURE 2. Urban administrative building, room A, dry pneumatic spud bar removal.

FIGURE 4. Commercial building, room 9 RFCI dry-hand-held scraper.

TABLE 1. Floor Tile Removal by AHERA Regulations Urban Middle School, Room 10

Bulk Sample Analysis of Three Patterns of 9 × 9 Floor Tiles

ID	Description	PLM	ATEM
1	Tan tile	None detected	None detected
	Black mastic	None detected	—
2	Light blue-gray tile	4–6% Chrysotile	16–23% Chrysotile
	Black mastic	1–2% Chrysotile	—
3	Dark/light green tile	None detected	<1% Chrysotile
	Yellow mastic	Insufficient sample	—

Baseline air samples

ID	Description	VOL (L)	PCM (f/cc)	ATEM total (st/cc)	ATEM >0.5 (st/cc)	ATEM ≥5 (st/cc)
B-1	Inside containment	750.5	0.046	0.012	0.012	<0.006
B-2	Inside containment	750.5	0.057	0.006	0.006	<0.006
B-3	Inside containment	918.3	0.056	0.026	0.020	0.006

AHERA Procedure

ID	Description	VOL (L)	PCM (f/cc)	ATEM total (st/cc)	ATEM >0.5 (st/cc)	ATEM ≥5 (st/cc)
A-1	Inside containment	741.0	0.042	0.24	0.22	0.025
A-2	Inside containment	731.5	0.022	0.13	0.12	0.012
A-3	Inside containment	950.0	0.027	0.093	0.087	0.006
A-4	Outside hallway	630.0	0.062	—	—	—

Clearance (Samples for comparison were collected within two feet of the contractor's clearance samples and reported as follows)

ID	Description	VOL (L)	PCM (f/cc)	ATEM total (st/cc)	ATEM >0.5 (st/cc)	ATEM ≥5 (st/cc)
C-1	Inside containment	1630.0	0.19	0.011	0.008	0.003
C-2	Inside containment	1610.0	0.22	0.009	0.009	<0.003
C-3	Inside containment	1590.0	0.21	0.006	0.006	<0.003
C-4	Outside containment	1470.0	0.34	—	—	—

NOTE: More than 12 hours elapsed between the completion of removal and the collection of the "clearance" samples.

and hand-held scraper RFCI[14] work practices. Removal of mastic was accomplished by amended water/long-handled floor scraper and Abatix 007 mastic remover (Table 3).

Following is a description for work in each of the areas where the investigation was conducted at the third location:

Room 7: Floor tile was removed by heating the surface with hand-held propane torches to make it pliable. Many of the tiles did not readily release from the floor and were broken during their removal from the floor with hand-held scrapers. (See Table 3A for analytical results.)

Mastic was removed after a settling period by RFCI[14] work practices, using amended water to wet the mastic and a long-handled floor scraper to peel the ridges down so that the floor would be suitable for installation of a new tile floor. A HEPA wet vacuum was used to pick up the residue and the floor was mopped to clean it. (See Table 3B for analytical results.)

Room 8: The floor tile in this room (Figure 3) was removed by dry ice cooling to release the dry tiles and/or mastic. A 2-inch thick layer of dry ice was placed in an approximately 2 × 5 foot movable frame, with a polyethylene bottom. The dry ice was left at each location for approximately 3 to 4 minutes. Measurements of carbon dioxide (CO_2) levels were made using a Dräger pump and direct indicating CO_2 tubes about 2 feet above the floor and above the frame. The highest level of CO_2 measured at this location was approximately 2500 ppm. The level of CO_2 found in the worker breathing zone was approximately 1000 ppm. The CO_2 level decreased rapidly as one moved a greater distance above the floor and from the frame. (See Table 3C for analytical results.)

Room 9: The floor tile in Room 9 (Figure 4) was removed using the hand-held scrapers in accordance with the RFCI[14] recommended work practices. (See Table 3D for analytical results.)

TABLE 2. Floor Tile Removal by Dry Hand Spud Bar, Dry Pneumatic Spud Bar, and Dry Hand-held Scraper (RFCI),[14] Administrative Building in an Urban School District

Bulk Sample Analysis of Three Patterns of 9 × 9 Floor Tiles

ID	Description	PLM	ATEM
A	Red Tile	10–15% Chrysolite	24–29% Chrysolite
	Black Mastic	5–7% Chrysolite	—
B	Gray Tile	10–15% Chrysolite	24–36% Chrysolite
	Black Mastic	3–5% Chrysolite	—
C	Brown Tile	7–10% Chrysolite	23–34% Chrysolite
	Black Mastic	2–4% Chrysolite	—

Baseline Air Sample (collected only in Room B due to activity in Room A)

ID	Description	VOL (L)	PCM (f/cc)	ATEM total (st/cc)	ATEM >0.5 (st/cc)	ATEM ≥5 (st/cc)
1-A	Rm. B, NW quarter	1479	0.042	0.003	0.003	<0.003

Room A—Dry Hand Spud Bar

ID	Description	VOL (L)	PCM (f/cc)	ATEM total (st/cc)	ATEM >0.5 (st/cc)	ATEM ≥5 (st/cc)
2-D	SW third	292	0.021	0.74	0.63	0.11
2-E	S middle	322	0.040	1.2	0.98	0.20
2-F	N middle	284	0.062	1.3	1.1	0.16

Room A—Dry Pneumatic Spud Bar (Day 1)

ID	Description	VOL (L)	PCM (f/cc)	ATEM total (st/cc)	ATEM >0.5 (st/cc)	ATEM ≥5 (st/cc)
2-I	SW third	248	0.079	6.4	5.7	0.70
2-J	S middle	228	0.12	6.0	5.4	0.57
2-K	N middle	204	0.12	8.3	7.6	0.73

Bulk Sample Analysis of Three Patterns of 9 × 9 Floor Tiles

ID	Description	PLM	ATEM
A	Red Tile	10–15% Chrysolite	24–29% Chrysolite
	Black Mastic	5–7% Chrysolite	—
B	Gray Tile	10–15% Chrysolite	24–36% Chrysolite
	Black Mastic	3–5% Chrysolite	—
C	Brown Tile	7–10% Chrysolite	23–34% Chrysolite
	Black Mastic	2–4% Chrysolite	—

Baseline Air Sample (collected only in Room B due to activity in Room A)

ID	Description	VOL (L)	PCM (f/cc)	ATEM total (st/cc)	ATEM >0.5 (st/cc)	ATEM ≥5 (st/cc)
1-A	Rm. B, NW quarter	1479	0.042	0.003	0.003	<0.003

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Table 2. Continued

Room A—Dry Hand Spud Bar

ID	Description	VOL (L)	PCM (f/cc)	ATEM total (st/cc)	ATEM >0.5 (st/cc)	ATEM ≥5 (st/cc)
2-D	SW third	292	0.021	0.74	0.63	0.11
2-E	S middle	322	0.040	1.2	0.98	0.20
2-F	N middle	284	0.062	1.3	1.1	0.16

Room A—Dry Pneumatic Spud Bar (Day 1)

ID	Description	VOL (L)	PCM (f/cc)	ATEM total (st/cc)	ATEM >0.5 (st/cc)	ATEM ≥5 (st/cc)
2-I	SW third	248	0.079	6.4	5.7	0.70
2-J	S middle	228	0.12	6.0	5.4	0.57
2-K	N middle	204	0.12	8.3	7.6	0.73

Room A—Dry Pneumatic Spud Bar (Day 2)

ID	Description	VOL (L)	PCM (f/cc)	ATEM total (st/cc)	ATEM >0.5 (st/cc)	ATEM ≥5 (st/cc)
3-D	S middle	446	0.082		Not analyzed/overloaded	
3-E	N middle	483	0.11		Not analyzed/overloaded	
3-F	SW third	446	0.14		Not analyzed/overloaded	

Room B—Dry Hand-held Scraper (RFCI Work Practices[14])

ID	Description	VOL (L)	PCM (f/cc)	ATEM total (st/cc)	ATEM >0.5 (st/cc)	ATEM ≥5 (st/cc)
2-A	W middle	760	0.032	1.3	1.3	0.066
2-B	NW quarter	929	Torn	—	—	—
2-C	E middle	890	0.033	1.0	0.97	0.046

Room B—Dry Pneumatic Spud Bar (Day 1)

ID	Description	VOL (L)	PCM (f/cc)	ATEM total (st/cc)	ATEM >0.5 (st/cc)	ATEM ≥5 (st/cc)
2-L	W middle	70	0.088		Volume too low	
2-M	NW quarter	70	0.074		Volume too low	
2-N	E middle	70	0.074		Volume too low	

Room B—Dry Pneumatic Spud Bar (Day 2)

ID	Description	VOL (L)	PCM (f/cc)	ATEM total (st/cc)	ATEM >0.5 (st/cc)	ATEM ≥5 (st/cc)
3-A	E middle	437	0.11		Not analyzed/overloaded	
3-B	NW quarter	446	0.092		Not analyzed/overloaded	
3-C	W middle	469	0.093		Not analyzed/overloaded	
3-I	E middle	582	0.094		Not analyzed/overloaded	
3-J	NW quarter	582	0.048		Not analyzed/overloaded	
3-K	W middle	582	0.059		Not analyzed/overloaded	

NOTE: The containment area was cleared by the owner upon completion of all work that disturbed ACM. No samples were collected as part of this study.

TABLE 3. Floor Tile Removal By Propane Torch Heat, Hand-held Scraper (RFCI),[14] Dry Ice, and Mastic Removal by Abatix 007 or Amended Water (RFCI),[14] Commercial Building in East Texas

Bulk Sample Analysis of Two Patterns of 9 × 9 Floor Tiles[A]

ID	Description	PLM	ATEM
1A	Tan tile	4–6% Chrysolite	13–18% Chrysolite
	Black mastic	ND	—
2A	Tan/Brown mottled tile	7–10% Chrysolite	20–27% Chrysolite
	Black mastic	2–4% Chrysolite	—

Baseline Air Samples[B]

ID	Description	VOL (L)	PCM (f/cc)	ATEM total (st/cc)	ATEM >0.5 (st/cc)	ATEM ≥5 (st/cc)
C101	Room 9	918	0.029	0.030	0.020	0.010
C102	Room 7	828	0.037	0.039	0.028	0.011
C103	Room 2	828	0.026	0.022	0.017	0.005

Floor Tile Removal Applying Heat with Hand-held Propane Torch[C]

ID	Description	VOL (L)	PCM (f/cc)	ATEM total (st/cc)	ATEM >0.5 (st/cc)	ATEM ≥5 (st/cc)
C211	Room 7	739	0.022	0.60	0.38	0.22
C212	Room 7	850	0.006	0.52	0.34	0.18
C213	Room 7	892	0.011	0.25	0.12	0.13

Mastic Removal with Amended Water and Extended-handle Floor Scraper (RFCI Work Practices[14])

ID	Description	VOL (L)	PCM (f/cc)	ATEM total (st/cc)	ATEM >0.5 (st/cc)	ATEM ≥5 (st/cc)
C301	Room 7	522	0.035	0.34	0.13	0.21
C302	Room 7	540	0.027	0.26	0.15	0.11
C303	Room 7	552	0.027	0.18	0.083	0.099

Floor Tile Removal Using Dry Ice[D]

ID	Description	VOL (L)	PCM (f/cc)	ATEM total (st/cc)	ATEM >0.5 (st/cc)	ATEM ≥5 (st/cc)
C208	Room 8	666	0.024	0.36	0.25	0.11
C209	Room 8	703	0.019	0.31	0.23	0.071
C210	Room 8	760	0.024	0.19	0.15	0.036

Dry Hand-held Scraper (RFCI Work Practices[14])

ID	Description	VOL (L)	PCM (f/cc)	ATEM total (st/cc)	ATEM >0.5 (st/cc)	ATEM ≥5 (st/cc)
C104	Room 9			—Pump Stopped—		
C105	Room 9	522	0.17	1.3	0.63	0.67
C106	Room 9	509	0.15	0.96	0.51	0.45

(continued)

Table 3. Continued

Mastic Removal Using Abatix 007 Mastic Remover

ID	Description	VOL (L)	PCM (f/cc)	ATEM total (st/cc)	ATEM >0.5 (st/cc)	ATEM ≥5 (st/cc)
C203	Room 9	1840	0.054	0.30	0.20	0.10
C204	Room 9	1890	0.052	0.52	0.42	0.10
C205	Room 9	1950	0.048	0.32	0.22	0.10

Clearance Samples for Commercial Building in East Texas

ID	Description	VOL (L)	PCM (f/cc)	ATEM total (st/cc)	ATEM >0.5 (st/cc)	ATEM ≥5 (st/cc)
C401	Room 7	1187	<0.004	<0.005	<0.005	<0.005
C402	Room 8	1187	<0.004	<0.005	<0.005	<0.005
C403	Room 11	1345	<0.004	0.004	0.004	<0.004
C404	Room 1	1100	<0.004	0.016	0.010	0.006
C405	Room 3	1288	<0.004	<0.004	<0.004	<0.004

[A]These types were mixed throughout the building area.
[B]Baseline samples were taken after the area was cleaned and the containment was erected. The floor was being walked on as these samples were taken.
[C]There was little breakage. The laboratory report noted altered structures probably caused by the heat.
[D]Cold was applied 3 to 4 minutes in each location. Some floor tile breakage occurred from insufficient release, or perhaps from brittleness due to the cold. This was usually limited to 2 to 4 pieces when breakage occurred.

Following removal of the floor tile and a settling period, the mastic was removed using Abatix 007 mastic remover. The area was then hand-rubbed with the least abrasive buffer pad to loosen it and the residue picked up using a squeegee. Final cleaning was done by mopping. (See Table 3E for analytical results.)

Analytical Procedures

BULK SAMPLE ANALYSIS. Bulk sample analyses were conducted using both PLM and ATEM. The PLM procedure was performed as described in 40 CFR 763, Subpart F, Appendix A.[(17)] The ATEM analysis was done in accordance with the procedure of Chatfield.[(18)]

For the PLM procedure, random portions of the floor tiles were dissected into small fragments while being examined for obvious asbestos fibers. These fragments were dissolved in a small amount of 1.550 n_D dispersion oil by gentle heating, visible fiber bundles were removed and placed in fresh 1.550 n_D oil and a large quantity of fresh oil was added to the remaining dispersed sample. The sample was analyzed using magnifications ranging from ×7 to ×400. Asbestos was identified based on morphology (frequently as chopped fragments), color and pleochroism, refractive indices, birefringence, extinction characteristics, and sign of elongation. Quantitation was by estimation from models of known composition and results were reported as area percent.

For the ATEM analysis, 100- to 500-mg samples were shaved from the floor tiles, which were then weighed. These samples were ashed in a muffle furnace at 480° ± 5°C. for at least 12 hours and weighed again. The ash was then dispersed in 2 ml of 6N HC1. When effervescence ceased, the residue was collected on a preweighed 0.2-μm polycarbonate filter, where it was rinsed with distilled water, oven dried, and weighed. The residue was resuspended in a known volume of water and 3 μl of the suspension were transferred to formvar-coated grids. After drying, the proportion of asbestos in the residue was visually estimated at ×16,000 and the upper and lower weight percents (±10%) were calculated and reported for asbestos, organic material and calcite and dolomite.

PHASE-CONTRAST MICROSCOPY. Phase-contrast microscopy following NIOSH 7400 Revision 3, May 15, 1989 was used to analyze representative portions of the 0.45-μm mixed cellulose ester filters for later comparison with ATEM. Quadrants of the filters were collapsed with acetone vapor, mounted in 1.460 n_D oil, and coverslipped. The quadrants were analyzed at ×400 and fibers greater than 5-μm long, with aspect ratios equal to or greater than 3, were counted using the NIOSH 7400 A rules. Results were reported as fibers per cc.

ANALYTICAL TRANSMISSION ELECTRON MICROSCOPY. Electron microscopy counts were obtained on the above filters, using the AHERA counting protocol described in 40 CFR 763, Subpart E, Appendix A[(2)] or EPA Level II analysis.[(16)] In brief, upon arrival in the lab, portions of the filters were collapsed on glass slides with acetone vapor and plasma etched until 10 percent of the surface was removed. They were carbon coated in a vacuum evaporator and small squares were placed on calibrated 200 mesh grids. The MCE plastic was removed in an acetone condensation washer. The samples were examined in an ATEM at a screen magnification of ×16,000 for asbestos fibers. Five 200 mesh grid squares were analyzed on each of two grids. The AHERA[(2)] protocol was used for the clearance samples. To be counted, a structure had to have a 5 to 1 aspect ratio or greater and be at least 0.5 μm long or greater. Selected area electron diffraction (SAED) and energy dispersive X-ray analysis (EDXRA) were used to confirm all asbestos structures. EDXRA alone was used to confirm nonasbestos. The structures were categorized as fibers, bundles,

TABLE 4. Data Summary

Removal Procedures	PCM f/cc			ATEM total st/cc		
	Mean	Standard Deviation	Geometric Mean	Mean	Standard Deviation	Geometric Mean
AHERA	.030	.010	.029	0.15	0.078	0.14
Dry hand spud bar	.041	.021	.037	1.1	0.30	1.0
Dry pneumatic spud bar (Room A)	.11	.024	.10	6.9	1.2	6.8
Dry pneumatic spud bar (all cases)	.092	.025	.089	I*	I*	I*
RFCI dry hand scraper (all cases)	.096	.0073	.096	1.2	0.23	1.1
Dry ice	.022	.0029	.022	0.28	0.086	0.27
Propane torch	.013	.0082	.011	0.46	0.18	0.43
Abatix 007 mastic remover	.051	.0031	.051	0.38	0.12	0.37
Wet mastic scraper	.030	.0046	.029	0.26	0.08	0.25

*ATEM data incomplete.

clusters, or matrices according to AHERA. Results were recorded as asbestos structures greater than or equal to 0.5 μm to less than 5 μm, or greater than or equal to 5 μm in length per cc and as total asbestos structures per cc.

A second ATEM method, known as EPA Level II, was published by Yamate *et al.*[16] This method was used to analyze all samples, except the clearance samples. The samples were collected and the filters prepared as in the AHERA[2] protocol. Asbestos structures were counted at ×16,000 and were classified as above. SAED and EDXRA were used to identify the structures. The data were made to conform to the AHERA counting rules[2] and were reported using the AHERA guidelines.[2]

All samples for electron microscopy were prepared by the direct method, as outlined above.

A one-way analysis of variance (ANOVA), associated with a Tukey Studentized Range Test, was performed on the ATEM $\log_{10}$ transformed data. The post hoc experiment-wise error rate, representing the probability of at least one falsely declared significant difference, was controlled at 5 percent for the 21 pair-wise comparisons of the seven treatment means.

Analytical Results—Synopsis

Representative floor tiles from each site were analyzed by PLM and ATEM. The only asbestos present was chrysotile, and the concentrations ranged from "none detected" to as high as 10 to 15 percent by PLM and 24 to 36 percent by ATEM, both percentages coming from the same tile. The average percent difference between the two analytical procedures was 194 percent, with ATEM always giving the higher results. Only chrysotile was found in the mastics, and it ranged in concentration from "none detected" to 5 to 7 percent by PLM.

Of the various removal procedures tested, the propane torch method produced the lowest concentration of airborne fibers per cc, which averaged 0.013 by PCM (see Table 4 and Figure 5). The RFCI[14] hand-held scraper (Room 9) produced the highest average concentration, with 0.16 fibers per cc (See "Analytical Results by Site" and Figure 4).

FIGURE 5. ATEM micrograph showing a chrysotile bundle (arrow) visible by PCM. Source was the urban administrative building, room B, dry pneumatic spud bar procedure. Bar = 1 μm.

FIGURE 6. ATEM micrograph of chrysotile fibers seen only by electron microscopy. Source was the East Texas commercial building Abatix 007 mastic procedure. Bar = 1 μm.

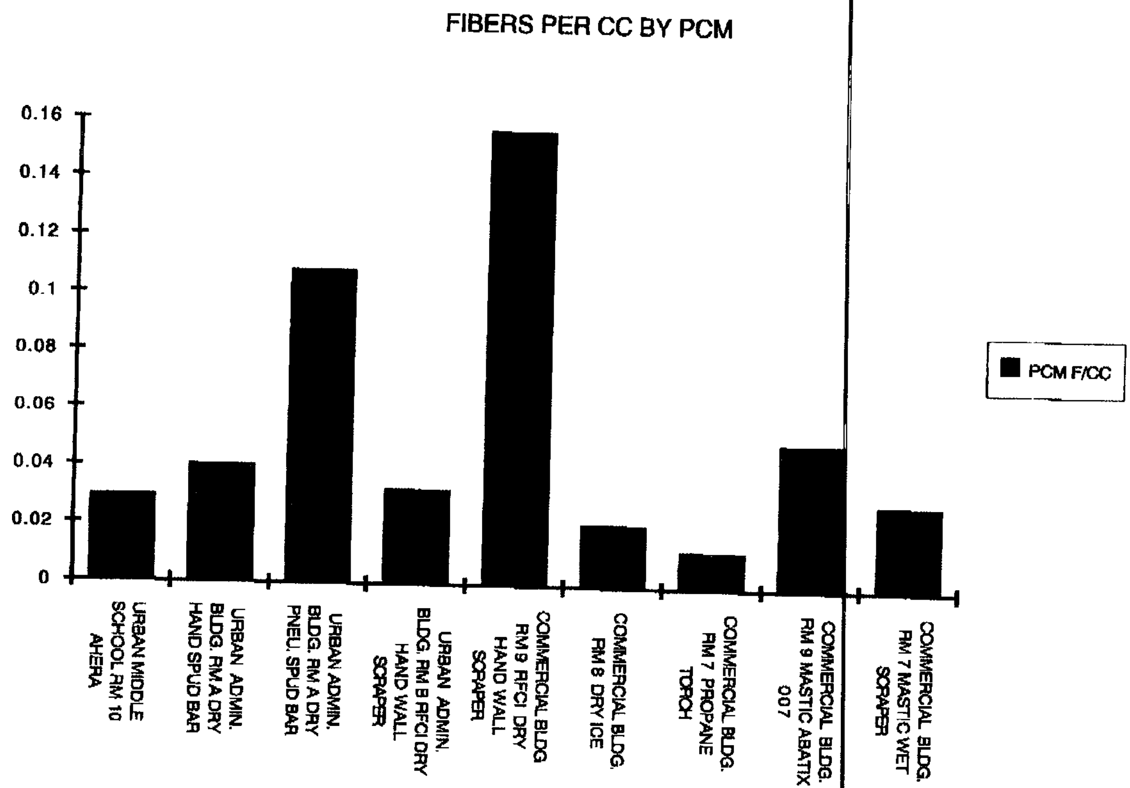

FIGURE 7. Fibers per cc by PCM.

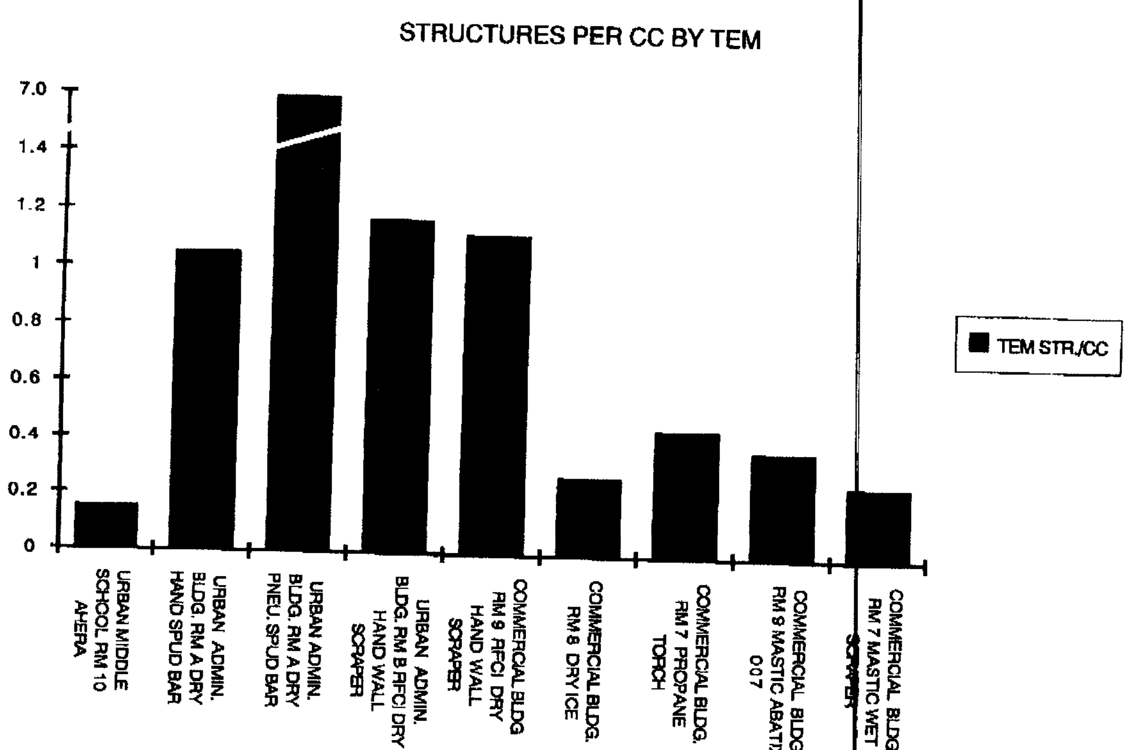

FIGURE 8. Structures per cc by TEM.

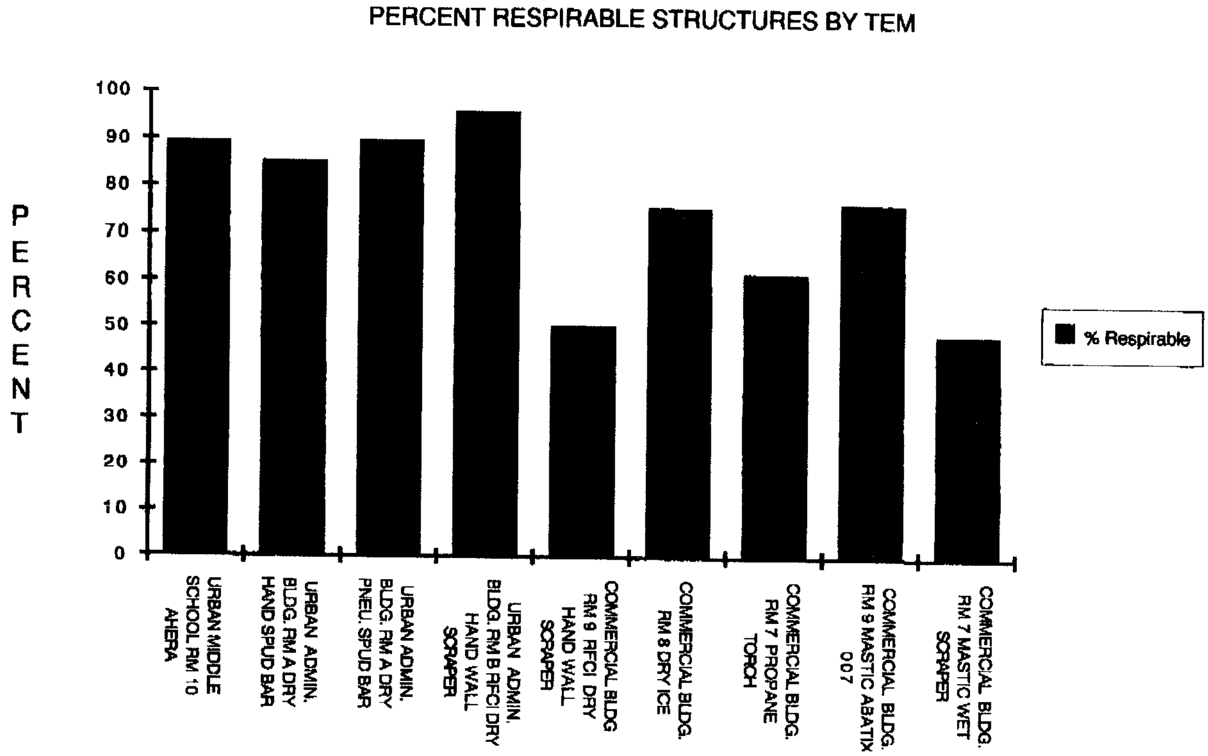

FIGURE 9. Percent respirable asbestos structures by ATEM.

ATEM results indicated the AHERA[2] procedure generated the least number of asbestos structures per cc, with an average of 0.15 (see Table 4 and Figure 6). This concentration was significantly lower than that for all other floor tile removal procedures except for the dry ice. The greatest concentrations, averaging 6.9 structures per cc, were produced by the dry-pneumatic spud bar. These concentrations were significantly higher than those for all other removal procedures. The average percent difference between the PCM and ATEM counts for the various floor tile removal procedures was 2840 percent, and the ATEM counts were always the higher. (See Table 4.)

The ATEM results also provided insight into the type and size of asbestos structures that were produced by the various removal procedures tested (Figures 7 and 8). The most common structures were fibers and matrices, many of which were respirable. Two amphibole fibers were identified during the electron microscopy analyses of the air samples; however, this was not considered to be a significant finding. The average percentage of respirable asbestos structures generated by each method is illustrated in Figure 9. The dry-hand-held scraper and the dry-pneumatic spud bar produced the highest percentages, 96.5 and 90.2, respectively, but all of the removal procedures produced at least 48.9 percent or greater respirable structures.

The above percentages represent conservatively low estimates of the respirable fractions because the AHERA[2] counting rules require lengths to be recorded in two categories: those structures greater than or equal to 0.5 μm to less than 5 μm and those greater than or equal to 5 μm. Diameters are not recorded. Therefore, all clusters and matrices greater than or equal to 5 μm in length were considered nonrespirable, even though some may have been respirable. All fibers and bundles were considered respirable.

Discussion

The techniques used in this study are those presently recommended and/or applied in floor tile removal. The data from the present studies confirm that asbestos fibers are released in appreciable numbers during application of each of the techniques. The AHERA procedure resulted in the least generation of asbestos-containing dust. Seven of 28 samples taken during dry procedures exceeded 0.1 f/cc by PCM analysis. Two of these samples were collected during dry removal by RFCI[14] hand-held scraper procedures and were reported as greater than 0.1 f/cc by PCM analysis. Three of four samples collected during dry removal by the RFCI[14] hand-held scraper method were reported greater than 1 str/cc by ATEM. Two of three samples collected during dry removal by hand spud bar were reported greater than 1 str/cc by ATEM.

While the purpose of this study was not focused on evaluation of potential health effects associated with these activities, it is obvious that a considerable fraction of the asbestos dust is of a respirable size. This point was documented by ATEM analysis of air samples in which the majority of freed fibers were too small to be detectable by the light microscope. Furthermore, any remaining nonrespirable, settled asbestos-containing particulates can be reduced to a respirable size by foot traffic or maintenance activities and can spread throughout the building.

Conclusion

Economic considerations have been used to justify decisions for floor tile removal by techniques other than full containment. These decisions frequently do not take into account either the potential exposure to workers and occupants, or the risk of contaminating the area of removal and other adjacent areas. The expense of training and compliance with OSHA[11] and MAP[21] requirements is often a significant consideration. However, while consideration of these costs is important, the data from the present study suggest that potentially respirable dust is created during floor tile removal and thus exposures occur for the workers and potentially others. Arguments made to the contrary and supported by PCM analysis are shown to be suspect by comparative ATEM analysis.

Prudent judgement, based on available knowledge, should be used when addressing floor tile removal procedures. The following recommendations are made to aid industrial hygienists and asbestos project designers:

1. Analyze all floor tile by ATEM bulk methods when reported 1 percent or less by PLM. Assuming asbestos at greater than 1 percent is always an option.
2. Conduct floor tile removals using a negative pressure enclosure, with polyethylene (1 layer) on walls and ceiling.
3. Use wet methods for floor tile removal.
4. Following cleanup and visual inspection, apply lock-down and allow to dry and settle.
5. Collect clearance samples by aggressive methods in accordance with 40 CFR 763, Subpart E.[2]
6. Analyze clearance samples by ATEM in accordance with 40 CFR 763, Subpart E.[2]

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