Zonolite Attic Insulation Exposure Studies

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Several studies were designed and conducted to evaluate amphibole asbestos exposures in homes containing Zonolite (expanded vermiculite) attic insulation (ZAI). A range of tasks selected for evaluation included cleaning, working around, moving, and removal of ZAI in attics and living spaces. The fieldwork for these studies was conducted at two homes in Spokane, WA and one home in Silver Spring, MD. Personal and area air samples were collected and analyzed as part of the exposure studies. Surface dust samples and bulk samples were also collected and analyzed. The results demonstrated that airborne concentrations of amphibole asbestos were not elevated if the material is undisturbed. The results also demonstrated that cleaning, remodeling, and other activities did produce significant concentrations of airborne amphibole asbestos when the ZAI was disturbed. *Key words*: asbestos; vermiculite; amphibole; exposure; insulation; renovation; remodeling; demolition; industrial hygiene; Zonolite; ZAI.

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INTRODUCTION

In 1926, the Vermiculite and Asbestos Company was formed to extract vermiculite from the Libby, MT area; since the time of the company's formation, it was known that vermiculite from Libby was contaminated with asbestos.[1] Two years later, on November 27, 1928, US patent number 1,693,015 was awarded to Joseph A. Babor and William L. Estabrooke for a molded insulating material made from expanded vermiculite, termed Zonolite.[2] One of the major uses of Zonolite was loose-fill insulation in attics of homes. By 1977 such loose-fill insulation, or Zonolite Attic Insulation (ZAI), constituted 15 % of domestic vermiculite use.[3] During each year of the 1970s alone approximately 53,000 tons of vermiculite were installed into US homes, according to a study commissioned by the United States Environmental Protection Agency (EPA).[4] The mines in Libby were the largest source of this vermiculite.[3]

Over the decades, studies were done at the Libby mine and mill as well as at other industrial sites evaluating exposures for asbestos-contaminated vermiculite.[5] Studies have also been performed, and ongoing studies are evaluating, past and current exposures to amphibole asbestos and resulting disease in the Libby area and numerous expansion plants.[6,7] W.R. Grace & Co. (WRG) produced and sold ZAI for many years. The company no longer produces ZAI and has filed for bankruptcy. The scientific and medical literature includes thousands of articles evaluating asbestos exposure and disease in asbestos mining and milling operations, asbestos product manufacturing and installation, and asbestos abatement. There is a small collection of articles that consider asbestos exposure and disease from fibers carried into the home from the workplace. Other studies have looked at concentrations of asbestos in the outdoor air, and some have summarized air sampling measurements inside public and commercial buildings. People are clearly exposed to airborne contaminants not only in the workplace but in the outdoors as well. However, many, if not most people spend more time in their home environment than any other and, significantly, there is a gap in the literature when considering asbestos exposure from materials in the home. In this study we looked at amphibole asbestos exposure in homes from attic insulation made from expanded vermiculite, or ZAI.

The first study to report exposures from disturbing in-place asbestos-contaminated vermiculite was presented at the American Industrial Hygiene Conference in 1997.[8] This study measured exposures to workers when demolishing a building with asbestos-contaminated attic insulation in Manitoba, Canada.[9] Samples of the vermiculite attic insulation were reported as containing generally less than 0.1% actinolite and/or tremolite asbestos. This study reported personal exposures to workers demolishing a ceiling, performing clean-up, and disposing of the waste, which ranged from 3.3 to 6.8 fibers greater than 5 μm in length per cubic centimeter (f/cc). The same samples analyzed by transmission electron microscopy (TEM) found 4.4 to 174 asbestos fibers greater than 5 μm per cubic centimeter (f/cc). This study did not address what expo-

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Figure 1—Home A.

Figure 2—Home B.

Figure 3—Home C.

sures, if any, might result from routine tasks performed by homeowners in attics with Zonolite vermiculite.

We designed and conducted a series of studies to evaluate amphibole asbestos exposures during specific activities conducted in homes containing ZAI. The tasks selected for evaluation were as follows:

- cleaning stored items in an attic with ZAI at the perimeter only;
- cleaning storage areas in an attic fully insulated with ZAI;
- cutting a hole in the ceiling of a living space below ZAI attic insulation;
- moving ZAI using the WRG method;
- moving ZAI using a homeowner method; and
- removing ZAI from the top of wall cavities with a shop vacuum.

METHODS

Selection of Homes

One of the authors visited over a dozen homes to determine if they were possible candidates. The primary criterion was the presence of Zonolite vermiculite used as insulation in the home. The homes also needed to be available for study and sampling over approximately a three- to four-day period. The testing was designed to avoid exposing the occupants to any additional asbestos. The homes selected needed to have reasonable access to the attics. The availability of electricity and water was also necessary. Three homes were selected (Figures 1, 2, and 3).

Selection of Tasks

Possible activities during which asbestos exposures might be measured were considered during preparation of the study design. These included cleaning tasks, service work, maintenance, remodeling, renovation, and demolition activities. The category "no activity" was considered and selected as a baseline for comparison with the tasks to be tested. Long-term sampling in occupied homes was not considered feasible due to time and budgetary constraints. Tasks selected for testing were those that might occur in homes and that might reasonably be expected to disturb in-place Zonolite insulation or the dust/debris from that insulation.

Description of Tasks

Before conducting testing, the area where each task would occur was separated from the rest of the house by erecting a two-stage decontamination station at the entrance to the attic or room. Each decontamination station consisted of two small rooms (approximately 4′ × 4′) separated by plastic flap doorways and was similar to those used on asbestos abatement projects. The inlet for a high efficiency particulate air (HEPA) filtered vacuum was placed in the room closest to the work area. The decontamination station was designed to prevent dust generated from the activities conducted from migrating out of the attic or room. It also served as a location for persons to change out of personal protective equipment and to clean themselves and equipment. As necessary, suspended shop lights were installed to provide better lighting. Area sampling equipment, extension cords, tripods, and miscellaneous tools/sup-

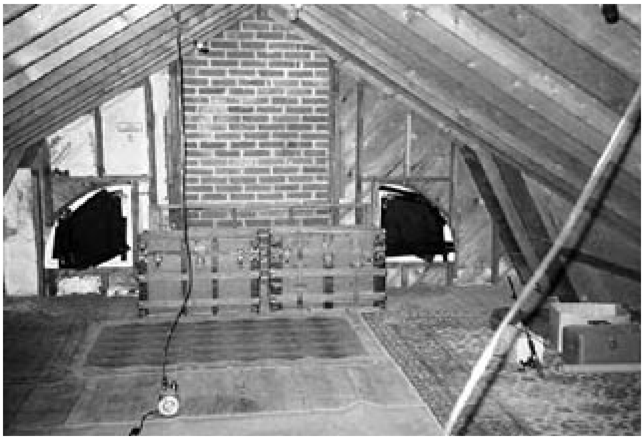

Figure 4—View of attic area cleaned in home B.

Figure 5—View of attic in home C.

plies necessary to perform the tasks were brought into the area.

After the tasks were performed, any items removed from the area were HEPA-vacuumed and wet-cleaned. Accessible Zonolite insulation in the attics of the homes was removed by a state licensed asbestos abatement contractor. During and after these activities, area air sampling was conducted by a local consulting firm to determine if asbestos had migrated to normally occupied locations and if the attics were clean after abatement.

Cleaning of stored items in an attic with Zonolite at the top of wall cavities only. This activity was performed in the attic of home B (Figure 4). In this home the Zonolite insulation was limited only to the perimeter (primarily the east and west sides) of the attic space at the top of the wall cavities. Cleaning was performed by one individual with an assistant to help move trunks and boxes.

The cleaning consisted of dusting the top surfaces of approximately eight stored boxes, two trunks, and fishing tackle with new cotton cloths, as well as sweeping exposed wood floor areas with a corn broom (Harper brand, model No. 100, Harper Brush Works, Fairfield, IA 52556). Rugs on the attic floor were cleaned with a standard upright vacuum cleaner (Eureka brand Upright Vacuum Cleaner, Household Type, Model No. 7600, The Eureka Company, Bloomington, IL 61710). The homeowner reported the attic had last been cleaned two years prior to this work and we followed the procedures in the same manner as that cleaning, as described by the homeowner. About half of the attic floor area was cleaned (approximately 390 ft^2). The cleaning activity took 31 minutes to complete and were completed in the following order: sweeping (1 min) dusting (13 min), and vacuuming (17 min).

Cleaning of storage area in an attic fully insulated with Zonolite. This activity was performed by one person in home C, who used a new corn broom to sweep spilled ZAI back into the space between ceiling joists in the attic (Figure 5). The person also used a hand broom to sweep ZAI from wooden boards located in the attic. The task took approximately 16 minutes to complete.

Cutting a hole in the ceiling of a living space below Zonolite attic insulation. This activity was performed at home A (Figure 6). The hole was similar to one that might be needed to install a recessed light fixture or ceiling fan. One person cut an opening in the ceiling measuring 15″ × 24″ in a room measuring 11′2″ × 13′4″ with the assistance of a second person. The ceiling material consisted of a stipple finish on 1⁄4″ wallboard, one layer of wallpaper, finish hard plaster, and a coating of gray hard plaster on wood lathe.

The cutting was started by drilling a 2″ diameter hole at one corner of the rectangle to be cut with a power drill equipped with a keyhole saw bit. The remainder of the cutting was performed with a Stanley brand 12″ hand compass saw (both the keyhole and the compass saw had eight-point blades). The entire cutting activity took 24 minutes to complete with drilling the starting hole taking less than one minute and the remainder of the time spent hand-sawing with periodic short rest breaks. The average depth of Zonolite insulation above the cutout area was 4″.

Moving aside Zonolite attic insulation (W.R. Grace & Co. method).[10] This activity was performed in the attic of home A (Figure 7). The floor of the attic was 756 ft^2 (28′ × 27′). This task was performed primarily by one person with the assistance of a second person.

The activity consisted of removing approximately 15 ft^2 (2′6″ × 6′) of ZAI having an average depth of 5″ from between the floor joists. This material was misted with water using a hand-held pump-up garden sprayer immediately before the work began. The Zonolite was scooped from between the floor joists and into plastic bags using a plastic dustpan. The remaining visible dust and debris was removed using a new HEPA-filtered vacuum cleaner (Ridgid brand, model no. WD09350, manufactured by Emerson Electric Co., with a Trapmax 3 model no. VF6000 HEPA filter rated at 99.97% efficient down to 0.3 microns installed).

Figure 6—View of ceiling after cutting, home A.

Figure 7—View of ZAI after moving by W.R. Grace & Co. method.

The activity took 33 minutes to complete, consisting of two minutes for misting with water, 25 minutes for scooping Zonolite into plastic bags, and six minutes for vacuuming.

Moving aside Zonolite attic insulation (homeowner method). This task was performed in the same attic (home A) as the previous test. This activity consisted of removing approximately 14.4 ft^2 (2'8″ × 5′5″) of Zonolite attic insulation with an average depth of 5″ from between the floor joists (Figure 8). The work was performed using the same methods, except the Zonolite was not misted with water at the start of the work and a whiskbroom and plastic dustpan were used to remove the visible dust and debris at the end of the work (O Cedar brand corn whiskbroom, 10″ long, bristle spread 8″ by 1″). The work took 29 minutes to complete, consisting of 15 minutes scooping ZAI into plastic bags and 14 minutes using a whiskbroom to clean dust and debris.

Removal of Zonolite insulation from the top of wall cavities with a shop vacuum. This activity was performed in the attic of home B (Figure 9). The removal was performed by one individual with an assistant. The work consisted of removing approximately 60′ of Zonolite insulation from a trough at the perimeter of the attic having an average width of 5.5″ and depth of approximately 4″. The equipment used to remove the Zonolite was a new standard shop vacuum (Ridgid brand, model no. WD0620, manufactured by Emerson Electric Co., with part no. VF4000 filter installed). The work took 44 minutes to complete and consisted of vacuuming up Zonolite until the shop vacuum was about half full (approximately three gallons) and dumping the contents into a plastic trash bag. The shop vacuum was emptied seven times during this activity.

Personnel Protection

Prior to the start of any field work, and again at the work sites, all personnel were briefed on the project and the known health and safety hazards likely to be encountered. During the testing, any persons entering the attics or other work areas were required to wear respiratory protection and two layers of full body protective clothing. Full-face powered-air purifying respirators equipped with high efficiency filters approved by the National Institute for Occupational Health and Safety (NIOSH) to prevent asbestos exposure were used. Personnel decontamination was performed on-site through the use of a HEPA-filtered vacuum followed by wet washing. Homeowners were not permitted to enter the home until after cleaning was completed by a state licensed asbestos abatement contractor and clearance air sampling had been completed.

Sampling Methods

Air, dust, and bulk samples were collected as part of this study. Sample logs and chain-of-custody forms were completed for all samples. Air, dust, and bulk samples were stored and transported separately to minimize the opportunity of cross-contamination between samples. The amphibole asbestos species identified by electron microscopy or polarized light microscopy in air, dust, or bulk samples are reported herein as "Libby amphiboles" and consisted of fibrous tremolite, richterite, winchite, and actinolite.[11,12]

Air sampling. Personal and area air sampling was conducted. Personal samples were collected in the breathing zone of the person, but outside the full-face respirator. The personal samples were secured to the full-face respirator at approximately eye level so the sample would not be located in the exhaust of the powered-air purifying respirator. The filter cassettes were positioned at approximately a 45-degree angle pointed downward. Personal samples were collected using battery-operated air sampling pumps calibrated before and after each set of samples during an activity (Mine Safety Appliance [MSA] brand model ELF sampling

Figure 8—View of Zonolite in attic after moving by homeowner method.

pumps and one MSA brand model Flowlite pump). Area samples were collected using electric air sampling pumps (Dawson brand Gast electric pumps). All personal sampling pumps were calibrated on-site using a primary flow meter (Bios International Corp., DryCal DC-Lite Primary Flow Meter, S/N 6615).

Personal samples were collected in pairs. One sample was collected on a mixed cellulose ester (MCE) membrane filter (25 mm diameter) having a pore size of 0.8 micrometers (μm). The other sample in the pair was collected on the same type of filter with a pore size of 0.45 μm. Personal samples were typically collected at flowrates between 0.5 and 1.0 liters per minute (l/min) due to the dusty environment anticipated. Area samples were typically collected at flowrates of seven to 10 l/min in less dusty environments and two to four l/min in more dusty environments.

During the testing, the personal and area air sample filters were visually inspected at least every five minutes to estimate dust loading. The sampling filters were changed whenever there was a visible discoloration of the filter surface to reduce the chance of excessive dust loading on the filters. Blank samples were collected at a rate of 10% or two per sampling batch, whichever was greater.

All air samples were submitted to a laboratory accredited by the American Industrial Hygiene Association (AIHA) and the National Voluntary Laboratory Accreditation Program (NVLAP) (administered by the National Institute of Standards and Technology (NIST), or were A2LA accredited under ISO Standard 17025. Personal air samples collected on 0.8 μm pore size MCE filters were analyzed by phase contrast microscopy (PCM) as described in NIOSH method 7400.[13] Personal and area air samples collected on 0.45 μm MCE filters were analyzed by transmission electron microscopy (TEM) using the direct preparation techniques described in the EPA Code of Federal Regulations.[14] This method is commonly referred to as the EPA AHERA method. The results of the PCM samples are reported as fibers per cubic centimeter of air sampled (f/cc). The results of the TEM samples are reported as structures per cubic centimeter of air samples (s/cc). Using the TEM fiber size information for four of the five sets of data, the PCM equivalent (PCME) concentrations were calculated and reported in f/cc.

Dust sampling. Surface dust samples were collected using ASTM method D 5755, Standard Test Method for Microvacuum Sampling and Indirect Analysis of Dust by Transmission Electron Microscopy for Asbestos Structure Number Concentrations.[15] This method uses a sampling pump calibrated at two l/min to vacuum dust onto a 0.45 μm pore size MCE filter from a measured surface area of typically 100 square centimeters (cm^2). These samples were analyzed by TEM as described in ASTM D 5755 and results reported as asbestos structures per square centimeter of surface area sampled (s/cm^2).

Bulk sampling. Bulk insulation samples were collected by placing a small quantity in a labeled sealed container, and submitted for analysis by polarized light microscopy (PLM) as described by the method EPA-

Figure 9—View of ZAI at top of wall cavity before shop vacuum removal.

TABLE 1 Summary of Air Sampling Results for Cleaning of Stored Items with Zonolite at the top of Perimeter Wall Cavities Only

Sample Location	Number of Samples n	PCM TWA f/cc	TEM TWA s/cc	s/cc >5 μm	PCME (f/cc)
Worker, personal	3,3	1.54	< 0.42	< 0.42	< 0.42
Assistant, personal	3,3	0.53	< 0.33	< 0.33	< 0.33
Area, in cleaning area	3	—	0.12	0.11	0.10
Area, adjacent to cleaning area	3	—	0.07	0.07	0.04
Area, ~10 feet away	3	—	0.06	0.06	0.06
Area, ~20 feet away	3	—	< 0.05	< 0.05	< 0.05
Area, before cleaning	4	—	< 0.002	< 0.002	< 0.002

600/MR-82-020, Interim Method for the Determination of Asbestos in Bulk Insulation Sample.[16] Results are reported as percentages of asbestos by volume. This standard EPA PLM method sometimes fails to detect the amphiboles present in vermiculite samples due to the non-homogeneous distribution of the amphiboles in the vermiculite. Since this work was performed, the EPA has published an improved method designed specifically for analyzing vermiculite-containing attic insulation.[17]

RESULTS

Cleaning of Stored Items in an Attic with Zonolite at Top of Perimeter Wall Cavities Only

Four area air samples were collected before the start of cleaning activities. No asbestos structures were detected in these samples and a detection limit of less than 0.002 s/cc was reported. During the cleaning activity the personal exposure measurements for the worker measured by PCM ranged between 0.82 and 2.53 f/cc, with a time-weighted average (TWA) during the 33-minute time period of 1.54 f/cc. During a 34-minute time period the personal exposure measurements for the assistant measured by PCM ranged between < 0.54 and 0.82 f/cc, with a TWA of 0.53 f/cc. The value of one-half the detection limit value was used to calculate the TWA where no fibers were detected in the sample. To use zero would likely bias the calculated TWA low, and to use the detection limit value would bias the calculated TWA value high. No asbestos structures were detected in three samples collected on the worker and the three samples collected on the assistant during the cleaning activity. The TWA values were < 0.42 s/cc for the worker and < 0.33 s/cc for the assistant.

Four sets of three area air samples (12 total) were collected during the cleaning activity and analyzed by TEM. The TWA during a 31-minute time period for the three samples in the group closest to the cleaning activity was 0.12 s/cc for all structures greater than 0.5 μm in length and 0.11 s/cc for structures > 5 μm in length. The TWA during a 32-minute time period for the next closest set of three area air samples was 0.07 s/cc for structures > 5 μm in length. The TWA during a 32-minute time period for the next closest set of three area air samples was 0.06 s/cc for structures > 5 μm in length. The TWA during a 31-minute time period for the set of three area air samples farthest from the cleaning activity was < 0.05 s/cc. No asbestos structures were detected in these three samples. The results for the air samples collected for this cleaning activity are summarized in Table 1.

Before the cleaning activity began four dust samples were collected from four non-porous attic surfaces. The results ranged from not detected to 38,000 s/cm^2, with an average (logarithmic mean) of 9500 s/cm^2. Three bulk samples of Zonolite collected from the attic perimeter were analyzed by PLM and found to contain a “trace” of Libby amphiboles by volume (a “trace” finding by PLM is an estimate of some value less than 0.1%).

Just prior to the cleaning activity four sheets of aluminum foil were placed on surfaces to collect dust settling during a 23-hour period. The locations ranged from about 10′ to 20′ away from the cleaning activity so they would not need to be disturbed during the cleaning activity. No asbestos structures were found in the four dust samples collected from the foil sheets. Values < 300 s/cm^2 are reported for each sample.

This cleaning study highlights a shortcoming in two commonly used air sampling methods when employed to measure fibers or asbestos structures in a “dusty atmosphere.” The direct preparation TEM method requires that small sample volumes be collected to prevent overloading of the filter surface. When the dust collected is predominantly asbestos, this is not a problem. When the dust collected is predominantly not asbestos, the non-asbestos dust obscures the asbestos structures. The result is a higher than desirable sensitivity. For the PCM samples, the non-asbestos fiber content of normal house dust (primarily cellulose fiber) provides for a high fiber count when only a fraction of those fibers are asbestos.

For this study, the three area air samples collected in the cleaning area provided the best asbestos fiber exposure information for an individual cleaning stored

TABLE 2 Summary of Air Sampling Results for Cleaning of Storage Area in an Attic Fully Insulated with Zonolite

Sample Location	Number of Samples n	PCM TWA (f/cc)	TEM TWA (s/cc)	s/cc >5 μm
Worker, personal	3,3	2.87	4.00	2.58
Assistant, personal	3,3	0.65	0.43	0.43
Area, sample set 1	3	—	0.88	0.61
Area, sample set 2	3	—	0.61	0.43
Area, sample set 3	3	—	0.39	0.30
Area, Pre-work	5	—	< 0.005	< 0.005

items in an attic with Zonolite located in the perimeter wall cavities. These data indicate an average exposure of 0.12 s/cc during cleaning, a value 60 times higher than the background measurements collected in the same area before the cleaning activity.

Cleaning of Storage Area in an Attic Fully Insulated with Zonolite

Five area air samples were collected before the start of cleaning activities. No asbestos structures were detected in these samples. A concentration of < 0.005 s/cc (limit of detection) was reported. During the cleaning activity the personal exposure measurements for the worker measured by PCM ranged between 2.71 and 3.00 f/cc with a TWA during the 18-minute time period of 2.87 f/cc. During the 18-minute time period the personal exposure measurements for the assistant measured by PCM ranged between < 0.55 and 1.05 f/cc, with a TWA of 0.65 f/cc.

Three sets of three area air samples (nine total) were collected during the cleaning activity and analyzed by TEM. Results were reported for structures greater than 0.5 μm in length and for structures > 5 μm in length. The TWA during a 16-minute time period for the three samples in the group closest to the cleaning activity was 0.88 s/cc and 0.61 s/cc. The TWA during a 16-minute time period for the next closest set of three area air samples was 0.61 s/cc and 0.43 s/cc. The TWA during a 16-minute time period for the farthest set of three area air samples was 0.39 s/cc and 0.30 s/cc. The results for the air samples collected for this cleaning activity are summarized in Table 2.

Three surface dust samples collected from the wood boards before cleaning contained 99,200 s/cm^2, 34,200 s/cm^2, and 96,600 s/cm^2. One sample of dust and other fine particles beneath spilled ZAI from a wooden surface contained 1.9 million s/cm^2.

From these data it may be concluded that persons cleaning an attic directly impacting Zonolite insulation will be exposed to significant concentrations of amphibole asbestos. The worker exposure was measured at almost 1000 times the background samples collected before the cleaning activity.

Cutting a Hole in the Ceiling of a Living Space Below Zonolite Attic Insulation

Prior to cutting the hole in the ceiling a set of three area air samples were collected in a second-floor bedroom. The TEM analysis found an average of 0.023 s/cc and 0.017 s/cc for structures > 5 μm in length. During the cutting process the worker and the assistant each wore two air sampling pumps for samples to be analyzed by PCM and TEM. Due to the dusty nature of the work, four sequential samples were taken for each pump (16 total). Four sequential samples were also collected at each of three area air sampling locations. These area samples were all analyzed by TEM.

The four PCM samples collected on the worker ranged from 1.42 f/cc to 14 f/cc, with a TWA of 5.8 f/cc during the 26-minute period. The four PCM samples collected on the assistant ranged from 0.81 f/cc to 16 f/cc, with a TWA of 5.4 f/cc during the 28-minute period. The difference between the 26 minute sample set and the 28 minute sample set is due the time needed to change filter cassettes on the sampling pumps.

The four TEM samples collected on the worker ranged from "not detected" (< 0.43 s/cc) to 4.98 s/cc (2.85 s/cc > 5 μm). The 26-minute TWA for the worker was 2.48 s/cc (1.32 s/cc > 5 μm). The four TEM samples collected on the assistant ranged from "not detected" to 1.83 s/cc (all structures were > 5 μm). The 28-minute TWA for the assistant was 0.80 s/cc (> 5 μm).

The three sets of four TEM area air samples collected in the same room had TWA values of 0.51 s/cc (set 1), 0.57 s/cc (set 2), and 0.77 s/cc (set 3). Considering only structures > 5 μm, the corresponding values were 0.41 s/cc (set 1), 0.54 s/cc (set 2), and 0.60 s/cc (set 3).

The data demonstrated that peak exposures occurred during the last five minutes of cutting the hole, when approximately 0.8 ft^3 of Zonolite spilled from the ceiling to the floor, a distance of about 9′. The TEM personal samples found 4.98 s/cc (2.85 s/cc > 5 μm) for the worker and 1.83 s/cc (all > 5 μm) during this phase of the work. The area air samples were similarly elevated during this phase of the work. The air sampling data are summarized in Table 3.

Three bulk samples of ZAI were collected and each found to contain less than 1% amphibole asbestos by PLM. A bulk sample of the ceiling that was cut was also analyzed by PLM for asbestos. The ceiling consisted of wood lathe, hard plaster, finish plaster, 1⁄4″ gypsum wallboard with wallpaper, and a stippled finish coat. Approximately 7% chrysotile asbestos was found in the stippled finish coat. No asbestos was found in the other materials. Accordingly, the ceiling system material cut was less than 1% chrysotile. Only Libby amphiboles were detected in the air samples.

Cutting a plaster/wallboard/wood ceiling is a dusty operation. The PCM method of measuring fiber concentrations in such an atmosphere is not a good pre-

TABLE 3 Summary of Air Sampling Results While Cutting Hole in Ceiling Below Attic with Zonolite Insulation

Sample Location	Number of Samples n	PCM TWA f/cc	TEM TWA s/cc	s/cc > 5 μm	PCME (f/cc)
Worker, personal	4,4	5.8	2.48	1.32	1.16
Assistant, personal	4,4	5.4	0.80	0.80	0.50
Area, sample set 1	4	—	0.51	0.41	0.38
Area, sample set 2	4	—	0.57	0.54	0.54
Area, sample set 3	4	—	0.77	0.60	0.56
Area, before activity	3	—	0.023	0.017	0.013

dictor of asbestos exposure. The TEM data provides the best exposure information in this instance since the method can distinguish between asbestos and non-asbestos structures. The use of the direct TEM method to measure asbestos in an atmosphere with considerable non-asbestos dust is a concern.

From this data it may be concluded that persons cutting a hole into a ceiling below Zonolite insulation will be exposed to significant concentrations of amphibole asbestos. The worker exposure was over 100 times the concentration in the background samples collected before the activity.

Moving Aside Zonolite Attic Insulation Using the W. R. Grace & Co. Method[10]

Before moving any ZAI three area air samples were collected for TEM analyses. No asbestos structures were detected in these samples. A detection limit of less than 0.002 s/cc is reported.

Personal samples were collected on the worker and the assistant during the activity. Four sequential samples were collected to prevent overloading of the filters for each sample set. Three sets of four area samples (12 total) were collected during this activity. The worker exposure was measured by four PCM samples and four TEM samples. For the assistant, both the PCM and TEM analyses were performed on the PCM filters only since the TEM filters were voided due to a sampling malfunction (crimped sampling tube).

The PCM results for the worker ranged from 4.61 f/cc to 16.24 f/cc, with a 34-minute TWA of 12.5 f/cc. The PCM results for the assistant ranged from 2.29 f/cc to 4.25 f/cc, with a 34-minute TWA of 3.12 f/cc. The TEM results for the worker ranged from 1.01 s/cc to 10.6 s/cc (1.01 s/cc to 8.58 s/cc > 5 μm), with a 34-minute TWA of 6.29 s/cc (4.85 s/cc > 5 μm). The TEM results for the assistant ranged from 4.35 s/cc to 6.42 s/cc (1.16 s/cc to 4.67 s/cc > 5 μm), with a 34-minute TWA of 5.50 s/cc (2.74 s/cc > 5 μm).

The TEM results for the three sets of area air samples as 34-minute TWAs were 3.78 s/cc (set 1), 1.86 s/cc (set 2), and 1.25 s/cc (set 3). Considering only structures greater than 5 μm, the 34-minute TWAs were 3.17 s/cc (set 1), 1.48 s/cc (set 2), and 0.90 s/cc (set 3). The results for all the area and personal samples are summarized in Table 4.

Moving Aside Zonolite Attic Insulation Using the Homeowner Method

A set of three background samples were collected from the attic before starting the activity. No asbestos structures were detected on these samples, and an average of < 0.003 s/cc was reported. The same sampling protocol was followed as was performed when moving the Zonolite using the Grace method.

The PCM results for the worker ranged from 9.48 f/cc to 18.81 f/cc, with a 31-minute TWA of 14.4 f/cc. The PCM results for the assistant ranged from 0.64 f/cc to 10.4 f/cc, with a 32-minute TWA of 4.98 f/cc. The TEM results for the worker ranged from 11.8 s/cc to 15.0 s/cc (8.4 s/cc to 12.1 s/cc > 5 μm), with a 31-minute TWA of 13.0 s/cc (10.3 s/cc > 5 μm). The TEM results for the assistant ranged from < 0.35 s/cc to 4.23 s/cc (< 0.35 to 3.82s/cc > 5 μm), with a 32-minute TWA of 2.38 s/cc (1.89 s/cc > 5 μm).

TABLE 4 Summary of Air Sampling Results During Moving Zonolite Attic Insulation Using the W.R. Grace Method

Sample Location	Number of Samples n	PCM TWA f/cc	TEM TWA s/cc	s/cc > 5 μm	PCME (f/cc)
Worker, personal	4,4	12.5	6.29	4.85	4.48
Assistant, personal	4	3.12	5.50	2.74	2.74
Area, sample set 1	4	—	3.78	3.17	2.90
Area, sample set 2	4	—	1.86	1.48	1.40
Area, sample set 3	4	—	1.25	0.90	0.82
Area, before activity	3	—	< 0.002	< 0.002	< 0.002

TABLE 5 Summary of Air Sampling Results During Moving Zonolite Attic Insulation Using the Homeowner Method

Sample Location	Number of Samples n	PCM TWA f/cc	TEM TWA s/cc	s/cc >5 μm	PCME (f/cc)
Worker, personal	4,4	14.4	13.0	10.3	9.27
Assistant, personal	4	4.98	2.38	1.89	1.75
Area, sample set 1	4	—	1.21	1.07	0.90
Area, sample set 2	4	—	2.00	1.57	1.47
Area, sample set 3	4	—	3.04	2.38	2.26
Area, before activity	3	—	< 0.003	< 0.003	< 0.003

The TEM results for the three sets of area air samples as TWAs were 1.21 s/cc (set 1, 28 minutes), 2.00 s/cc (set 2, 39 minutes), and 3.04 s/cc (set 3, 39 minutes). Considering only structures greater than 5 μm, the TWAs were 1.07 s/cc (set 1), 1.57 s/cc (set 2), and 2.38 s/cc (set 3). The results for the air samples are summarized in Table 5.

The results of sampling during the two methods of moving aside ZAI demonstrated that neither method effectively controls the generation of amphibole asbestos dust. Evaluation of the Grace method found the worker exposure to be 3100 times the levels in the background measurements, and analytical results of the homeowner method indicated the worker exposure to be 4300 times the levels in the background measurements. A review of the workers' individual sample results showed a significant exposure reduction during the last nine minutes of the task using the Grace method. This was likely due to the use of the HEPA-filtered vacuum to remove dust from between the attic floor joists during this time frame. Personal sampling results indicated 18.81 f/cc without the HEPA vacuum and 4.61 f/cc with the HEPA vacuum. A similar reduction was seen in the TEM data. Visually, the air in the vicinity of the HEPA vacuum (and the worker) became clearer. It appears the HEPA vacuum was functioning not only to scrub dust particles from the air, but also to capture dust at the surface.

Both methods of moving ZAI were dusty procedures. However, since much of the airborne fibrous dust was amphibole asbestos, the limitations of using PCM and direct TEM were not as pronounced. In a different attic that might contain ZAI and another product, such as treated cellulose or mineral wool, interference from non-asbestos fibers would likely make sampling and analysis more challenging since the non-asbestos fibers would be interpreted as asbestos by the PCM method. The TEM method can disregard the non-asbestos fibers, but in a dusty environment may make the analysis difficult, if not impossible. In some instances it may be necessary to use the indirect TEM preparation technique to overcome the overloaded sample.

The use of water to mist the ZAI was not very effective as a dust suppressant. This may have been due to the thickness of the attic insulation and the micaceous product itself. Caution should be used when using water on Zonolite attic insulation. Old and poorly insulated electric wiring is often found in the loose attic fill material. This poses an electric shock hazard.

Removal of Zonolite Attic Insulation with a Shop Vacuum from the Top of Perimeter Wall Cavities

Before beginning the removal of ZAI from the top of perimeter wall cavities, a set of four area air samples were collected to establish the background concentration of asbestos. No asbestos was detected in these samples and the limit of detection values of less than 0.0016 s/cc were reported.

Personal samples were collected on the worker and the assistant during the activity. Four sequential samples were collected to prevent overloading of the filters for each sample set. Four sets of four area samples (16 total) were collected during this activity. The worker's exposure was measured by four PCM samples and four

TABLE 6 Summary of Air Sampling Results During Removal of Zonolite Insulation with a Shop Vacuum from the Top of Wall Cavities

Sample Location	Number of Samples n	PCM TWA f/cc	TEM TWA s/cc	s/cc >5 μm	PCME (f/cc)
Worker, personal	4,4	2.90	1.47	0.98	0.97
Assistant, personal	4	2.90	1.69	1.10	1.03
Area, sample set 1	4	—	0.52	0.37	0.32
Area, sample set 2	4	—	0.67	0.45	0.40
Area, sample set 3	4	—	0.89	0.57	0.47
Area, sample set 4	4	—	1.00	0.73	0.63
Area, before activity	4	—	< 0.0016	< 0.0016	< 0.0016

TABLE 7 Summary of Air Sampling Results

Activity Evaluated	Personal Samples f/cc	Personal Samples s/cc	Personal Samples s/cc >5µm	Area Samples s/cc	Area Samples s/cc >5 µm
Cleaning items in an attic	1.54	< 0.42	< 0.42	0.08	0.07
Cleaning storage area in an attic	2.87	4.00	2.58	0.63	0.47
Cutting hole in ceiling below ZAI	5.80	2.48	1.32	0.62	0.52
Moving ZAI-manufacturer method	12.5	6.29	4.85	2.30	1.85
Moving ZAI-homeowner method	14.4	13.00	10.30	1.82	1.47
Shop vacuum removal	2.90	1.47	0.98	0.77	0.53
No activity	—	—	—	< 0.003	< 0.003

TEM samples. For the assistant, eight samples were also collected, but the PCM and TEM analyses were performed on the PCM filters (0.8 µm pore size) since the TEM samples were voided due to sampling malfunction (crimped sampling tube).

The PCM results for the worker ranged from 1.19 f/cc to 5.28 f/cc, with a 46-minute TWA of 2.90 f/cc. The PCM results for the assistant ranged from 1.47 f/cc to 4.81 f/cc, with a 46-minute TWA of 2.90 f/cc. The TEM results for the worker ranged from 1.05 s/cc to 2.16 s/cc (0.58 s/cc to 1.32 s/cc, >5 µm), with a 46-minute TWA of 1.47 s/cc (0.98 s/cc, > 5 µm). The TEM results for the assistant ranged from 0.67 s/cc to 2.15 s/cc (<0.67 s/cc to 1.79 s/cc, > 5 µm), with a 46-minute TWA of 1.69 s/cc (1.10 s/cc, > 5 µm).

The TEM results for the four sets of area air samples as TWAs were 0.52 s/cc (set 1, 43 minutes), 0.67 s/cc (set 2, 42 minutes), 0.89 s/cc (set 3, 42 minutes), and 1.00 s/cc (set 4, 45 minutes). Including only structures greater than 5 µm, the TWAs were 0.37 s/cc (set 1), 0.45 s/cc (set 2), 0.57 s/cc (set 3), and 0.73 s/cc (set 4). The results for the air samples are summarized in Table 6.

Just prior to the removal activity, four sheets of aluminum foil were placed on surfaces to collect dust which might settle during the activity and for a period of 20 to 33 minutes following completion of the activity. The total collection time was 65 to 78 minutes. No asbestos structures were found in two of the samples (< 300 s/cc reported as the limit of detection). The other two samples found 300 s/cm^2 and 700 s/cm^2 of amphibole asbestos. The data, when viewed together with the area air sampling, indicate that one hour may not be sufficient time to allow for the asbestos structures to settle out of the air.

The worker and the assistant exposure data were very similar for this activity. The likely cause was that the worker and assistant worked together to dump the Zonolite from the vacuum into plastic bags. This was a visually dusty operation.

The data from the use of a standard shop vacuum to remove Zonolite insulation demonstrated that this activity resulted in significant exposure to amphibole asbestos. The worker exposure for this study was found to be 735 times the levels measured in the background samples collected before the activity began.

Additional Observations

All air sampling results from our studies are summarized in Table 7. These studies were limited to only three homes with ZAI. Under contract to the US EPA, Versar, Inc. has also conducted a series of studies to characterize exposures from vermiculite attic insulation.[18] Some of these studies consisted of activities in a small containment, a large containment, and one home in Vermont. The activities they considered were as follows:

1. installing and removing vermiculite attic insulation;
2. performing wiring/small renovations in an attic with vermiculite;
3. using an attic with vermiculite insulation as storage space;
4. living in a house where disturbances to vermiculite insulation occurs; and
5. measuring background levels in a house with vermiculite attic insulation.

Versar conducted air sampling before, during, and after 20 activities. In general, they found significantly increased airborne concentrations when the vermiculite attic insulation was directly disturbed.

Additional studies in other homes evaluating exposures from these types of activities as well as other activities may be helpful. While Versar's studies addressed measured amphibole from asbestos-contaminated vermiculite attic insulation, vermiculite was also commonly used as fill-in for concrete block walls. The authors of this present study are not aware of published studies evaluating exposures from vermiculite filled block walls. This is an area deserving future research.

The EPA has conducted several studies evaluating exposures to ZAI. These studies as well as guidance for homeowners may be found at http://www.epa.gov/asbestos/pubs/verm.html. In the US and Canada ZAI was used in homes, with much of the insulation coming from the Libby, MT deposit. To what extent this same material may have been exported outside of these two countries is unknown.

Analyses conducted in the field and on laboratory blank samples indicated there was no systematic contamination of the samples in the field or the laboratory. Samples collected outdoors failed to detect any amphibole asbestos.

The background samples collected in the attics of the three houses indicated that absent any disturbance, there was not an elevated concentration of asbestos in the air. Similar sampling should be conducted in homes during high wind storms. Anecdotal information from at least one homeowner indicates that some Zonolite insulation is blown out from wall cavities under certain circumstances.

Home C had an attic fan that may have been responsible for the displacement of some of the ZAI. Another interesting investigation would be to determine the exposures among occupants in homes with ZAI when attic fans are operating.

CONCLUSIONS

This series of studies indicatesd that ZAI present in the attic of homes, if undisturbed, seems not to result in elevated exposures. Likewise, the data presented here demonstrated that many routine cleaning, maintenance, and remodeling activities that disturb ZAI can generate significant airborne amphibole asbestos exposures. A review of Tables 2 to 6 demonstrates that the OSHA excursion limit for asbestos of 1 f/cc during any 30-minute period was often exceeded. Depending on the length of the work, the OSHA eight-hour permissible exposure limit (PEL) would often have been exceeded. When such work in attics are performed by homeowners, the OSHA regulations do not apply. This is one of the gaps in regulatory coverage for asbestos.

There is a need to assess what exposures occur during the demolition of homes with ZAI and evaluate control measures that will eliminate or minimize the exposures experienced by workers and the community. A standard protocol for the removal of ZAI from homes should be developed.

Analyses conducted of the bulk ZAI in these homes and other buildings generally results in amphibole asbestos concentrations of less than 1% and often less than 0.1 %. However, the exposure data presented here, and the exposure data from the Manitoba building referenced earlier, demonstrate that significant exposures can still occur. These exposures can be in excess of current regulatory exposure limits.

To what extent these results may be generalized to the disturbance of other materials in buildings with less than 1% asbestos, such as some wall plasters, has not been established. However, it would be prudent to evaluate exposures for materials where asbestos is detected in the bulk samples at any level. One type of Zonolite vermiculite was also used in some fireproofing for structural steel with no added asbestos. We are not aware of any published data evaluating exposures during disturbances of this material. Publication of such information could assist building owners and managers in reducing future exposures.

Requiring the control of exposures arising from building materials containing less than 1% asbestos has a number of policy implications. Traditionally the regulatory agencies, such as OSHA and EPA, have set a limit of 1% to trigger the identification of a material as "asbestos-containing." With improved analytical techniques, regulatory agencies should revisit the definition of an asbestos-containing material to include some at levels below 1%.

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