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Project Summary

Evaluation of Three Cleaning Methods for Removing Asbestos from Carpet: Determination of Airborne Asbestos Concentrations Associated with Each Method

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A study was conducted to compare the effectiveness of three cleaning methods for removal of asbestos from contaminated carpet and to determine the airborne asbestos concentrations associated with each. Baseline measurements before cleaning showed an average concentration of 1.6 billion asbestos structures per square foot (s/ft²) of carpet. The effectiveness of dry vacuuming using cleaners with and without a high-efficiency particulate air filter was compared with that of wet cleaning with a hot-water extraction cleaner. The wet cleaning method reduced the level of asbestos contamination in the carpet by approximately 60%, whereas neither dry cleaning method had any notable effect on the asbestos level. The type of cleaner used had little effect on the difference between the airborne asbestos concentration before and during cleaning.

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

Introduction

Asbestos-containing materials (ACM) may release asbestos fibers into the building air as a result of disturbance, damage, or deterioration over time. A concern exists about the extent to which carpet and furnishings may be reservoirs of asbestos fibers and about the behavior of these fibers during normal custodial cleaning operations.

A 1988 study by the Risk Reduction Engineering Laboratory (RREL) of the U.S. Environmental Protection Agency (EPA) compared how effectively dry vacuuming and wet cleaning removed asbestos fibers from artificially contaminated carpet. Airborne asbestos concentrations also were measured during the carpet-cleaning activities. Artificially contaminating the carpet with known levels of asbestos resulted in a carefully controlled experiment with sufficient replication to demonstrate that the wet cleaning method removed significantly more asbestos material from the carpet than did the dry cleaning method. Both methods increased airborne asbestos concentrations significantly.

As a follow-up to this study, EPA's RREL conducted a "real-world" study to determine whether the experimental results obtained with artificially contaminated carpet would also apply to carpet naturally contaminated with asbestos fibers released from in-place ACM. The carpet on which these methods were tested was naturally contaminated over a period of 15 to 20 yr as a result of asbestos-containing ceiling material and spray-applied fireproofing above the ceiling. The effectiveness of dry vacuuming using vacuum cleaners with and without a high-efficiency particulate

air (HEPA) filter was compared with that of wet cleaning with a hot-water extraction cleaner.

The primary objectives of this study were (1) to determine the ability of three cleaning methods to remove asbestos structures from carpet, (2) to determine airborne asbestos levels during carpet cleaning by each method, and (3) to compare fiber concentrations measured by phase contrast microscopy (PCM) during each cleaning method with the Occupational Safety and Health Administration (OSHA) action level of 0.1 fiber per cubic centimeter (f/cm^3).

Study Design and Methods

Test Site

This study was conducted in an unoccupied cafeteria area of the East High Rise Building of the Social Security Administration, Baltimore, MD, where the removal of asbestos-containing ceiling material and spray-applied fireproofing above the ceiling was planned. The acoustical ceiling material contained 1% to 5% chrysotile, and the fireproofing contained 35% to 40% amosite.

Approximately 3700 ft^2 (58 ft x 64 ft) of the carpeted dining area was isolated as the test area. Within this area, nine equally dimensioned areas (19 ft 4 in. by 21 ft 4 in.), each with approximately 400 ft^2 of carpet, were defined as experimental test cells. Each test cell was covered by a floor panel 19 ft 4 in. by 21 ft 4 in., which served as a protective barrier against cross-contamination during each experiment. The floor panel was removed for each experiment and replaced when the experiment was complete. The floor panel frame was constructed of 2- by 4-in. lumber, and 6-mil-thick plastic sheeting was stretched across the top surface. A 24- by 27-ft office enclosure was constructed adjacent to the test area. The test area was entered from the office area through a 5- by 13-ft decontamination facility. The decontamination enclosure consisted of three equally dimensioned chambers: an equipment-change room, a shower room, and a clean room.

Air Filtration

Five HEPA filtration units were used to reduce the airborne asbestos concentrations to background levels after each experiment. These units were operated during the preparation phase of the experiment but not during the carpet-cleaning phase. Four of the units cleaned and recirculated the air; the fifth unit cleaned and discharged the air to the outdoors via flexible ducting. Makeup air was brought into the test area from outdoors via the door at the adjacent decontamination facility.

Experimental Design

Three methods of carpet cleaning were evaluated: (1) dry vacuuming with a HEPA-filtered vacuum cleaner, (2) dry vacuuming with a conventional vacuum cleaner (i.e., without HEPA filtration), and (3) wet cleaning with a hot-water extraction cleaner. Each method was tested three times (with different cleaners of the same model) to yield a total of nine experiments.

The carpeted area was divided into nine equal 400-ft^2 areas. To allow for possible spatial trends in the contamination level across the carpet, the three cleaning methods were applied according to a 3 x 3 Latin square design. The entire carpet was divided by a grid of three rows and three columns, and each cleaning method was applied once in each row and each column. This provided three tests of each method.

A single experiment consisted of collecting six baseline work-area air samples and six bulk carpet baseline samples; dry vacuuming or wet cleaning the carpet for 60 min; concurrently collecting a second set of six work-area air samples and three personal breathing zone samples; collecting a set of six postcleaning bulk carpet samples; dry vacuuming or wet cleaning the carpet a second time for 60 min; collecting a second set of three personal breathing zone samples; collecting a second set of postcleaning bulk carpet samples; covering the carpet with a protective floor panel; and ventilating the area with five HEPA-filtration units for 4 hr.

Although six air samples were collected before and during cleaning and six carpet samples were collected before and after cleaning, three randomly selected samples from each set of six were analyzed. Statistical significance was achieved with the reduced set, and the remaining samples were archived.

Materials and Methods

Fourteen General Service Administration (GSA) field offices in 11 states across the country were surveyed to identify the commonly used conventional vacuum cleaner. In the 1988 EPA study, a similar survey was made of 14 GSA offices and 6 trade associations to select the HEPA-filtered dry vacuum cleaner and hot-water extraction cleaner. The same model HEPA-filtered dry vacuum cleaner was used in this study. Because the HEPA-filtered hot-water extraction cleaner used in the 1988 study is no longer manufactured, a hot-water extraction cleaner without HEPA filtration (but manufactured by the same company) was selected. The conventional dry vacuum cleaner selected was the model most frequently mentioned during the GSA survey.

Carpet Cleaning Equipment

The HEPA-filtered dry vacuum had an airflow capacity of 87 ft^3/min and a 75-in. static water lift and was equipped with a 16-in. carpet nozzle with a rotating brush. The hot-water extraction cleaner had an airflow capacity of 95 ft^3/min and a 117-in. static water lift and was equipped with a 3-in.-diameter by 14-in.-long motorized agitator brush. The conventional vacuum cleaner was an upright unit with an airflow capacity of 110 ft^3/min and a 10-in. static water lift and was equipped with a belt-driven agitator brush.

Carpet Cleaning Technique

The carpet in each experiment was methodically vacuumed or wet-cleaned for approximately 60 min to collect enough air volume to obtain an analytical sensitivity of 0.005 s/cm^3. Each of the two cleaning periods consisted of three passes over the carpet with each cleaner. Each pass was at a 90° angle to the previous pass.

Sampling Methodology

Carpet Samples

Bulk carpet samples were collected before and after cleaning with a 10-cm (4-in.) square template and a utility razor knife. Each sample was cut in half to provide a duplicate sample for archiving. Each piece of carpet was placed in a separate, labeled, wide-mouth polyethylene jar with a polypropylene screw cap. The template and utility razor were thoroughly cleaned between each sample collection to avoid cross-sample contamination.

Area Air Samples

Air samples were collected on open-face, 25-mm-diameter, 0.45-µm-pore-size, mixed cellulose ester (MCE) filters with a 5-µm-pore-size cellulose support pad contained in a three-piece cassette. The filter cassettes were positioned approximately 5 ft above the floor with the filter face at a 45° angle toward the floor. The filter assembly was attached to an electric-powered vacuum pump operating at a flow rate of approximately 9 L/min. Air volumes ranged from 487 to 705 L. The sampling pumps were calibrated both before and after sampling with a precision rotameter.

Personal Breathing Zone Air Samples

The person cleaning the carpet during each experiment wore a personal sampling pump with the filter assembly positioned in his/her breathing zone. The samples were collected on open-face, 25-mm-diameter, 0.8-μm-pore-size MCE membrane filters and cellulose support pad contained in a three-piece cassette with a 50-mm conductive cowl. The filter assembly was attached to a constant-flow, battery-powered vacuum pump operating at a flow rate of approximately 2 L/min. The sampling assembly was worn for the duration of each carpet-cleaning activity. Air volumes ranged from 110 to 192 L. The sampling pumps were calibrated both before and after sampling with an electronic mass flowmeter.

Analytical Methodology

Carpet Samples

A sonication procedure was used to extract asbestos structures from the bulk carpet samples for subsequent analysis by transmission electron microscopy (TEM).

Area Air Samples

The MCE filters were prepared and analyzed in accordance with a modified nonmandatory TEM protocol, as described in the Asbestos Hazard Emergency Response Act final rule (40 CFR Part 763, p. 41870).

Personal Breathing Zone Air Samples

The 0.8-μm-pore-size MCE filters used to collect the personal breathing zone samples were analyzed in accordance with NIOSH Method 7400 by using PCM at the EPA TEM laboratory. The analytical sensitivity was approximately 0.01 f/cm^3. A subset of these samples was also analyzed by TEM in accordance with the protocol described for the area air samples.

Statistical Analysis

Carpet Samples

A single estimated concentration for each cleaning method and replicate combination was obtained before and after cleaning by calculating the arithmetic mean of the three individual estimates. This yielded nine pairs of concentrations, three for each cleaning method. The relative change in asbestos concentration was measured by the ratio of the concentration after cleaning to the concentration before cleaning. These ratios were compared by taking the natural logarithm and comparing the averages by standard analysis of variance (ANOVA) techniques.

Area Air Samples

The statistical analysis of the area air concentrations was similar to that for the carpet samples. A single estimated concentration for each cleaning method and replicate combination was obtained before and during cleaning by calculating the arithmetic mean of the three individual estimates. The relative change in asbestos concentration was measured by the ratio of the concentration during cleaning to the concentration before cleaning. These ratios were compared by taking the natural logarithm and comparing the averages by standard ANOVA techniques.

Personal Breathing Zone Samples

The three personal breathing zone samples collected during both cleaning stages in an experiment yielded a total of 54 personal samples. For each experiment, a single estimated concentration was then obtained during the first and second cleanings by taking the arithmetic mean of the three individual estimates. This yielded nine pairs of concentrations, one for each experiment. The relative change in asbestos concentrations was measured by comparing the ratio of the concentration during the first cleaning with the concentration during the second cleaning. These ratios were compared by taking the natural logarithm and comparing averages by standard ANOVA techniques.

Quality Assurance

Specific quality assurance procedures for ensuring the accuracy and precision of the TEM analyses of air samples included the use of lot, laboratory, and field blanks and replicate and duplicate analyses.

Results and Discussion

Area Air Samples

Table 1 presents summary statistics for airborne asbestos concentrations measured before and during the first cleaning stage. The three fixed-station area samples collected before and during the first cleaning stage in each experiment yielded a total of 54 area air samples. For each experiment, a single estimated concentration was then obtained before and during cleaning by taking the arithmetic mean of the three individual estimates. This yielded nine pairs of concentrations, one for each experiment.

Figure 1 shows the average airborne asbestos concentrations measured before and during the carpet-cleaning activity with each of the three cleaners. Average airborne asbestos concentrations increased during carpet cleaning with each of the three cleaners. Results from the one-factor ANOVA indicated that the type of cleaning method had no statistically significant effect on the difference between airborne asbestos concentrations before and during cleaning ($p=0.3127$); i.e., the mean relative increase in the airborne asbestos concentration during carpet cleaning did not vary significantly with the type of cleaner.

The increase in airborne asbestos concentration during the carpet-cleaning activity was statistically significant ($p=0.004$). Specifically, a 95% confidence interval for the mean airborne asbestos concentration during carpet cleaning as a proportion of the baseline concentration before cleaning showed that the overall mean airborne asbestos concentration was between 1.3 and 2 times greater during carpet cleaning.

Personal Breathing Zone Samples

All 54 individual samples showed PCM concentrations below the OSHA (TWA*) action level of 0.1 f/cm^3. The maximum personal breathing zone concentration was 0.333 f/cm^3. (≈1-hr sample)

Results of the one-factor ANOVA showed that the type of cleaning method had no statistically significant effect on the difference between personal breathing zone concentrations during the first and second cleanings ($p = 0.5716$).

Thirteen of the 54 personal breathing zone samples, selected to represent those with the highest concentration measured by PCM, were also analyzed by TEM. Overall, the concentrations determined by TEM were consistently higher, which was not unexpected because PCM is unable to detect fibers less than 5 μm in length and less than 0.25 μm in width. Most of the structures measured by TEM were less than 2 μm in length. The Pearson correlation coefficient associated with these measurements ($r = 0.03$) indicates no significant linear relationship between TEM and PCM concentrations.

Effectiveness of Cleaning Methods

Figure 2 shows the average (geometric mean) concentrations of asbestos structures in the carpet before and after cleaning. The 95% confidence intervals for the

* Time Weighted Average

Table 1. *Summary Statistics for Airborne Asbestos Concentrations Before and During First Cleaning*

Cleaning Method	Number of Data Points *,+	Asbestos Concentration, s/cm³ Mean	Minimum	Maximum
Before cleaning				
Conventional dry vacuum	2	0.034	0.053	0.015
HEPA-filtered dry vacuum	3	0.079	0.025	0.163
Hot-water extraction	3	0.046	0.040	0.056
During cleaning				
Conventional dry vacuum	3	0.047	0.030	0.065
HEPA-filtered dry vacuum	3	0.094	0.043	0.168
Hot-water extraction	3	0.093	0.066	0.109

* *Each data point represents the average of three work-area samples.*
\+ *Results from Experiment 1 are not included because they were an apparent anomaly.*

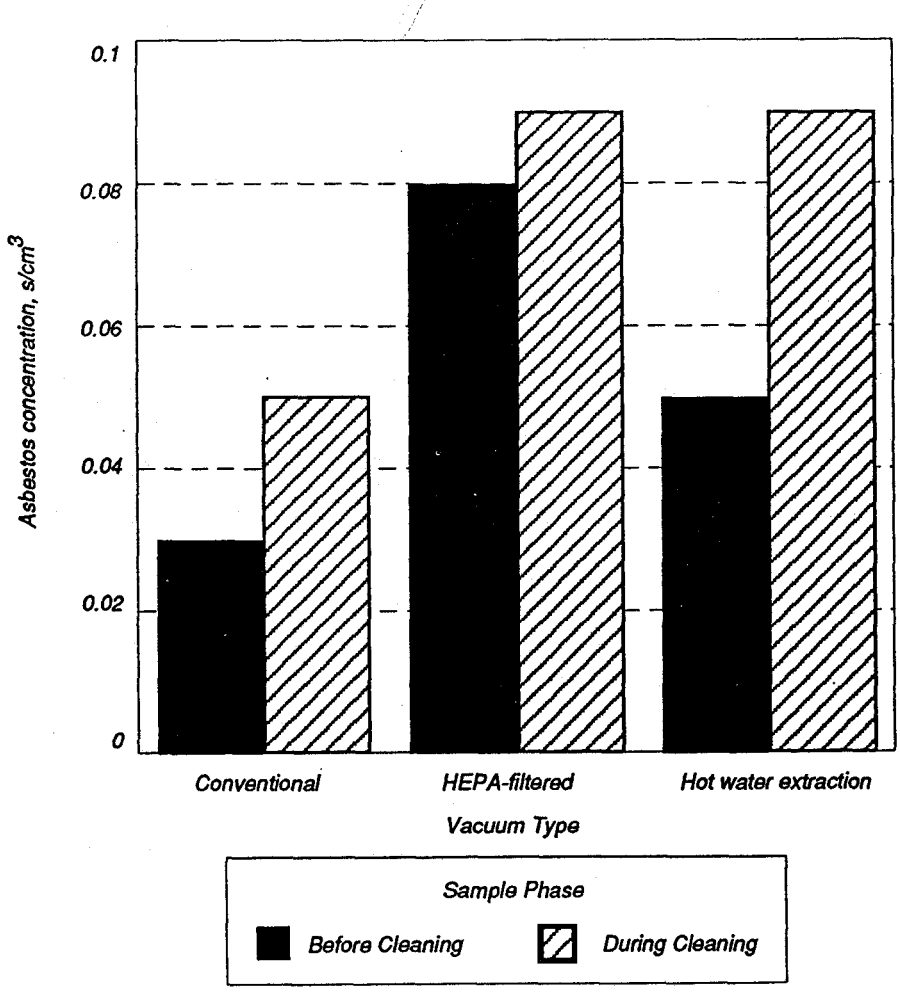

Figure 1. *Airborne asbestos concentrations (arithmetic mean) before and during carpet cleaning. (Samples were analyzed by transmission electron microscopy.)*

geometric mean concentrations are presented in Table 2. For each experiment, a single estimated concentration was obtained before cleaning, after the first cleaning, and after the second cleaning by taking the arithmetic average of the three individual estimates. This yielded nine triplicates of concentrations, one for each experiment.

After First Cleaning

Results of the one-factor ANOVA indicated that the type of cleaning method had a statistically significant effect on the difference between asbestos concentrations in the carpet before and after the first cleaning ($p=0.0164$); i.e., the mean relative change in asbestos concentration in the carpet after cleaning varied significantly with the type of cleaner. The estimated asbestos concentration in the carpet after cleaning as a proportion of the asbestos concentration before cleaning for each cleaning method and the corresponding 95% confidence interval are presented in Table 3.

The asbestos concentration after wet cleaning was approximately 0.4 of the asbestos concentration before cleaning (i.e., a 60% reduction in the concentration). The upper 95% confidence limit for this proportion (Table 3) is less than 1, which indicates this is a statistically significant reduction.

The asbestos concentration in the carpet after dry vacuuming with a conventional and a HEPA-filtered dry vacuum cleaner was 1.3 and 1.2 times the concentration before cleaning, respectively. The 95% confidence intervals for both estimates include the number 1, which indicates the data do not provide statistically significant evidence of either an increase or a decrease in asbestos concentration after dry vacuuming with either a conventional or a HEPA-filtered vacuum cleaner.

These results are consistent with the findings from the 1988 EPA controlled research study, which evaluated the efficacy of HEPA-filtered dry vacuum and HEPA-filtered hot-water extraction cleaners on carpet that was artificially contaminated with asbestos. The controlled study also showed that the efficacy of wet cleaning was significantly greater than that of dry vacuuming. That study showed an approximately 70% reduction in carpet contamination levels after wet cleaning, compared with an approximately 60% reduction in this study. The 1988 study also did not show statistically significant evidence of either an increase or a decrease in asbestos concentration after dry vacuuming.

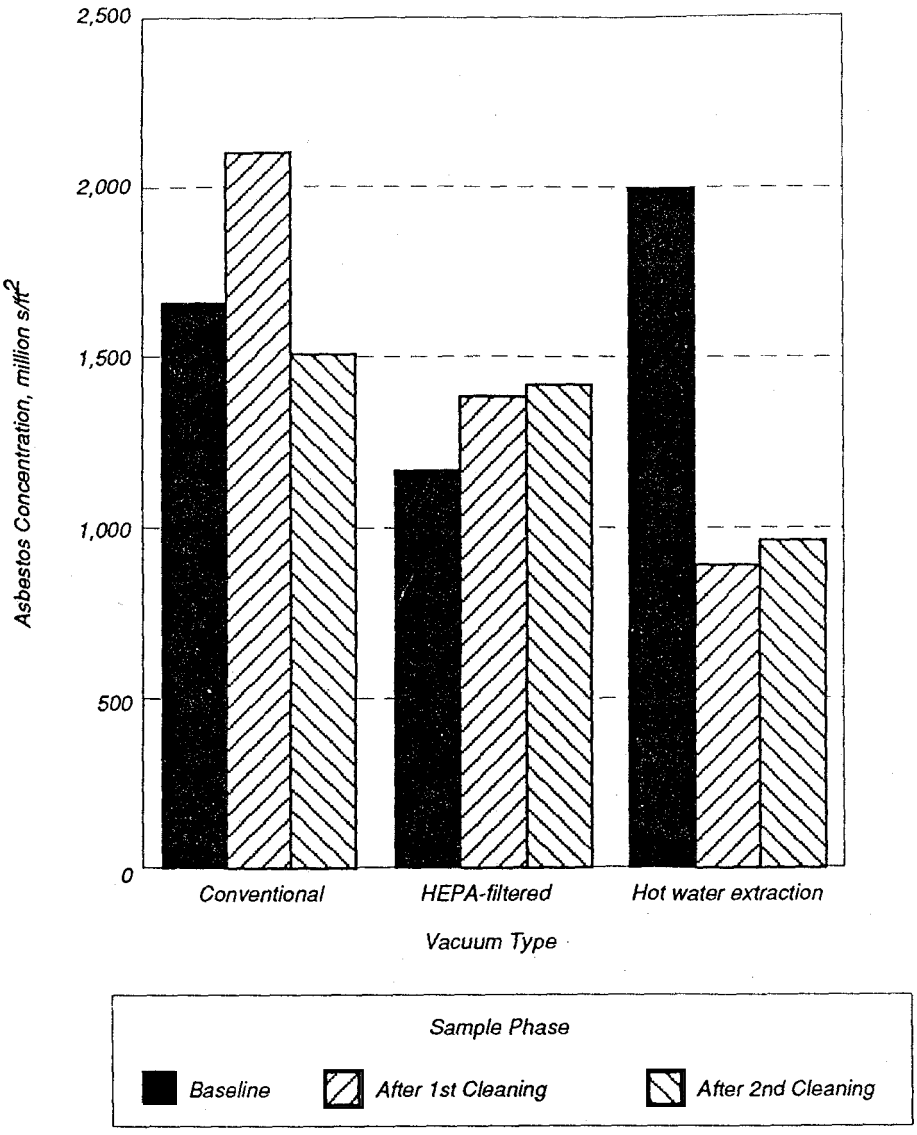

Figure 2. *Asbestos concentrations in the carpet before and after cleaning.*

After Second Cleaning

The carpet was dry-vacuumed or wet-cleaned a second time to determine the effect of repeat vacuuming or cleaning. The type of cleaning method used had no statistically significant effect on the difference between asbestos concentrations in the carpet after the first and second cleanings (p=0.5314). The estimated asbestos concentration in the carpet after the second cleaning as a proportion of the asbestos concentration after the first cleaning is given in Table 4 for each cleaning method, together with a 95% confidence. The 95% confidence intervals for these estimates include the number 1, which indicates the data do not provide statistically significant evidence of either an increase or a decrease in asbestos concentration after cleaning the carpet a second time.

Comparison With 1988 Controlled Carpet Study

In the controlled carpet-cleaning study performed in 1988, new carpet was sprayed with an aerosol containing known concentrations of chrysotile asbestos suspended in water. After the carpet dried, it was rolled with a 200-lb steel roller to simulate the effects of normal foot traffic in working the asbestos into the carpet. The results of the present study, which represent a real-world carpet (with unknown contaminants, similar asbestos contamination levels [1.6 billion s/ft^2 average], and wear characteristics) are quite comparable with the results of the high-concentration (1 billion s/ft^2) controlled experiment in terms of the reentrainment of asbestos during cleaning procedures; i.e., the airborne asbestos concentrations measured in this study were 1.3 to 2 times greater during carpet cleaning versus 2 to 4 times greater in the 1988 study. The results of the present study are also comparable regarding the effectiveness of the cleaning methods to remove asbestos structures from carpet; i.e., the present study showed a 60% reduction in asbestos concentrations in the carpet after wet-cleaning compared with a 70% reduction in the 1988 study. Both studies showed that dry vacuuming did not significantly change the asbestos concentration in the carpet.

Conclusions

Wet cleaning reduced the asbestos concentration in the carpet by approximately 60%, whereas no significant evidence of an increase or decrease was found in asbestos concentrations after dry vacuuming.

Both wet cleaning and dry vacuuming of carpet resulted in a statistically significant increase in airborne concentrations in the work area. Concentrations were 1.3 to 2 times greater during carpet-cleaning activities than before.

Although the personal breathing zone samples analyzed by PCM were all below the OSHA action level of 0.1 f/cm^3 of air, considerably higher exposures were indicated by the samples analyzed by TEM because PCM does not detect the smaller fibers (<5 μm in length and <0.25 μm in width) measured by TEM. The structures measured by TEM analyses were predominantly <5 μm in length, i.e., 99.6% and 97.1% during dry and wet carpet-cleaning activities, respectively.

The results of this study involving carpet with natural asbestos contamination and wear characteristics are comparable with those obtained in a controlled study under artificial, simulated conditions in both efficacy of the carpet cleaning methods and reentrainment of asbestos structures during cleaning activities.

Recommendations

In buildings containing friable ACM, vacuuming of carpets during routine custodial activities should be performed with HEPA-filtered dry vacuum cleaners. Carpets should be cleaned periodically by a

Table 2. Summary Statistics for Asbestos Concentrations in Carpet Before and After Cleaning

Cleaning Method	Number of Data Points •	Asbestos Concentration, Billion s/ft²	
		Geometric mean	95% CI +
Baseline			
Conventional dry vacuum	3	1.6	(0.85, 3.1)
HEPA-filtered dry vacuum	3	1.1	(0.28, 4.0)
Hot-water extraction	3	2.0	(1.1, 3.5)
After 1st Cleaning			
Conventional dry vacuum	3	2.1	(1.2, 3.7)
HEPA-filtered dry vacuum	3	1.3	(0.39, 4.3)
Hot-water extraction	3	0.85	(0.32, 2.3)
After 2nd Cleaning			
Conventional dry vacuum	3	1.3	(0.23, 7.3)
HEPA-filtered dry vacuum	3	1.4	(0.82, 2.4)
Hot-water extraction	3	0.88	(0.24, 3.3)

• *Each data point represents the average of three work-area samples.*
+ *95% confidence interval for the geometric mean.*

Table 3. Estimated Asbestos Concentration in Carpet After First Cleaning as a Proportion of the Concentration Before Cleaning (P)

Cleaning Method	P	95% Confidence Interval
Conventional dry vacuum	1.3	(0.75, 2.1)
HEPA-filtered dry vacuum	1.2	(0.74, 2.0)
Hot water extraction cleaner	0.43	(0.26, 0.72)

Table 4. Estimated Asbestos Concentration in Carpet After Second Cleaning as a Proportion of the Concentration Before Cleaning (P)

Cleaning Method	P	95% Confidence Interval
Conventional dry vacuum	0.63	(0.26, 1.5)
HEPA-filtered dry vacuum	1.1	(0.45, 2.6)
Hot water extraction cleaner	1.0	(0.43, 2.5)

wet-cleaning method (e.g., a hot-water extraction cleaner). If ACM has been released onto a carpeted area during an operation and maintenance activity or as a result of fallen surfacing material, the gross debris should be removed by a HEPA-filtered dry vacuum cleaner, followed by wet cleaning of the carpet.

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The complete report, entitled "Evaluation of Three Cleaning Methods for Removing Asbestos from Carpet: Determination of Airborne Asbestos Concentrations Associated with Each Method," (Order No. PB93-218568; Cost: $19.50, subject to change) will be available only from:

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