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Project Summary

Asbestos Fiber Reentrainment During Dry Vacuuming and Wet Cleaning of Asbestos-Contaminated Carpet

John R. Kominsky and Ronald W. Freyberg

A study was conducted to evaluate the potential for asbestos fiber reentrainment during cleaning of carpet contaminated with asbestos. Two types of carpet cleaning equipment were evaluated at two carpet contamination levels. Airborne asbestos concentrations were determined before and during carpet cleaning to evaluate the effect of the cleaning method and contamination loading on fiber reentrainment during carpet cleaning. Overall, airborne asbestos concentrations during carpet cleaning were two to four times greater than concentrations prior to cleaning. The level of asbestos contamination and the type of cleaning method used had no statistically significant effect on the relative increase of airborne asbestos concentrations during carpet 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

Buildings that contain friable asbestos-containing materials (ACM) may present unique exposure problems for custodial workers. Under certain conditions, asbestos fibers can be released from fireproofing, acoustical plaster, and other surfacing material. The release of asbestos by aging and deteriorating ACM is known to be episodic and relates to a myriad of factors, such as the condition and amount of asbestos present, the accessibility of the material, activity within the area, vibration, temperature, humidity, airflow, use patterns, etc. A major concern is the extent to which carpet and furnishings may serve as reservoirs of asbestos fibers and what happens to these fibers during normal custodial cleaning operations.

The U.S. Environmental Protection Agency (EPA) performed a series of controlled experiments in an unoccupied building 1) to evaluate the effectiveness of a high-efficiency particulate air (HEPA)-filtered vacuum cleaner and a HEPA-filtered hot-water extraction cleaner in the removal of asbestos from carpet, and 2) to evaluate the potential for reentrainment of asbestos fibers during carpet-cleaning activities. The study was designed to compare carpet asbestos concentrations before and after cleaning with each cleaning method at two known contamination levels. Concentrations of airborne asbestos in the work area before and during carpet cleaning were also compared.

The report summarized here presents only the air monitoring results from the dry vacuuming and wet cleaning of the asbestos-contaminated carpet to evaluate the

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potential for fiber reentrainment during cleaning. The results of the carpet sample analyses and the effectiveness of two cleaning methods in removing asbestos fibers from contaminated carpet are presented in a separate report.

Study Design

Test Facility

This study was conducted in an unoccupied building at Wright-Patterson Air Force Base in Dayton, OH. Two rooms, each containing approximately 500 ft^2 of floor space, were constructed in a large bay of the building. The rooms were constructed of 2- x 4-in. lumber with studs spaced on 24-in. centers and 3/4-in. plywood floors. The inside of the rooms (the ceiling, floor, and walls) was double-covered with 6-mil polyethylene sheeting. (The interior layer of polyethylene sheeting was encapsulated and replaced after each experiment.) Where the joining of separate sheets of polyethylene was necessary, the sheets were overlapped at least 12 in. and joined with an unbroken line of adhesive to prohibit air movement. Three-in.-wide tape was then used to seal the joint further on both the inside and outside of the plastic sheeting.

Entry from one room to another was through a double-curtained doorway consisting of two overlapping sheets of 6-mil polyethylene placed over a framed doorway. Each sheet was secured along the top of the doorway; the vertical edge of one sheet was secured along one vertical side of the doorway and the vertical edge of the other sheet was secured along the opposite vertical side of the doorway.

Room size (approximately 29 x 17 x 7.5 ft) was based on the minimum amount of time required to vacuum or wet-clean the room and to attain an adequate volume of sample air to achieve a specified analytical sensitivity. A 52-in., ceiling-mounted, axial-flow, propeller fan was installed in each room to facilitate air movement and to minimize temperature stratification.

Separate decontamination facilities for workers and waste materials were connected to the experimental areas. The worker decontamination facility consisted of three totally enclosed chambers as follows:

1) An *equipment change room* with double-curtained doorways, one to the work area and one to the shower room.

2) A *shower room* with double-curtained doorways, one to the equipment change room and one to the clean change room. The one shower installed in this room was constructed so that all water was collected and pumped through a three-stage filtration system. The three-stage filtration system consisted of a 400-µm nylon-mesh, filter-bag prefilter; a 50-µm filter-bag second-stage filter; and a 5-µm final-stage filter. Filtrate was disposed of as asbestos-contaminated waste. Water was drained from the filtration system exit into a sanitary sewage system.

3) A *clean change room* with double-curtained doorways, one to the shower room and one to the noncontaminated areas of the building.

Air Filtration

After each experiment, the airborne asbestos concentrations were reduced to background levels by HEPA filtration systems. These units were operated during both preparation and decontamination of the test rooms; they were not intended to be operated during the carpet cleaning phase of each experiment.

One HEPA filtration system was dedicated to each test room. Each unit provided approximately 8 air changes per every 15-min period. The negative pressure inside the test rooms ranged from -0.08 to -0.06 in. of water. All exhaust air passed through a HEPA filter and was discharged to the outdoors (i.e., outside the building). All makeup air was obtained from outside the building through a window located on the opposite side of the building from the exhaust for the HEPA filtration systems.

Experimental Design

Two carpet cleaning methods, dry vacuuming with a HEPA-filtered vacuum and wet cleaning with a HEPA-filtered hot-water extraction cleaner, were evaluated on carpet artificially contaminated at two levels, with approximately 100 million and with 1 billion asbestos structures per square foot (s/ft^2). Each combination of cleaning method and contamination level was replicated four times.

Four different (same model) HEPA-filtered vacuums and four different (same model) HEPA-filtered hot-water extraction units were used in this study so that the results would not be influenced by the peculiarities of a single unit. Each machine was used only once per combination of cleaning method and contamination level. This experimental design yielded a total of 16 experiments. Three work-area air samples were collected before carpet cleaning and three work-area air samples were collected during carpet cleaning for each of the 16 experiments.

Two experiments were conducted each day of the study. Each combination of cleaning method and contamination level was tested twice in each test room. A single experiment consisted of contaminating a new piece of carpet (approximately 500 ft^2) with asbestos fibers, collecting work-area air samples, dry vacuuming or wet cleaning the carpet while concurrently collecting a second set of work area air samples, removing the carpet, and decontaminating the test room. Each test room was decontaminated by encapsulating the polyethylene sheeting on the ceiling, walls, and carpet before their removal. These materials were replaced after each experiment.

Materials and Methods

A survey was made of 14 General Service Administration (GSA) field offices in 11 States distributed across the United States to determine the most prevalent types of carpet, HEPA-filtered vacuum cleaner unit, and HEPA-filtered hot-water extraction unit to use in this study. Building managers were asked to identify 1) the specific type and manufacturer of carpet, 2) the manufacturer and model of HEPA-filtered vacuum cleaner, and 3) the manufacturer and model of HEPA-filtered hot-water extraction cleaners routinely used in their GSA buildings.

None of the GSA offices routinely wet-cleaned their carpet. When wet-cleaning was necessary, contractors were hired to perform the work. Therefore, six trade associations were surveyed to obtain their recommendations on a HEPA-filtered hot-water extraction cleaner.

Selection of Carpet

Eight of the fourteen GSA offices indicated a preference for the same manufacturer and type of carpet. The selected carpet was first-grade, 100% nylon, with 0.25-in. cut pile, 28 oz of yarn per square foot, and dual vinyl backing. The carpet was manufactured in roll sizes of 4.5 by 90 ft.

Selection of Carpet Cleaning Equipment

HEPA-Filtered Vacuum

The HEPA-filtered vacuum selected for this study was the model most frequently mentioned in the GSA survey. The unit had an airflow capacity of 87 ft^3/min and a suction power of 200 watts. This unit was also equipped with a motor-driven carpet nozzle with a rotating brush.

Hot-Water Extraction Cleaner

Three of the trade associations surveyed recommended the same hot-water extraction unit. The selected cleaner was equipped with a HEPA-filtered power head with a moisture-proof, continuous-duty, 2-horsepower vacuum motor that develops a 100-in. waterlift. This unit was also equipped with an extractor tool that uses a motor-driven 4-in.-diameter by 14-in.-long cylindrical nylon-bristle brush to agitate and scrub the carpet during the extraction process.

Sampling Methodology

Air samples were collected on open-face, 25-mm-diameter, 0.45-µm pore-size, mixed cellulose ester membrane filters with a 5-µm pore-size, mixed cellulose ester backup diffusing filter and cellulose ester support pad contained in a three-piece cassette. The filter cassettes were positioned approximately 5 ft above the floor with the filter face at approximately a 45° angle toward the floor. The filter assembly was attached to an electric-powered vacuum pump operating at a flow rate of approximately 10 L/min. In each test room, the air samplers were positioned in a triangular pattern. Air samples were collected for a minimum of 65 min before and again during carpet cleaning to achieve a minimum air volume of approximately 650 L. The sampling pumps were calibrated both before and after sampling with a precision rotameter.

Analytical Methodology

The mixed cellulose ester filters were analyzed by transmission electron microscopy (TEM). These filters were prepared and analyzed in accordance with the nonmandatory TEM method as described in the Asbestos Hazard Emergency Response Act (AHERA) final rule (52 CFR 41821).

Statistical Analysis

Airborne asbestos concentrations were determined before and during carpet cleaning to study the effect of the cleaning method and contamination loading on fiber reentrainment during the carpet cleaning. Three work-area samples were collected before and during the carpet cleaning for each experiment. A single estimate of the airborne asbestos concentrations before and during cleaning was then determined by averaging the three respective work-area samples. As a measure of relative change in airborne asbestos concentration, the ratio of the concentration during cleaning to the concentration before cleaning was computed. The natural log of this ratio was then analyzed by using a two-factor analysis of variance (ANOVA) with the cleaning method and contamination level as the main factors. The two-factor interaction term was also included in the model. This analysis is equivalent to assuming a lognormal distribution for airborne asbestos measurements and analyzing the log-transformed data for differences between airborne asbestos concentration before and during cleaning. The lognormal distribution is commonly assumed for measurements of asbestos and other air contaminants. Summary statistics (arithmetic mean and standard deviation) were calculated according to cleaning method and contamination level.

Carpet Contamination

Selected levels of carpet contamination for this study were based on reported field data. These data indicated that asbestos concentrations in contaminated carpet ranging from approximately 8,000 to 2 billion s/ft^2 had been detected by use of a microvac technique. Bulk sample sonication of the samples had revealed levels ranging from 30 million to 4 billion s/ft^2. Based on these reported results, the two target experimental asbestos contamination levels of approximately 100 million and 1 billion s/ft^2 were believed to represent carpet contamination likely to be present in buildings where asbestos-containing materials are present.

For this project, the decision was made to prepare sealed ampules of fiber dispersions so that the contents of one ampule dispersed in 6 L of freshly distilled water would provide the concentration of suspension required for artificial contamination of one 500-ft^2 sample of carpet. Calculations of the amount of chrysotile required were based on the assumption that all of the fibers needed to contaminate one carpet sample would be contained in a volume of 50 mL sealed in one ampule.

Application of Dispersion to Carpet

A meticulously cleaned, hand-pumped, garden sprayer was used to apply the asbestos dispersion to the carpet. A fixed number of pumps was used for each batch to provide consistent spray pressure. The desired controlled spray was experimentally determined by trial and error before the tests with asbestos began. The pressure was kept within the desired range by adding a fixed number of pump strokes after each fixed area was sprayed in a predetermined pattern by following a grid work of string placed over the carpet before the beginning of each experiment. The tank was periodically agitated to help keep the asbestos fibers suspended. Dehumidifiers were placed in the room overnight to aid in drying the carpet. The following day, a 200-lb steel lawn roller was rolled over the carpet surfaces to simulate the effects of normal foot traffic in working the asbestos into the carpet.

To ensure no bacterial growth had occurred in the sprayer between uses, the inside of the sprayer and the outlet pipe were treated with a 10% to 15% solution of Clorox* to remove any bacteria and their byproducts. Any bacterial growth would scavenge fibers from the suspension and cause fibers to become attached to the wall of the container. The container and outlet pipe were then rinsed with isopropyl alcohol.

Carpet Cleaning Technique

The carpet was vacuumed or wet-cleaned for a period of approximately 65 min to allow the collection of a sufficient volume of air to attain an analytical sensitivity of 0.005 s/cm^3 of air. The carpet was cleaned in two directions, the second direction at a 90° angle to the first.

Quality Assurance

TEM Analyses

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.

Filter lot blanks consisted of unused fillers selected at random and submitted for prescreening analysis for background asbestos contamination before the start of field work to determine the integrity of the entire lot of filters purchased for EPA research studies. One hundred lot blanks were submitted for TEM analysis. No asbestos structures were detected in the 1000 grid openings analyzed. The lot of filters was subsequently considered acceptable for use.

During the setup of the air sampling pumps, preloaded filter cassettes were labeled and handled in a manner similar to that for the actual sample filters, but they were never attached to the pump. One field blank was collected for each of the 16 experiments. Two of the 16 filters each contained one asbestos structure. Also, before each of the 16 experiments, one sample cassette was selected from the filter inventory to be used as a laboratory blank. These samples were sealed and submitted for use by the analytical laboratory to ensure against any blank inter-

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

ference during the analytical procedures. Two of the 16 sealed blanks each contained two asbestos structures. Analysis of the field and laboratory blanks demonstrated that filter contamination was comparable to background levels of asbestos on filters; these background levels are defined as 70 s/mm² in the AHERA final rule (October 30, 1987; 52 CFR 41826).

Duplicate sample analysis provides a means of quantifying intralaboratory precision and refers to the analysis of the same grid preparation by a second microscopist. Five samples were randomly selected for duplicate analysis. Replicate sample analysis provides a means of quantifying any analytical variability introduced by the filter preparation procedure and refers to the analysis of a second grid preparation from the original filter. Five samples were randomly selected for replicate analysis. The coefficient of variations associated with the duplicate and replicate sample analyses were 22% and 32%, respectively. Since the replicate analyses used different filter preparations, a higher coefficient of variation is expected.

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

Approximate Contamination Loading, s/ft²	HEPA-Filtered Cleaner	Number pf Data Points*	Airborne Asbestos Concentration, s/cm³	
			Average	Standard Deviation
100 million				
Before cleaning	Hot-water extraction	3	0.0673	0.0874
	Dry-vacuum	3	0.0571	0.0315
During cleaning	Hot-water extraction	3	0.1639	0.0911
	Dry-vacuum	3	0.2531	0.1655
1 billion				
Before cleaning	Hot-water extraction	4	0.0761	0.0471
	Dry-Vacuum	4	0.1424	0.1235
During cleaning	Hot-water extraction	4	0.1577	0.0690
	Dry-vacuum	4	0.2248	0.1499

*Each data point is the average of three work-area samples.

Spray-Application Techniques

To confirm the validity of the spraying technique, an additional experiment was conducted using a pesticide sprayer identical to those used to apply the chrysotile to the carpet samples. An ampule of low-concentration suspension was diluted to 500 mL, and then further diluted to 6L in the pesticide sprayer, using freshly distilled water. The sprayer was thoroughly shaken and the contents were sprayed out into several containers. Three 500-mL samples of the spray were collected, one at the beginning of spraying, one when approximately 50% of the contents had been discharged, and one just before the end of spraying. These three samples were analyzed to determine if the concentration and size distribution of the fibers changed during the period of spraying. The average asbestos structure concentration for these three samples was 2.33, 2.18, and 2.38 s/L, respectively. These results indicate no significant loss of fibers during the transfer of the diluted liquid suspension through the sprayer's hose and nozzle. Similarly, no significant change in fiber size distribution was evident during the transfer of the diluted liquid suspensions.

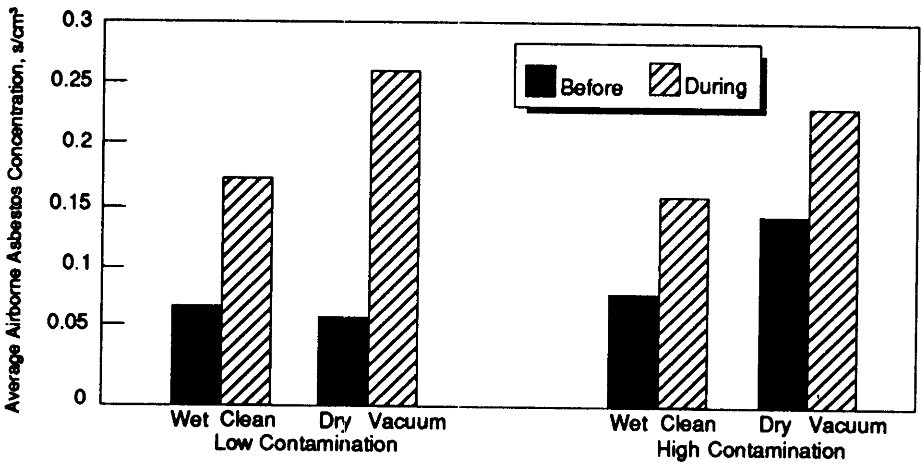

Figure 1. *Average airborne asbestos concentrations before and during carpet cleaning.*

Results and Discussion

Figure 1 presents the average airborne asbestos concentrations measured before and during cleaning for each cleaning method and carpet contamination loading. The samples collected before cleaning were obtained after the carpet was contaminated to determine the baseline concentration in the test room. Table 1 presents the summary statistics (arithmetic average and standard deviation).

Air sampling results from 2 of the 16 experiments showed that the average airborne asbestos concentrations decreased during both wet cleaning and dry vacuuming of the carpet. The explanation for this anomaly is that the HEPA filtration system used to ventilate the test rooms was inadvertently operating during the carpet cleaning phase of these two experiments. Therefore, these results were omitted from the statistical analysis of the data.

There was no statistically significant interaction between cleaning method and contamination level ($p=0.8901$); that is, the effect of the cleaning method on airborne asbestos did not vary significantly with contamination level. No statistically significant difference was evident between cleaning methods with respect to fiber reentrainment ($p=0.5847$); that is, the mean relative increase in airborne asbestos con-

Table 2. Structure Morphology Distribution for Air Samples Collected Before and During Carpet Cleaning

Structure Type	Number of Bundles	Number of Clusters	Number of Fibers	Number of Matrices	Total
Chrysotile	30	7	2,661	59	2,757
Amphibole	0	2	5	1	8
Ambiguous	2	0	70	2	74
Total	32	9	2,736	62	2,839

centration during carpet cleaning with a dry vacuum was not significantly different from that found during wet cleaning.

Similarly, no statistically significant difference was evident between carpet contamination loadings with respect to fiber reentrainment ($p=0.0857$); that is the mean relative increase in airborne asbestos concentrations during carpet cleaning when the carpet contamination level was 100 million s/ft^2 was not significantly different from that found when the carpet contamination leading was 1 billion s/ft^2.

The ANOVA results do, however, indicate that, overall, the mean airborne asbestos concentration was significantly higher during carpet cleaning than just before cleaning ($p=0.0001$). Specifically, a 95% confidence interval for the mean airborne asbestos concentration during carpet cleaning as a proportion of the airborne concentration before cleaning showed that the mean airborne asbestos concentration was between two and four times greater during carpet cleaning.

Airborne Asbestos Fiber Distribution

The TEM analysis of the 95 work-area samples before and during cleaning yielded a total of 2839 structures. Of these, 2757 (97.1%) were chrysotile, 8 (0.03%) were amphibole, and 74 (2.6%) were ambiguous. The structure morphology distribution is summarized in Table 2.

These data indicate that the original chrysotile fibers used to prepare the diluted asbestos suspension remained intact as fibers. There appeared to be no significant tendency for the fibers to clump together as a result of the suspension preparation, the carpet contamination, or the cleaning technique.

The presence of amphibole asbestos fibers in the air was probably due to conditions existing before the experiment. Prestudy air monitoring identified two amphibole asbestos fibers in seven air samples collected.

Eighty-four percent of the chrysotile structures identified were 1 µm or less in length. Only nine particles were identified with lengths greater than 5 µm. Figure 2 compares the fiber sizes of airborne asbestos during carpet cleaning with fibers in the low- and high-concentration asbestos suspensions. For example, approximately 60% of the asbestos fibers used to contaminate the carpet with 100 million s/ft^2 were greater than 1.1 µm. Less than 15% of the fibers observed in the air during carpet cleaning were greater than 1.1µm. These data suggest that the larger asbestos particles either remained in the carpet or were prevented from escaping into the air by the carpet cleaning activity.

Conclusions

Both dry vacuuming and wet cleaning of carpet artificially contaminated with asbestos fibers resulted in a statistically significant increase in airborne asbestos concentrations. The increase did not vary significantly with the type of cleaning method (wet or dry) or with the two levels of asbestos contamination applied to the carpet.

Although this research revealed significant increases in airborne asbestos concentrations during cleaning activities in a controlled study under artificial, simulated conditions, it is not known if such increases occur in real-world custodial operations. Obviously, this possibility is a concern.

Recommendations

This research suggests that normal custodial cleaning of asbestos-contaminated carpet may result in elevated airborne asbestos concentrations. Further research is needed to determine actual exposure risk to custodial workers performing these activities in buildings containing friable asbestos-containing materials.

The full report was submitted in fulfillment of Contract No. 68-03-4006 by PEI Associates, Inc., under the sponsorship of the U.S. Environmental Protection Agency.

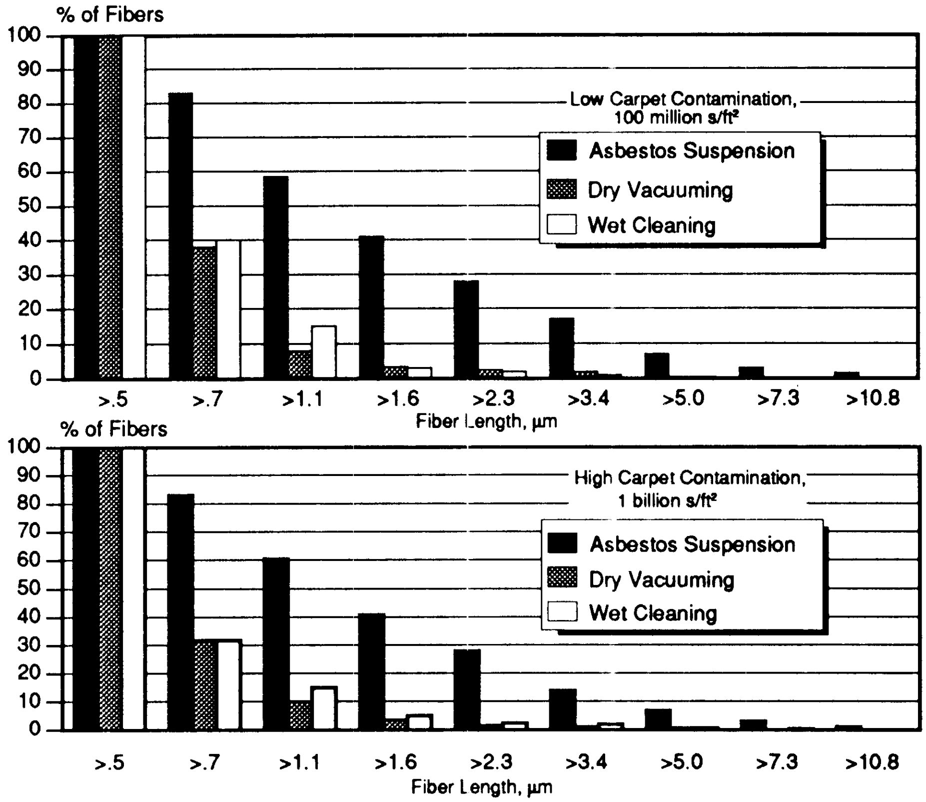

Figure 2. Comparative plot of cumulative percentages of airborne asbestos fibers during dry vacuuming and wet cleaning of carpet with asbestos fibers in the low and high concentration suspensions.

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J.R. Kominsky and R.W. Freyberg are with PEI Associates, Inc., Cincinnati, OH 45246
***W.C. Cain and T.J. Powers** are the EPA Project Officers (see below).*
The complete report, entitled "Asbestos Fiber Reentrainment During Dry Vacuuming and Wet Cleaning of Asbestos-Contaminated Carpet," (Order No. PB91-161695AS; Cost: $17.00, subject to change) will be available only from:
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