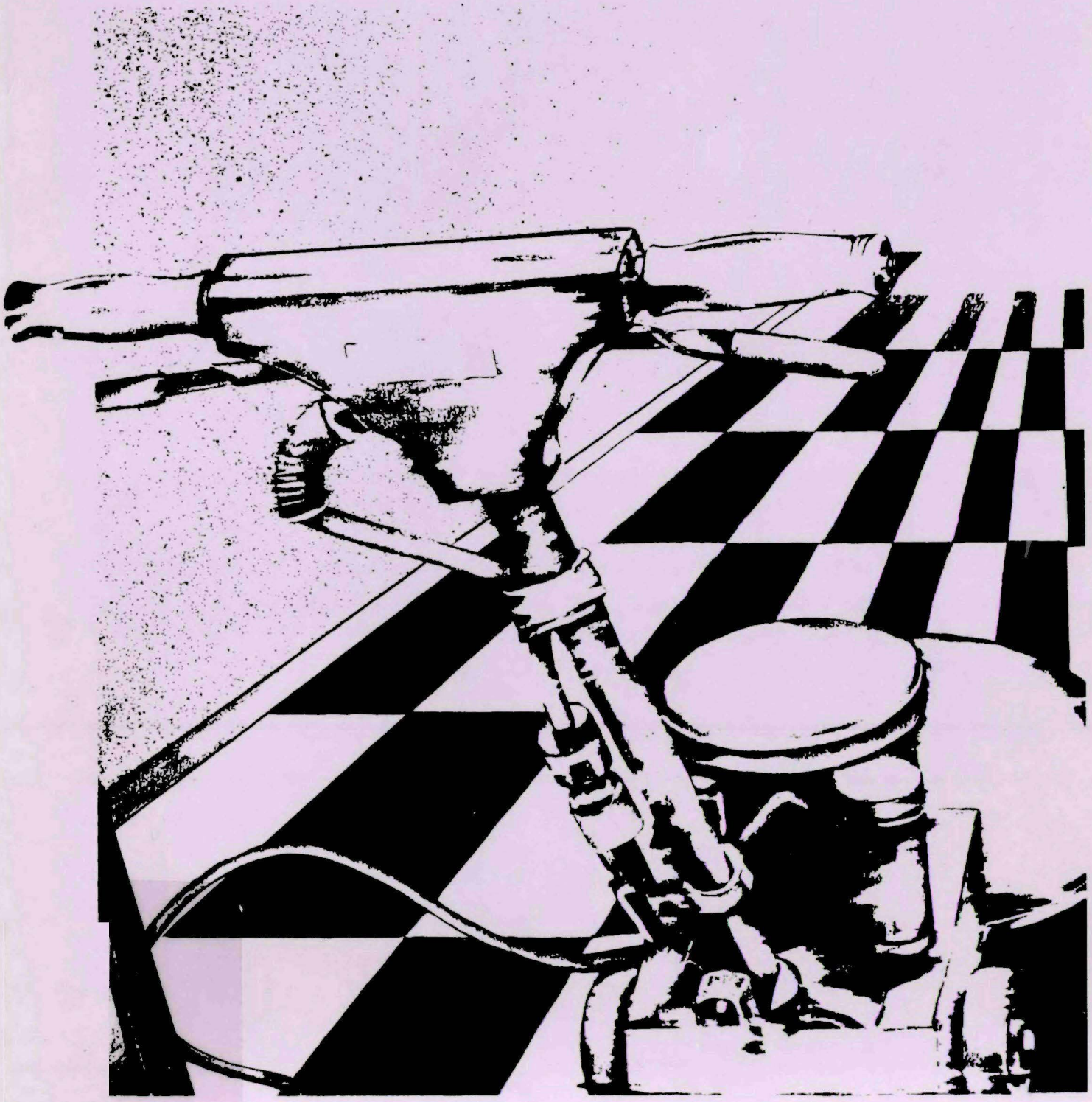
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EPA Evaluation of Asbestos Fiber Release During Maintenance of Asbestos-Containing Floor Tile



EVALUATION OF ASBESTOS FIBER RELEASE DURING MAINTENANCE OF ASBESTOS-CONTAINING FLOOR TILE

FINAL REPORT

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Office of Pollution Prevention and Toxics
U.S. Environmental Protection Agency
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March, 1993

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AUTHORS AND CONTRIBUTORS

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ACRONYMS

AHERA	Asbestos Hazard Emergency Response Act
ANOVA	Analysis of Variance
EDS	Energy Dispersive Spectrometry
EED	Exposure Evaluation Division
EPA	(U.S.) Environmental Protection Agency
f/cc	fibers per cubic centimeter
HEPA	High Efficiency Particulate Air
HVAC	Heating, Ventilation and Air-Conditioning
NIOSH	National Institute of Occupational Safety and Health
NBC	National Broadcasting Company
OSHA	Occupational Safety and Health Administration
PEI	International Technology Corporation (formerly PEI Associates, Inc.)
PCM	Phase Contrast Microscopy
P.G.	Prince Georges (County Public Schools)
QA	Quality Assurance
QAPjP	Quality Assurance Project Plan
QC	Quality Control
RREL	Risk Reduction Engineering Laboratory
SAED	Selected Area Electron Diffraction
s/cc	(asbestos) structures per cubic centimeter
TEM	Transmission Electron Microscopy
TWA	Time Weighted Average
VAT	Vinyl Asbestos Tile

EXECUTIVE SUMMARY

In 1990, the U.S. Environmental Protection Agency (EPA), with the assistance of the resilient flooring manufacturing and floor care industries, developed interim guidance (the "EPA method") on appropriate procedures for maintenance of asbestos-containing floor coverings (U.S. EPA 1990). The guidance was provided in response to numerous questions raised by school districts and building managers regarding the feasibility of stripping wax from asbestos-containing floor tile. Some of these questions had been prompted by a limited study conducted by a local television station (WRC-TV, the Washington, D.C., NBC affiliate station). Subsequently, a designed experiment was conducted to evaluate the interim guidance, and to develop reliable information on airborne asbestos levels during stripping of wax from asbestos-containing floor tile. The experiment compared the EPA method to a (presumed) more aggressive method in use by the Prince Georges County, Maryland, public schools (the "P.G. method"). The study was conducted at the Bowie High School Annex, in Upper Marlboro, Maryland.

The objectives of the study were to:

1. Compare airborne asbestos levels during vinyl asbestos tile floor wax stripping by the EPA and P.G. methods to levels in the room before wax stripping began;

2. Compare the effects of the two wax stripping methods on airborne asbestos levels during floor stripping and rebuilding of the wax layer;

3. Compare fiber concentrations measured by Phase Contrast Microscopy (PCM) during wax stripping with the OSHA action level of 0.1 f/cc;

4. Compare the effect of the two wax stripping methods on residual airborne asbestos levels after the work had been completed.

To meet these objectives, a study was designed which took measurements from both area and personal monitors in six matched pairs of rooms in the school. For the P.G. method, a 3M black pad was used while a 3M green pad was used in the EPA method. The study design called for the same procedures for each type of pad to allow for comparisons during identical stripping and rebuilding phases. The design specified a total of 240 area measurements to be taken and analyzed using transmission electron microscopy (TEM) techniques. Of the total, 120 measurements were to be taken for each method, with 30 each in four periods (before stripping began, during stripping of wax, during the rebuilding of the wax layer, and after the process was complete). Of the 240 planned measurements, 237 were actually obtained. A total of 72 personal measurements were taken during the stripping and rebuilding periods, 36 for each method of wax stripping (3 for

each room). The personal samples, in accordance with OSHA practice, were analyzed using the NIOSH 7400 Phase Contrast Microscopy (PCM) protocol. An additional 9 personal samples were taken during stripping and analyzed by TEM.

The study found no significant difference between airborne asbestos concentrations, measured by TEM, from area samples for the P.G. and EPA methods of stripping wax from vinyl asbestos tile. More specifically, although there was a difference between the overall mean airborne asbestos concentrations for the two methods during stripping (0.53 s/cc for the EPA method and 1.18 s/cc for the P.G. method), the difference was not statistically significant, because of the variability between rooms in the experiment.

Differences between airborne asbestos concentrations over the time period of interest (before stripping began, during stripping, during rebuilding of the wax layer, and after the process was complete) were a statistically significant factor in the study. Specifically, for both the EPA method and the P.G. method airborne asbestos concentrations during stripping were significantly elevated as compared to all other times in the process. There were, however, no significant differences in concentrations between the other three time periods. This can be interpreted to mean that there are no short term residual effects of the stripping process (since airborne levels are not significantly different before or after wax stripping). Also, there were no differences in this regard between the two methods of wax stripping.

The largest of all of the 72 airborne asbestos concentrations obtained from personal monitors and analyzed by PCM in the study was 0.056 fibers/cc. These measurements are not strictly comparable with the OSHA action level of 0.1 f/cc 8 hour Time Weighted Average (TWA), since the maximum sampling time was 52 minutes. The total time elapsed during the maintenance process (stripping and rebuilding combined) averaged 1 hour and 35 minutes. The most conservative approach to comparing the measurements in this study to the OSHA level is to assume the worker would be exposed at the same levels of asbestos for a full 8-hour shift. This would result in TWA's exactly equal to the figures reported in this study. Clearly such a situation is the worst case. Therefore, it was concluded that neither floor stripping protocol exposed maintenance workers in this study to TWA airborne concentrations of asbestos exceeding OSHA's action level.

Although the personal PCM samples were all below the OSHA action level of 0.1 f/cc, considerably higher exposures are indicated by the TEM area samples. This is confirmed by the 9 personal TEM samples taken during stripping, which ranged in concentration from 0.26 s/cc to 1.49 s/cc. There are two reasons for this. First, PCM cannot detect fibers thinner than 0.25 μm. Second, the PCM protocol used in this study does not count fibers shorter than 5 μm. The TEM analysis results show that PCM did

not account for all the fibers present in the workplace. For example, the concentration of fibers longer than 5 μm in the TEM area samples is 2 orders of magnitude lower than the total structure concentration for these samples. Thus, caution should be exercised in interpreting the PCM measurements taken in this study.

1.0 INTRODUCTION

1.1 BACKGROUND

In 1990, the U.S. Environmental Protection Agency (EPA), with the assistance of resilient flooring manufacturing and floor care industries, developed interim guidance (the "EPA method") on appropriate procedures for maintenance of asbestos-containing floor coverings (U.S. EPA 1990). The guidance was provided in response to numerous questions raised by school districts and building managers regarding the feasibility of stripping wax from asbestos-containing floor tile. Some of these questions had been prompted by a limited study conducted by a local television station (WRC-TV, the Washington, D.C., NBC affiliate station).

Following the airing of the WRC-TV program, a number of school districts conducted studies of asbestos exposure during floor-tile maintenance. At least one State placed a ban on mechanical maintenance of floor tile. In order to evaluate its own interim guidance, as well as to develop reliable information on airborne asbestos levels during stripping of wax from asbestos-containing floor tile, EPA decided to conduct a designed experiment. The experiment compared the EPA method to a (presumed) more aggressive method in use by the Prince Georges County, Maryland, public schools (the "P.G. method"). The study was conducted at the Bowie High School Annex, in Upper Marlboro, Maryland.

This report describes the study design, field and laboratory methods employed, statistical analysis of the data, and conclusions derived from the study.

1.2 OBJECTIVES

The objectives of the study were to:

1. Compare airborne asbestos levels during vinyl asbestos tile floor wax stripping by the EPA and P.G. methods to levels in the room before wax stripping began;

2. Compare the effects of the two wax stripping methods on airborne asbestos levels during stripping and rebuilding of the wax layer;

3. Compare fiber concentrations measured by Phase Contrast Microscopy (PCM) during wax stripping with the OSHA action level of 0.1 f/cc;

4. Compare the effect of the two wax stripping methods on residual airborne asbestos levels after the work had been completed.

1.3 APPROACH

The study was conducted in a school building with asbestos-containing floor tile. Site preparation included cleaning, construction of containment areas, and pre- and post-study sampling to ensure that the school was returned to the school district in as good or better condition than at the beginning of the study.

Two methods of wax stripping were compared in the study:

- A method based on EPA's recommended wax stripping procedure; and
- Prince George's County Public Schools' (presumed) more aggressive wax stripping procedure.

The methods are described in Appendix A. Since it was not possible to explore all possible tile maintenance procedures in a single study, the stripping methods selected were those of greatest interest to the study participants. EPA's primary objective was to document the performance of a procedure that is consistent with the EPA Interim Guidelines, developed with the assistance of industry. Prince George's County Public School System was interested in documenting the performance of its own procedures that are somewhat more aggressive than those recommended by EPA. Even though the study did not provide information on every maintenance procedure that might be applied to floor tile, it may provide a basis for decision-making by individual building owners, as well as defining areas of future research.

The experimental design was a randomized block with six groups (blocks) of two rooms each. The two rooms within any given group were chosen to be as similar as possible to each other in terms of floor tile (type, color, wear, etc.), physical layout (size, fittings, air circulation, etc.), and any other factor that could affect the outcome of the experiment. The two treatments were assigned at random to the rooms within a group. Ideally, both treatments in a given group should be applied simultaneously. Since this was impossible, the order of treatments was randomized and both treatments in a given group were carried out as close in time to each other as possible.

Airborne asbestos concentrations were measured before wax stripping for each of the two methods under consideration and while the floor wax stripping was in progress using both area and personal samples. Passive sampling techniques were employed. During the wax stripping process, there were two sampling phases: (1) while wax was being stripped from the floor, and (2) during rebuilding of a new wax surface. Area samples were analyzed by transmission electron microscopy (TEM) using a direct transfer technique (AHERA, 40 CFR Part 763, Appendix A to Subpart E).

While wax stripping was being performed, personal samples were collected according to OSHA sampling procedures. These samples were analyzed by Phase Contrast Microscopy (PCM) using the NIOSH 7400 protocol (Revision 3, June 5, 1989, National Institute of Occupational Safety and Health Manual of Analytical Methods). However, an additional 9 personal samples were analyzed by TEM.

After each treatment was completed, area samples were collected using a modified aggressive sampling technique to obtain a measure of residual asbestos levels.

2.0 CONCLUSIONS

The specific conclusions reached, by objective, follow as "1" through "4". Conclusion 5 addresses the differences between PCM and TEM measurements taken in the study. Conclusion 6 discusses qualitative differences between the EPA and P.G. samples observed by the laboratory analysts.

1. **Compare airborne asbestos levels during vinyl asbestos tile floor wax stripping (using either of the two methods for stripping which are described in Appendix A) with levels in the room before wax stripping began.**

   Differences between airborne asbestos concentrations over the time period of interest (before wax stripping began, during stripping, during rebuilding of the wax layer, and after the process was complete) were a statistically significant factor in the study. Specifically, there was a statistically significant increase in airborne asbestos concentrations (for both methods) from before stripping to during stripping.

2. **Compare the effect of each wax stripping method on airborne asbestos levels during application.**

   The study found that there was <u>not</u> a significant difference between airborne asbestos concentrations measured from area samples for the P.G. method of stripping wax from vinyl asbestos tile as opposed to the floor stripping method consistent with EPA interim guidelines.

   There was an apparent difference between the overall mean airborne asbestos concentration for the two methods during stripping (0.53 s/cc for the EPA method and 1.18 s/cc for the P.G. method). However, the variability between blocks of rooms in the experiment forced the conclusion that the difference in levels was not statistically significant. A larger study, involving more rooms and, possibly, more schools, would be needed to determine whether the EPA method truly results in lower exposures than the P.G. method. Such a study, if conducted, should consider fewer measurements per room, as the variability in levels within rooms was small in the present study. It might also be useful to evaluate a less abrasive pad (e.g., a red pad) than the green pad used in the EPA method in the present study.

3. **Compare fiber concentrations from personal monitors measured by Phase Contrast Microscopy (PCM) during wax stripping with the OSHA action level of 0.1 f/cc.**

   The largest of all of the 72 airborne asbestos concentrations obtained from personal monitors and analyzed using Phase Contrast Microscopy (PCM) techniques in the study was 0.056 fibers/cc which is smaller than the OSHA

action level of 0.1 f/cc. There were therefore no exceedances of the OSHA action level during this study.

4. **Compare the effect of each of the two wax stripping methods on residual asbestos levels after the work has been completed.**

   There was no significant difference, for either of the two floor stripping methods, between measurements taken before stripping began and after the process was complete. Thus, there is no evidence of a short-term residual effect of the stripping process on airborne asbestos levels.

5. **Although the personal PCM samples were all below the OSHA action level of 0.1 f/cc, considerably higher exposures are indicated by the TEM area samples.**

   There are two reasons for this. First, PCM cannot detect fibers thinner than 0.25 μm. Second, the PCM protocol used in this study does not count fibers shorter than 5 μm. The TEM analysis results show that PCM did not account for all the fibers present in the workplace. In particular, the concentration of fibers longer than 5 μm in the TEM area samples is generally over 2 orders of magnitude lower than the total structure concentration. Thus, caution should be exercised in interpreting the PCM measurements taken in this study.

6. **In most cases, more complex matrix structures, with larger attached particles and longer fibers and bundles protruding from the matrix material, were found on the filters from samples taken during stripping by the P.G. method.**

   Based on the professional opinion of the laboratory analysts, chlorine and titanium peaks identified by EDS indicate a VAT origin for the matrix material from the P.G. stripping samples. The matrix material often had ill-defined edges and probably represented vinyl material softened and swollen during the preparation of the samples. While these matrices are not countable under AHERA rules, they may have originally represented smaller matrices with exposed asbestos fibers. This deserves further study. In future experiments, it would also be of value to examine the surface of VAT floor samples under a scanning electron microscope before and after the stripping operation to observe the overall condition of the surface on a microscopic scale, and to assess the prevalence of exposed asbestos structures (if such sampling would not create unacceptable damage to the floor under study).

3.0 STUDY DESIGN

3.1 EXPERIMENTAL DESIGN

The experimental design employed for this study was a randomized block with six groups (blocks) of two rooms each. A (complete) randomized block design is one in which each experimental treatment is applied, in random order, to each specimen in the test. Because each set of treatments is compared on the same specimen, the influence of variability between the specimens on the results is minimized. In this study, a true randomized block would have involved applying the EPA and PG methods to the same room. This was not possible for many reasons, the principal one being that contamination introduced during the first test in a room could influence the results of the second test. Therefore, an approximation to a randomized block was devised, in which, instead of applying the two treatments to the same room, a matched pair of rooms (called a block) was used. The assignment of method (PG or EPA) to rooms within a pair was at random.

The two rooms within any given block were chosen to be as similar as possible to each other in terms of floor tile (type, color, wear, etc.), and physical layout (size, fittings, air circulation patterns, etc.). However, the condition of the wax was not considered as a test variable, nor was it tested for asbestos content.

Airborne asbestos concentrations were measured before application of each method and while the wax stripping was in progress using area samples and a passive sampling protocol. For purposes of comparison, the same stripping and rebuilding protocols were followed for each method (except for the pad used), regardless of the outcome. For example, the length of time during stripping was the same for both methods. There were two sampling phases during wax stripping: (1) while wax was being stripped from the floor, and (2) during rebuilding of a new wax surface. Samples were analyzed by Transmission Electron Microscopy (TEM) using a direct transfer technique (the "AHERA" protocol).

While stripping and rebuilding were being carried out, personal samples were collected according to OSHA sampling protocols. These samples were analyzed by Phase Contrast Microscopy (PCM) using the NIOSH 7400 protocol.

After a treatment was completed, area samples were collected using a modified aggressive sampling technique to obtain a measure of residual asbestos levels.

3.2 SAMPLE COLLECTION

The study was conducted at the Bowie High School Annex of the Prince George's County Public School System in Upper Marlboro, Maryland. The test area consisted of individual classrooms all located on the ground floor in an unused area of the building (Figure 3-1). Each classroom contained approximately 900 square feet of 9" x 9" asbestos-containing floor tile. Based on samples collected by Prince George's County Public Schools in December 1988, it was thought that tiles and mastic from one classroom contained approximately 10 percent and 20 percent chrysotile asbestos, respectively. The samples had been analyzed using polarized light and dispersion staining microscopy (40 CFR Part 763, Vol. 52, No. 210). The asbestos content of the floor tile was investigated further by EPA RREL prior to the present study. RREL analyzed each type of floor tile from each classroom and determined that the floor tiles contained greater than 1 percent asbestos. A confirmatory analysis of ten tile samples collected by EPA-RREL on May 24, 1990, showed that the floor tile contained 14 to 26 percent chrysotile asbestos. The EPA-RREL samples were analyzed by TEM using Chatfield's Method (SOP-1988-02, Revision No. 1: Analysis of Resilient Floor Tile). Other sources of asbestos in the building include thermal system insulation on the hot water tank and boiler, and on pipes, elbows, and valves, all located only in the boiler room.

The test site was partitioned into three zones to facilitate air flow and negative-air pressure conditions. These zones were further partitioned by air-locks created from triple curtained 6-mil polyethylene doorways. The locations of the air-locks and high efficiency particulate air (HEPA) filtration systems are shown in Figure 3-1. The HEPA units were used to maintain a negative-air pressure (-0.02 inches water gauge) in the study area during the experiments. The units also served to ventilate the classrooms after each experiment; the test area was also ventilated with outside air.

Prior to conducting the experiments, the classrooms were wet-cleaned and double-flap 6-mil polyethylene curtains were installed at the entrance to each room. The perimeter wall-mounted heating, ventilation, and air-conditioning (HVAC) units were sealed with 6-mil polyethylene. The student lockers in each corridor and the ceiling vents were also covered with 6-mil polyethylene.

Details of each method of floor wax stripping are given in Appendix A. The specifications (e.g., rotational pad speed) of the floor care machines are also included. The floor care machine selected for the EPA procedure was randomly selected from five different machines which all had rotational pad speeds between 170 to 300 RPM. The wax-stripping chemicals used in the EPA procedure were selected based on consultation with resilient floor tile manufacturers.

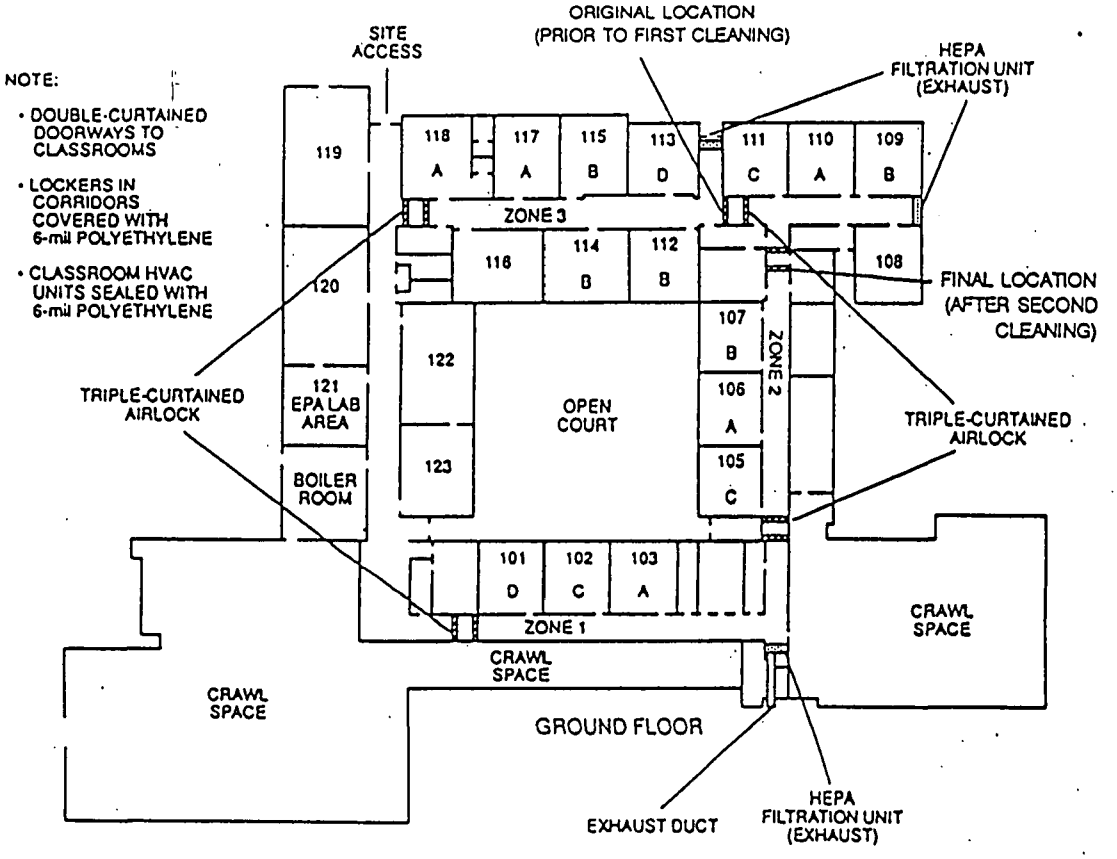


Figure 3-1. Layout of Test Area in Bowie High School Annex.

4.0 FIELD METHODS

4.1 SAMPLING AIRBORNE ASBESTOS

4.1.1 Air Sampling Strategy

Pre-study site evaluation -- Pre-study site evaluation samples were collected to document the background asbestos contamination in each classroom. The primary purpose of these samples was for comparison with the post-study evaluation samples if airborne asbestos levels at the end of the study were elevated with respect to outdoor levels. The sampling was conducted using modified aggressive sampling techniques, i.e., floors and walls (up to a height of five feet) of each classroom were swept with the exhaust of a one-horsepower leaf blower. One stationary fan (18-inch diameter axial flow) per 10,000 ft^2 of floor area was positioned with the air directed toward the ceiling to maintain air movement during sampling. One air sample was collected in each of 15 classrooms and in each of the three corridors. Five air samples were collected outdoors. Two quality assurance samples (one closed and one open field blank) were also collected in each of the three zones, and one open field blank was collected outdoors. The field blanks were collected in accordance with the procedures specified in the AHERA final rule. This yielded a total of 30 prestudy air samples.

Four of the five outdoor samples showed no asbestos structures; the fifth had a concentration of 0.01 s/cc. However, the prestudy samples collected in the classrooms and corridors showed elevated levels of background contamination inside the test area. The average airborne asbestos concentrations in Zones 1, 2, and 3 (see Figure 3-1) were 0.044, 0.145, and 0.041 s/cc, respectively. Therefore, the test area was recleaned before beginning the study. The classrooms and corridors were dry-vacuumed with a HEPA-filtered vacuum cleaner, and then the floors were wet-mopped. Three of the six classrooms in Zone 2 were eliminated from the study design (rooms 105, 106 and 107) because of the high airborne asbestos concentrations in these rooms and in the corridor outside these three rooms (average concentration, 0.231 s/cc). The test area was therefore reduced to two zones by reconfiguring Zone 3 to include the other three classrooms from Zone 2 (rooms 109, 110 and 111). Additional samples were then collected to document background asbestos concentrations in the test area after the classrooms were cleaned. The sampling was again conducted using modified aggressive sampling techniques. Stationary fans were used to maintain air movement during sampling. One air sample was collected in each of 12 classrooms and in each of the two corridors. Five air samples were collected outdoors. One closed and two open field blanks were also collected in each of the two zones, and one open field blank was collected outdoors. This yielded a total of 26 air samples. All five outdoor samples showed zero asbestos structures. The average airborne concentrations in Zones 1 and 3 after the classrooms were cleaned were 0.011 s/cc and 0.042 s/cc, respectively. The overall average concentration in the 12 rooms

in which the experiment was performed was 0.03 s/cc. However, we note that the pre-study cleaning did not have a lasting effect: airborne asbestos concentrations in the 12 rooms, measured by passive sampling just prior to the start of the experiment, averaged 0.3 s/cc (see Table 7-1).

Experiment baseline -- Before each experiment, air samples were collected to establish a baseline airborne asbestos concentration in the classroom for comparison with the concentration measured during the maintenance treatment. These samples were collected under passive sampling conditions. Five baseline air samples were collected in each classroom. One open field blank and one closed field blank were also collected. This provided 7 baseline samples for each experiment for a total of 84 baseline samples.

Five area air samples were collected to document the background concentrations of airborne asbestos in the perimeter of the test area before the study was conducted. These samples were collected under passive sampling conditions. One open and one closed field blank were also collected. This provided a total of 7 baseline perimeter samples.

During experiment -- During each experiment, area air samples were collected in the classroom, under passive sampling conditions, for comparison with the experimental baseline samples. Five area air samples were collected in each classroom during stripping of the floor wax. One open and one closed field blank were also collected. This provided 7 area samples during stripping for each room, a total of 84 samples. The same sampling plan was followed during rebuilding of the wax layer in each room, resulting in 84 area samples for the rebuilding period also. The average sampling time for the area samples was 50 minutes during stripping and 45 minutes during rebuilding.

Additionally, two personal air samples were collected on each worker performing the floor maintenance treatments. Two workers (an equipment operator and a helper) performed the stripping treatments, and one worker performed the wax refinishing. These samples were collected under passive sampling conditions. One open and one closed field blank were also collected. This provided 6 personal samples during each stripping treatment, and 4 personal samples during each rebuild treatment, for a total of 120 personal air samples to be analyzed by Phase Contrast Microscopy using the NIOSH 7400 protocol. An additional 9 personal samples were collected during stripping and analyzed by TEM. The sampling times for the personal samples were slightly shorter than for the area samples, averaging 44 minutes during stripping and 35 minutes during rebuilding.

To document the background concentrations of airborne asbestos in the perimeter of the test area while the experiments were being conducted, area air samples were collected during each of the four days of sampling. The samples were collected under passive sampling conditions. Five perimeter samples were

collected on each of the first two days of the study, whereas two perimeter samples were collected on each of the third and fourth day of sampling. Fewer perimeter samples were collected on the third and fourth day of sampling because three additional pumps were needed to collect experimental samples during the maintenance treatments on these days. One open and one closed field blank were also collected in the perimeter area on each day of sampling. This provided a total of 22 perimeter samples during the study.

Post Experiment -- After each experiment, area air samples were collected to determine if the maintenance treatments left the classrooms with an elevated level of airborne asbestos, i.e., to establish the residual level of contamination in the classroom. The sampling was conducted using modified aggressive sampling techniques, i.e., floors and walls (up to a height of five feet) of each classroom were swept with the exhaust of a one-horsepower leaf blower for 20 minutes. Five area air samples were collected in the classroom after each experiment. One open and one closed field blank were also collected after each experiment. This provided 7 area samples after each experiment. A closed blank was not collected for one experiment; therefore, a total of 83 post experiment samples were collected.

Poststudy site evaluation -- Post-study site evaluation samples were collected to determine if the site (the classrooms and corridors) was acceptable for reoccupancy. Similar to the post experiment step, the sampling was conducted using modified aggressive sampling techniques. One air sample was collected in each of the 15 classrooms and in each of the corridors of the original three test zones. Five air samples were also collected outdoors (all showed zero asbestos structures). One open and one closed field blank were also collected in each of the three zones, and one open field blank was collected outdoors. This yielded a total of 30 poststudy air samples. The average airborne asbestos concentration for the 18 worksite samples was 0.029 s/cc, which is comparable to the levels obtained in the pre-study evaluation after re-cleaning of the site.

4.1.2 Sampling Methodology

Area air samples -- The area 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 support pad contained in a three piece cassette. The filter cassettes were positioned approximately five feet above the floor with the filter face at approximately a 45-degree angle toward the floor. The filter assembly was attached to an electric-powered (110 VAC) 1/6-horsepower vacuum pump operating at a flowrate of approximately 9 liters per minute. The sampling pumps were calibrated both before and after sampling with a calibrated precision rotameter (Manostat Model 36-54b-215). The precision rotameter is a secondary air flow standard in that it has mechanical moving parts; therefore, it was calibrated with a primary air flow standard. The primary standard used was an electronic bubble flowmeter (see Section 4.3.2).

The range of air volumes for each type of area sample is shown below:

Type of area sample	Air volume range (liters)
Prestudy site evaluation	1248 to 1610
Experiment baseline	1225 to 1794
During experiment	217 to 685
Post experiment	858 to 1898
Poststudy site evaluation	1758 to 2781

Some of the air volumes in the "During" phase are below the 560 liter minimum required under the EPA interim TEM analytical method. In such cases, the laboratory analysts compensated by reading additional grid openings to achieve the desired analytical sensitivity.

Blanks -- At the sampling site, the open blanks were opened for not more than 30 seconds at the time of sampling. The blanks accompanied the regular samples through the field operations and transport to the laboratory and were handled in an identical fashion. Closed blanks were not opened. Apart from this, they were treated in the same way as open blanks.

Personal air samples -- Personal samples were collected on the floor maintenance personnel, i.e., each worker wore a personal sampling pump with the filter assembly positioned in his breathing zone area. The samples for analysis by PCM were collected on open-face, 25-mm diameter, 0.8-μm pore-size, mixed cellulose ester membrane filters with 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 flowrate of approximately 2 liters per minute. The sampling assembly was worn by the worker during the entire duration of the maintenance treatment. The sampling pumps were calibrated before and after sampling by using a calibrated electronic mass flow meter (Kurz Model 580). The

mass flow meter is a secondary air flow standard, therefore, it was calibrated with a primary air flow standard (refer to Section 4.3.2).

4.1.3 Sampling Conditions

The environmental conditions (dry bulb temperature and relative humidity) were measured inside the test area and in the perimeter area each day during the study. The average dry-bulb temperature during the week the study was conducted was 86 degrees. The average relative humidity was 75 percent.

4.2 FIELD DOCUMENTATION AND CONTROL

4.2.1 Sample Documentation

An important part of any field program is the observations and accurate records of the field team. This information was recorded (in ink) on bound notebooks and/or data forms. At a minimum, the following information was recorded on a Sampling Data Form (Figure 4-1):

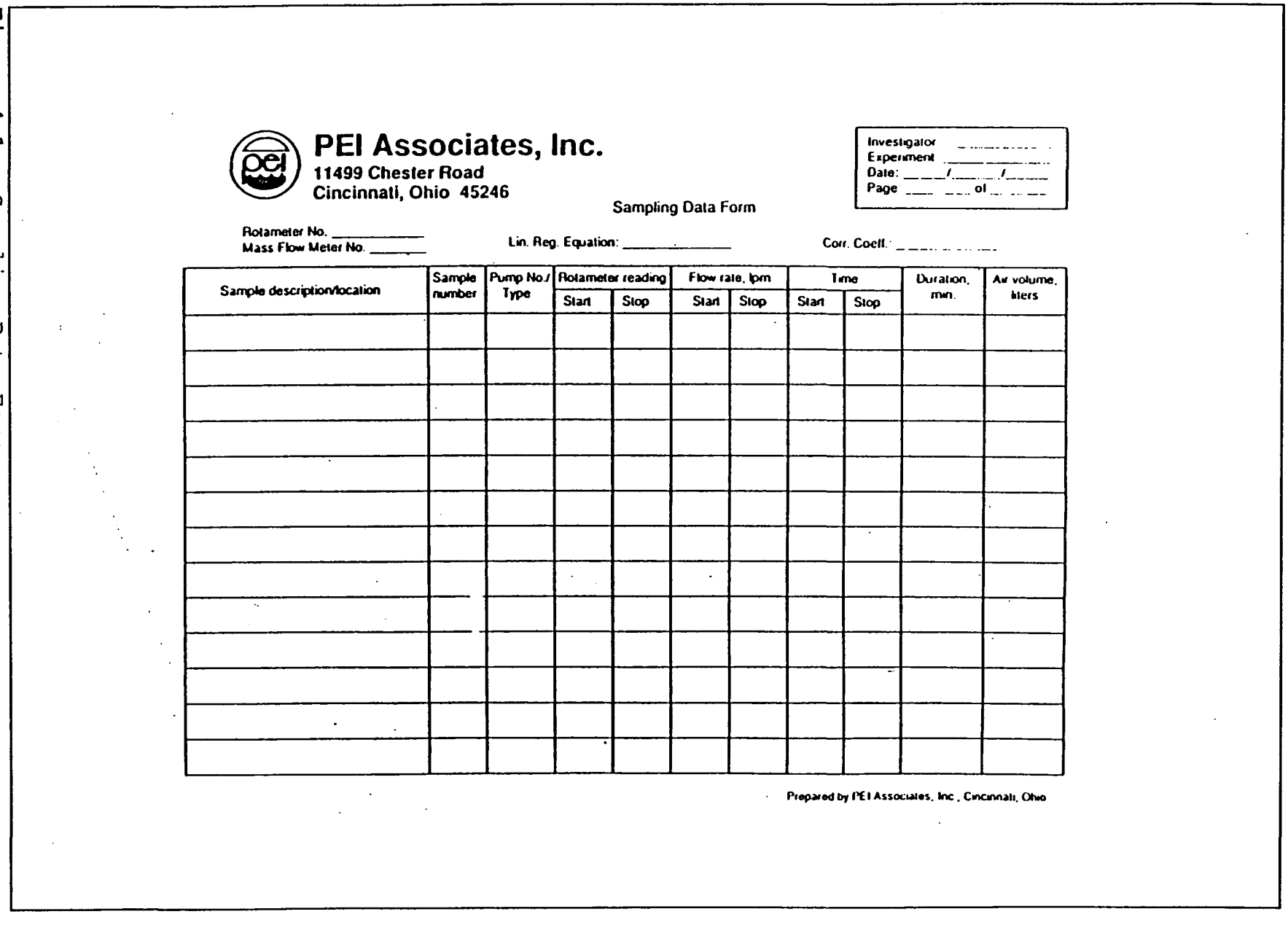
- Name of person collecting the sample
- Experiment number
- Date of record
- Location of sample
- Type of sample (e.g., personal, area, etc.)
- Sample number
- Rotameter number and reading (start/stop)
- Sample time (start/stop).

Relevant notes describing sampling and environmental conditions, technical problems/solutions, equipment performance, operator work practices, etc., were recorded in the bound notebook.

4.2.2 Traceability Procedures

Standard PEI sample documentation procedures were used to ensure sample traceability. Chain-of-custody procedures documented the identity of each sample and its handling from its first existence as a virgin filter until analysis and data reduction were completed. Chain-of-custody records traced each sample from its collection until it was transferred to the analytical laboratory. Internal laboratory records then documented the custody of the sample through its final disposition.

Each sample was issued a unique project identification number. This identification number was recorded on a PEI Sampling Data Form (Figure 4-1) along with the other information specified on the form. After the labelled sample cassettes were recovered from the sampling trains, the on-site industrial hygienist filled out (in ink) a Request for Analysis Form (Figure 4-2) and a Chain-of-Custody Record (Figure 4-3). This form accompanied the samples, and each person having custody of the



PEI Associates, Inc.
11499 Chester Road
Cincinnati, Ohio 45246

Sampling Data Form

Investigator _____
Experiment _____
Date: ____/____/____
Page ____ ____ of ____ ____

Rotameter No. _____
Mass Flow Meter No. _____

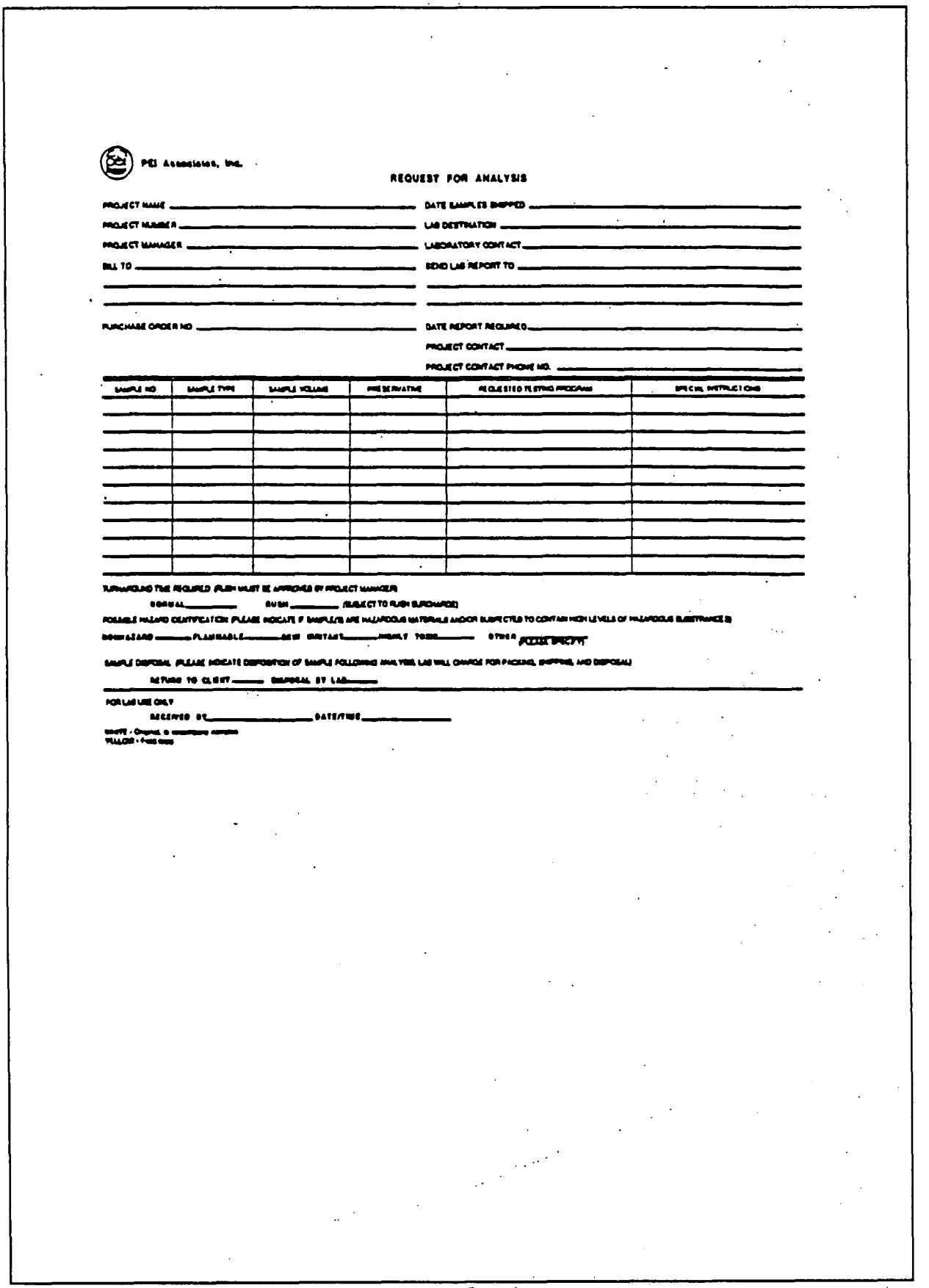
Lin. Reg. Equation: _____

Corr. Coeff. _____

Sample description/location	Sample number	Pump No./ Type	Rotameter reading		Flow rate, lpm		Time		Duration, min.	Air volume, liters
			Start	Stop	Start	Stop	Start	Stop		

Prepared by PEI Associates, Inc., Cincinnati, Ohio

Figure 4-1. Sampling Data Form.



PEI Associates, Inc.

REQUEST FOR ANALYSIS

PROJECT NAME _____ DATE SAMPLES SHIPPED _____

PROJECT NUMBER _____ LAB DESTINATION _____

PROJECT MANAGER _____ LABORATORY CONTACT _____

BILL TO _____ SEND LAB REPORT TO _____

_____ _____

_____ _____

PURCHASE ORDER NO _____ DATE REPORT REQUIRED _____

PROJECT CONTACT _____

PROJECT CONTACT PHONE NO. _____

SAMPLE NO	SAMPLE TYPE	SAMPLE VOLUME	PRESERVATIVE	REQUESTED TESTING PROGRAM	SPECIAL INSTRUCTIONS

TURNAROUND TIME REQUIRED (RUSH MUST BE APPROVED BY PROJECT MANAGER)

NORMAL _____ RUSH _____ (SUBJECT TO RUSH SURCHARGE)

POSSIBLE HAZARD IDENTIFICATION (PLEASE INDICATE IF SAMPLE(S) ARE HAZARDOUS MATERIALS AND/OR SUSPECTED TO CONTAIN HIGH LEVELS OF HAZARDOUS SUBSTANCES)

NON-HAZARD _____ FLAMMABLE _____ HIGH VIRULENT _____ HIGHLY TOXIC _____ OTHER (SPECIFY)

SAMPLE DISPOSAL (PLEASE INDICATE DISPOSITION OF SAMPLE FOLLOWING ANALYSIS. LAB WILL CHARGE FOR PACKING, SHIPPING, AND DISPOSAL)

RETURN TO CLIENT _____ DISPOSAL BY LAB _____

FOR LAB USE ONLY

RECEIVED BY _____ DATE/TIME _____

WHITE - Original to accompany samples

YELLOW - Field copy

Figure 4-2. PEI Request for Analysis Form.

PEI Associates, Inc.

CHAIN-OF-CUSTODY RECORD

PROJECT NAME/NUMBER _____ LAB DESTINATION _____

SAMPLE TEAM MEMBERS _____ CARRIER/WAYBILL NO. _____

SAMPLE NUMBER	SAMPLE LOCATION AND DESCRIPTION	DATE AND TIME COLLECTED	SAMPLE TYPE	CONTAINER TYPE	CONDITION ON RECEIPT (NAME AND DATE)

SPECIAL INSTRUCTIONS: _____

POSSIBLE SAMPLE HAZARDS _____

SIGNATURES: (NAME,COMPANY,DATE,AND TIME) _____

1. RELINQUISHED BY: _____ 3. RELINQUISHED BY: _____

RECEIVED BY: _____ RECEIVED BY: _____

2. RELINQUISHED BY: _____ 4. RELINQUISHED BY: _____

RECEIVED BY: _____ RECEIVED BY: _____

WHITE - To accompany samples
YELLOW - Field copy

Figure 4-3. PEI Chain-of-Custody Form.

samples noted receipt of same and completed an appropriate section of the form. Samples were hand delivered to the TEM laboratory. The laboratory's sample clerk examined the shipping container and each filter cassette for any evidence of damage or tampering, noted any damage or indication of tampering on the accompanying chain-of-custody form, and then forwarded the form to the PEI Project Manager.

4.3 SPECIALIZED FIELD PROCEDURES

4.3.1 Filter Handling Procedures

The following procedures were followed to ensure consistent handling of all samples collected in the field:

- Use of pre-loaded filter cassettes from a lot prescreened by TEM to minimize the possibility of contamination.
- After sampling, the filter cassettes were sealed and placed in boxes so that the cassettes would remain in an upright position. No material other than closed cassettes was shipped in the boxes.
- Hand delivery of all samples to the laboratory for analysis.

4.3.2 Air Flow Calibration Procedures

The following precautions were followed in the handling of the air flow equipment employed in the field.

Area samples -- A limiting orifice was used to regulate the sampling flow rate through the sampling train during sampling. The air flowrate was determined both before and after sampling by a calibrated precision rotameter (Manostat Model 36-54b-215).

Personal samples -- The personal samples were collected using a constant flow (±5%) sampling pump, i.e., the pump has an in-line feedback control to monitor air flow through the pump mechanism and to adjust pump speed to maintain constant air flow. This control system ensures, within limits, constant flow regardless of load variations or other factors that would normally change the flow rate. The air flowrate was determined both before and after sampling by a calibrated electronic mass flow meter (Kurz Model 580).

The precision rotameter and electronic mass flow meter were calibrated in the field using a primary standard airflow calibrator (Gilibrator brand electronic bubble flowmeter).

A detailed record was maintained. It included a written record (in ink) of all relevant calibration data, including the following elements:

- Rotameter model and serial number.
- Sampling device (0.45-μm or 0.8-μm pore-size, 25-mm mixed cellulose filter contained in a three piece cassette) in line during calibration.
- X- and Y-coordinate calibration data.
- Intercept, slope, and correlation coefficient from a linear regression analysis of the calibration data.
- Linear regression equation to be used to determine a flowrate.
- Dry bulb temperature.
- Barometric pressure.
- Relevant calculations.
- Name of person performing the calibration.

5.0 LABORATORY METHODS

5.1 SAMPLE CONTROL

5.1.1 Sample Receipt and Log-In

Samples were received in the laboratory by the Sample Custodian and checked against the sample receiving form to verify information. The chain of custody form was checked for completeness and signed and dated to document receipt. In the laboratory, a unique sample identification number was assigned to each sample batch and to each sample using a standard protocol.

The sample number was recorded on the sample container label, and samples were placed in a bag or box labelled with the sample batch number. The sample numbers were recorded on the sample receiving form and on the chain of custody form.

Sample numbers were recorded chronologically along with the date of receipt, project number, the name of the sample project leader, type of sample media, analysis to be performed, and the initials of the sample recipient. The information was computerized on a WordPerfect chain-of-custody file.

5.1.2 Sample Storage and Disposal

After log-in, the samples, chain of custody form, and sample receiving form were placed in the prep laboratory. Unused portions of samples were archived. The disposition of the samples was noted on the chain-of-custody form.

5.1.3 Recordkeeping and Filing

The completed sample receiving and chain of custody forms were maintained in a file folder along with all analysis documents. The folders were stored chronologically by project number in a file cabinet in the laboratory. Project completion was documented on the computerized WordPerfect file. A permanent record of this data will be maintained.

5.2 LABORATORY PROCEDURES

5.2.1 Sample Preparation

The outside surfaces of the cassettes containing samples to be analyzed were carefully wiped with a lint-free cloth that had been dampened with particle-free water to remove contamination. The sample containers were then placed on the clean bench in the HEPA laminar flow hood.

Portions of the filters were placed on slides and collapsed with the Chatfield DMF mixture. The slides were placed in sealed petri dishes and taken to the main laboratory for low temperature plasma ashing and carbon coating. The coated filters were again placed in sealed petri dishes and returned to the prep laboratory

for placement on grids and dissolution of the filter material on Jaffe Wicks. Until they were analyzed, the prepared grids were stored in numbered grid boxes in the main laboratory.

5.2.2 Analytical Methods

The analytical methodology used for TEM examination of the area samples followed the procedures detailed in 40 CFR Part 763, AHERA Non-Mandatory Method. The length and width of all asbestos-containing structures was also recorded. Clusters and matrices were sized by measuring the length and diameter of the longest asbestos fiber within the structure.

5.2.3 Analysis Documentation

Identification of Structure by Energy Dispersive Spectrometry (EDS) and Selected Area Electron Diffraction (SAED): EDS and SAED were used to confirm the identification of asbestos and non-asbestos structures which was noted on the TEM Asbestos Analysis Data form. The identifications were periodically documented by printing out EDS spectra. EDS print-outs were obtained for each type of asbestos present in the sample. Micrograph and spectrum numbers were recorded on the TEM Asbestos Analysis Data form.

Data Recording: All analytical data were carefully recorded so that the details of the analysis were complete and clear. Counting and sizing data were recorded on "TEM Asbestos Analysis Data" forms. The original forms were retained in the project files along with identification validation data such as EDS spectra, SAED patterns, and photomicrographs. Analysis data was initialled and dated by the analyst. Data was transferred to Lotus 1-2-3 files, stored on disk, and entered into the EPA mainframe computer database.

Results Calculation: Results were calculated according to the standard AHERA formulae. Calculations were performed by computer. Hand calculations, computer entries, and data transfers were double checked by a second analyst. Calculations were hand checked for at least one out of every hundred samples.

Reporting: Analytical results were reported only if quality control results were acceptable (see Section 6.0). Reports were signed and dated by the analyst. The reports were reviewed by the Chief of the Toxics Control Branch and the RREL QA Manager before the data was released.

6.0 QUALITY ASSURANCE

The Quality Assurance Project Plan (QAPjP) for this study mandated quality control (QC) checks to be performed for each of the three key functions within the study: field data collection, laboratory analysis, and data analysis. This chapter contains a brief discussion of the QC checks implemented. For details of the field, laboratory or data analysis methods, the reader is referred to Chapters 4, 5 and 7 respectively.

6.1 FIELD QUALITY CONTROL PROCEDURES

QC procedures for the field sampling aspects of this study included the following:

- The use of standardized forms (e.g., Figures 4-1 and 4-2), checklists, and field notebooks to ensure completeness, traceability and comparability of data and samples collected.
- Strict adherence to the sample chain-of-custody procedures outlined in the QAPjP for this project.
- Selection of sample locations in an unbiased manner as outlined in the QAPjP.
- Field cross checking of data forms to ensure accuracy and completeness by the field coordinator/supervisor from the organization responsible for field data collection.

6.2 LABORATORY QUALITY CONTROL CHECKS

A total of 48 field (open) blanks, one per sampling period in each room, were analyzed by RREL. In addition, 47 sealed blanks, one per period per room with the exception of the "after" period for the EPA method in the 6th group of rooms, were analyzed. The blanks were not distinguishable from regular samples to the analysts. All but two of the 95 blanks showed zero structures. One field blank and one sealed blank showed a single asbestos structure in the 10 grid openings examined. A laboratory blank was added to each group of samples prepared. One of the 38 lab blanks analyzed contained 2 asbestos structures in 10 openings, 5 contained 1 structure, and the remaining 32 were free of any structures.

To measure laboratory precision, 3 samples per experimental group were selected at random and analyzed a second time by RREL. Two of the three were replicates, that is, repeat counts of the same preparation. The third sample in each group was a duplicate, i.e., a new preparation from a different filter quadrant. Thus, a total of 12 replicates and 6 duplicates were analyzed. The repeat analyses were carried out blind by the analysts.

For the replicates, 11 of the 12 coefficients of variation (CV's) for the two analyses were less than 25%. The 12th CV was 130%. All 6 CV's for the duplicates were 20% or less. These results are well within acceptable ranges for repeat direct TEM analyses, although it is curious that the CV's for the duplicates are smaller than those for the replicates.

The total number of TEM analyses performed in the study was 397: 237 regular samples, 48 open blanks, 47 sealed blanks, 18 repeat analyses by the same laboratory, 9 personal samples analyzed by direct TEM, and 38 laboratory blanks prepared with the study samples. The pre- and post-study site evaluations were additional.

6.3 EXTERNAL QUALITY ASSURANCE ANALYSES

As a check on the performance of the RREL laboratory, certain filters were selected for reanalysis by an external laboratory (RJ Lee Group). Each reanalysis consisted of preparation and direct TEM analysis of a different filter quadrant from the one originally analyzed by RREL. Pairwise comparison of the measured airborne asbestos concentrations was then used to assess any differences in the analytical performance of the two laboratories.

The QAPjP called for the selection of 3 samples at random from each of the 6 pairs of rooms for external QA analysis, for a total of 18 external QA samples. The actual selection of samples deviated slightly from the QAPjP. For each combination of 2 methods (EPA, P.G.) and 3 periods (Before, During/Rebuild, After), 3 external QA samples were selected at random, for a total of 18. In addition, 4 more samples were selected entirely at random from the study samples, giving a total of 22 external QA samples analyzed by RJ Lee Group. Thus, although the sample selection procedure specified in the QAPjP was not followed, there is no reason to believe that the external QA samples actually selected are not adequate to represent the laboratories' performance.

The airborne asbestos concentrations reported by RJ Lee Group and RREL are highly correlated (correlation coefficient of 0.96), but the RJ Lee results are generally higher than those of RREL. Of the 22 samples, 16 have higher concentrations reported by RJ Lee, a statistically significant result ($p = 0.03$). A paired t-test of the difference between the natural logarithms of the RREL and RJ Lee measurements also indicates a statistically significant elevation of the RJ Lee measurements ($p = 0.003$). Among the external QA samples, orders of magnitude differences in airborne asbestos concentrations are present, so that an analysis on the log scale is most appropriate. This gives an estimate of the geometric mean ratio between RJ Lee and RREL measurements of 1.32, with a 95% confidence interval of 1.11 to 1.57. Thus, on average, the RJ Lee measurement is 32% higher than the RREL measurement, with 95% confidence bounds of 11% to 57%.

The above analysis indicates that there is a measurable, but small, positive bias of the RL Lee laboratory versus the RREL laboratory. Relative interlaboratory biases of the magnitude found are common in asbestos analysis, and can be due to extremely subtle differences in procedures. Thus, there is no cause for concern in the results found, and the external QA analyses are satisfactory.

6.4 QUALITY CONTROL CHECKS FOR DATA PROCESSING

PEI provided information linking sample ID's with sampling locations and any other field data relevant to the interpretation of the results. Laboratory results for each sample ID were also provided, in computer readable form.

The field and laboratory data were entered into a computer data base. Each entry was verified against the information provided by RREL and PEI. Any discrepancies were documented and their solution and subsequent correction recorded. A traceable link was retained between the original data and all data sets that were created and used for statistical analysis.

7.0 STATISTICAL ANALYSIS

7.1 INTRODUCTION

Tables 7-1 and 7-2 contain arithmetic mean airborne asbestos levels for area (TEM) and personal (PCM) samples respectively. The concentration values and the number of samples on which each is based are shown in Table 7-1, broken down by wax stripping method. The two methods appearing as columns in the table correspond to the two methods for stripping wax from the vinyl

Table 7-1. Arithmetic mean airborne asbestos concentrations (s/cc by TEM) for area samples.

	EPA Method		P.G. Method	
	Arithmetic Mean	Number of samples	Arithmetic Mean	Number of samples
Before	0.11	29	0.50	30
During stripping	0.53	30	1.18	30
During rebuild	0.23	29	0.32	30
After	0.19	29	0.21	30

asbestos tile floors: the method used by Prince Georges County Public Schools (P.G. method) and a method consistent with EPA Interim Guidelines (EPA method). The four row headings in the tables refer to the four stages of the wax stripping process at which measurements where taken:

- before wax stripping
- during the actual floor stripping process
- during the process of rebuilding the wax layer
- after the process was complete.

The mean values shown in Table 7-1 are arithmetic means for the 30 measurements that were taken for each combination of method and time period (only 29 measurements were available for EPA "Before", "Rebuild", and "After"). The units of measurement are asbestos structures per cubic centimeter (s/cc). These measurements were obtained using direct Transmission Electron Microscopy (TEM). The 30 measurements are comprised of five measurements per room in each of six rooms (there are three missing values: one in the third room for EPA "Before"; one in the sixth room for EPA "After"; one in the sixth room for EPA "Rebuild"). A full description of the design of the experiment is given of Chapter 4 of this report.

Table 7-2 contains arithmetic means, the range of values measured (minimum to maximum), and the number of samples broken down by wax stripping method and time period of the airborne

asbestos PCM concentrations. These measurements were obtained from personal monitors worn by the maintenance staff who stripped and waxed the floors (as discussed in Chapter 5). As data was collected only during the stripping and rebuilding steps of the process, only those two time periods are shown in the table. During stripping each of the two workers wore two personal monitors each making four measurements in each of six rooms (for a total of 24). During rebuilding, there was only one worker, therefore, the two monitors per room for six rooms makes a total of 12 measurements per method. The concentrations shown in Table 7-2 are in units of fibers per cubic centimeter (f/cc). These measurements were obtained using Phase Contrast Microscopy (PCM) in accordance with the NIOSH protocol 7400.

Table 7-2. Arithmetic mean airborne asbestos concentrations (f/cc by PCM) of personal samples.

	EPA Method	P.G. Method
During stripping		
Arithmetic mean	0.0070	0.0092
Range	0-0.030	0-0.026
Number of samples	24	24
During rebuild		
Arithmetic mean	0.010	0.0070
Range	0-0.056	0-0.025
Number of samples	12	12

In this study, the PCM measurements should be carefully interpreted. While the personal samples show the largest concentration to be less than the OSHA action level of 0.1 f/cc, PCM, as a tool of sample analysis, is likely to miss fibers released from the tile. The data produced by TEM analysis of area samples collected during stripping provide evidence that PCM did not measure all fibers present in the workplace air. On average, the concentrations reported by TEM analysis during stripping reached 1.18 s/cc, whereas the highest concentration reported by PCM analysis was 0.056 f/cc. In addition, the 9 personal samples taken during stripping and analyzed by TEM had an average concentration of 0.75 s/cc, with a range from 0.26 s/cc to 1.49 s/cc.

An examination of the limitations of PCM may support the findings. Practically, PCM is capable of resolving fibers of width greater than 0.25 μm. Further, the protocol employed for PCM analysis in this study counts only fibers greater than 5 μm in length. The great majority of the fibers released from stripping asbestos-containing floor tile were shorter than 5 μm. Table 7-3 shows arithmetic mean airborne asbestos concentrations of fibers longer than 5 μm, broken down by method and period, for

the same area samples reported in Table 7-1 (a small number of amosite fibers longer than 5 μm have been excluded from these counts because of their non-VAT origin). The concentration of fibers longer than 5 μm is typically over two orders of magnitude lower than the total structure concentration.

Table 7-3. Arithmetic mean airborne concentrations of non-amosite asbestos fibers > 5 μm (f/cc by TEM) for area samples.

	EPA Method		P.G. Method	
	Arithmetic Mean	Number of samples	Arithmetic Mean	Number of samples
Before	0.0000	29	0.0008	30
During stripping	0.0054	30	0.0076	30
During rebuild	0.0031	29	0.0010	30
After	0.0012	29	0.0008	30

7.2 DATA ANALYSIS

The data analysis was designed to satisfy the four study objectives stated in Section 1.2 of this report. Three of the research objectives are met by examining comparisons of mean values obtained from different breakdowns of the data using an analysis of variance (ANOVA) model. The other goal, relating to how airborne concentrations obtained from personal monitors compared to OSHA action levels, has already been discussed. In order to systematically present an analysis of the remaining three objectives, this data analysis chapter is structured as follows:

- discussion of the underlying assumptions of the model.
- analysis of the high level ANOVA model.
- discussion of the multiple comparisons inherent in the model (among which are the basic study objectives mentioned in Chapter 2).
- discussion of alternative methods of analysis that were considered.

7.2.1 Analysis of ANOVA model assumptions

ANOVA is based upon a linear model of the effects of the components of the experiment which were varied. In this case, the experiment consisted of two different types of floor wax removal, four different times of measurement, and six different pairs of rooms in which measurements were taken. Each of these three variables is called a factor in the model. Further, the model assumes that varying the different factors results in a linear change in the overall mean of the measurement, in this case, airborne asbestos concentration. The final aspect of this model is that the measurements are not used in the scale f/cc or s/cc directly. As is common with environmental measurements, a transformation was applied to the data to conform to the assumptions underlying the ANOVA model.

To use ANOVA models confidently, one must check that certain basic underlying assumptions of those models are satisfied by the data under consideration. Consider first the assumptions of normality of the analysis of variance (ANOVA) model and equality of the variance of the error terms. As mentioned above, it is common with environmental measurements that a transformation of the raw measurements be made so that adherence to the normality assumption is ensured. Therefore, this data set was transformed using a natural logarithm transformation.

To check the normality of the resulting residuals, two diagnostic graphical displays were obtained. Those are shown in Figures 7-1 and 7-2. Figure 7-1 is a residual plot. It shows the residuals, the differences between the actual measurements and the fitted values predicted by the ANOVA model, plotted against the fitted values. When the model conforms to the standard assumptions of normality of residuals and equality of the variance of the error terms, the plot will appear to have no pattern. The residual values will be clustered about the value zero with the density of residuals diminishing as the distance from zero increases (both of which are present in Figure 7-1). A sign that the model does not conform to the assumption of equality of error variance is a funnel-shaped appearance of the residuals, where the funnel tends to increase as the size of the fitted value increases. There is no evidence in Figure 7-1 of such behavior. The only aspect of the graphic shown in Figure 7-1 that requires some discussion is the single value shown at the bottom of the graph, with an associated residual value of approximately -1.0. This is the only value that appears to be out of the cluster of values. Since there is only one such value and since it corresponds to a error of less than one standard deviation, we conclude that the assumption of equality of the error variance, required by ANOVA, is acceptable.

The normality plot shown in Figure 7-2 is a graphical device to determine whether the assumption of normality of residuals is satisfied. The closer this graph is to a straight line, the stronger is the assumption of normality. The normal probability plot shown in Figure 7-2 is visually linear in appearance. The

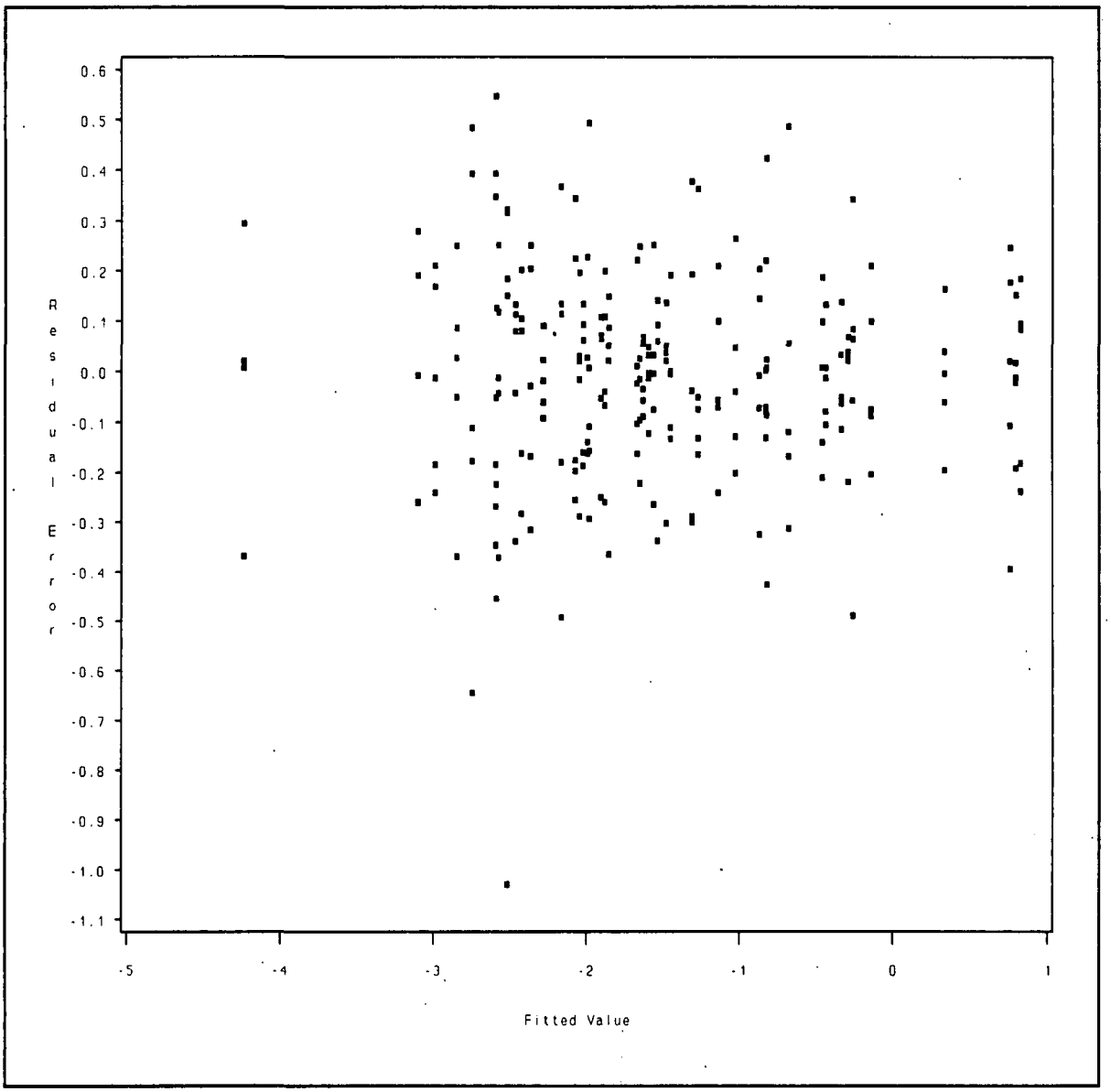


Figure 7-1. Residuals from the ANOVA model for airborne asbestos concentrations (TEM) plotted against fitted values.

same residual value mentioned with regard to Figure 7-1 is also present in Figure 7-2, and it represents the only outlier in the linear appearance of the normal probability plot. We conclude that adherence to both of the assumptions of normality and equality of error terms were sufficiently satisfied so as to warrant application of the ANOVA model.

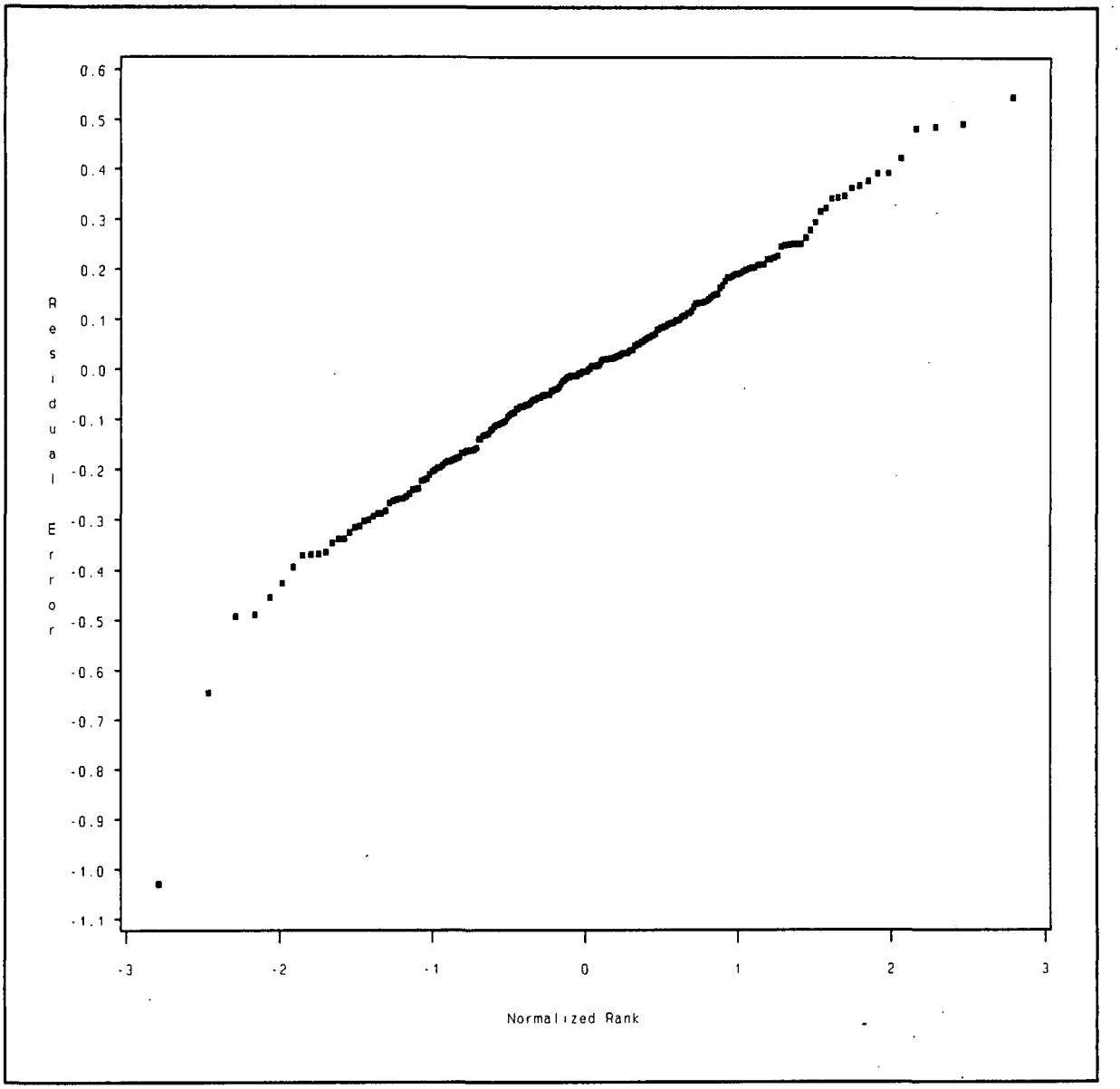


Figure 7-2. Probability plot of residuals from ANOVA model of airborne asbestos concentrations (area samples by TEM).

7.2.2 Analysis of the basic ANOVA model

The study was designed as a randomized block with rooms nested within the wax stripping method; therefore, the analysis proceeded by first obtaining the analysis of variance components. Table 7-4 contains the basic ANOVA table. This table shows the main effects and all interactions relating to the effect of the wax stripping method, period of measurement (before wax stripping began, during stripping, during rebuilding, and after the process was complete), and the block effect of matched rooms. All statistical tests relating to the main and interaction effects inherent in this model can be derived from this table. Following accepted practice with ANOVA models, one looks first at the main effects of the model. Table 7-5 contains a summary of both the

main and interaction effects. The most important effect to be considered is that of the wax stripping method, EPA versus P.G. The results of Table 7-5 reveal that the overall effect was not significant (with an F-ratio of 1.07 and p-value of 0.35). The p-value is interpreted as the probability that, under the hypothesis of equality of population means, the difference between means which was encountered (or a larger difference) would occur. It is customary to infer that the assumption is false if the probability of such an occurrence is 0.05 or less. Since the p-value encountered in this case is 0.35, it is not possible to make the desired inference; and it is concluded that there is <u>not</u> a significant quantitative difference between the two wax stripping methods.

Table 7-4. Analysis of variance table of log airborne asbestos concentrations (s/cc by TEM) from area samples.

Source	DF	Sum of Squares	Mean Square Error
Rooms	5	31.757	6.351
(Stripping) Method	1	6.541	6.541
Rooms*Method	5	30.553	6.111
Period	3	92.064	30.688
Rooms*Period	15	83.418	5.561
Method*Period	3	5.794	1.931
Rooms*Method*Period	15	22.678	1.512

This result appears to contradict the large difference shown in Table 7-1 between the arithmetic means of area measurements of airborne asbestos obtained during the stripping process for the EPA versus the P.G method. The explanation is as follows. It was the goal of this study to infer the existence of differences between these two methods when applied to any randomly selected set of rooms in which the wax stripping methods could be applied. The study used a specific set of rooms. To make an inference to all rooms, one must use what is called the Random Effects Model to obtain tests of significance. This model assumes that the set of rooms used is a sample of rooms as opposed to the complete set of all rooms about which the inference is to be made. Because the study revealed a large variability <u>between room pairs</u> as compared to the difference between methods within room pairs, the tests of significance resulted in F-values which were not significant. This means that, although the magnitude of the

differences revealed in Table 7-1 is substantial, it cannot be concluded that the result would be significant for a different selection of rooms.

This study was designed to detect a tenfold difference in the geometric means of concentrations. The ratio of the geometric mean of the P.G. measurement during stripping (0.84 s/cc) to the geometric mean of the EPA measurement during stripping (0.48 s/cc) is less than 2. Therefore, the study was not designed to find such a difference as significant.

Table 7-5. Summary of main effects for log of airborne asbestos concentrations (s/cc by TEM) from area samples.

Source	DF	F-Ratio	P-value
Rooms	5	115.60	< 0.0001
Method *	1	1.07	0.3483
Rooms*Method	5	111.22	< 0.0001
Period *	3	5.52	0.0093
Rooms*Period	15	101.21	< 0.0001
Method*Period *	3	1.28	0.3180

* indicates the use of a fixed effects model to determine the F-ratio; all other effects are assumed random.

Two comments relating to other values in Table 7-5 are required. One comment relates to the test whether there is a difference between mean airborne asbestos concentrations over the time period of measurement (before wax stripping, during stripping, during rebuild, and after). As shown in Table 7-5, this difference was significant at the 0.0093 level even using the random effects model. This indicates a very clear effect deriving from when the measurement was taken during the treatment process. This effect is discussed further in the next subsection.

A second comment concerns the impact of the difference between pairs of rooms in the experiment. As Table 7-5 shows, there was a very strong difference between the room pairs ($F = 115.6$ and $p < 0.0001$). This ties together with the inability to infer a difference between wax stripping methods. The room pairs were sufficiently different that any difference between the EPA and P.G. methods which may be present could not be detected.

7.2.3 Analysis of the multiple comparisons

Three of the four objectives given in Section 1.2 of this report can be derived directly by looking at comparisons between means of subgroups within the context of the study design. Since it is planned to make numerous comparisons of such means, it is appropriate to employ standard multiple comparison tests (Miller 1981). The Bonferroni method of multiple comparisons was selected. This method is applied by allocating a fraction of the total significance level that is to be used in the totality of all tests to be made, usually 0.05, to each of the separate tests. For example, if ten comparisons are to be made, each will be considered "significant" if a p-value of 0.05/10 or 0.005 or less is achieved. This method was used to analyze all pairs of differences between mean asbestos concentrations obtained for wax stripping methods and time period combinations. Since there were 2 x 4 or 8 wax stripping method by time period combinations, there are (7 x 8)/2 = 28 different comparisons of means. Using the Bonferroni test, we counted as significant, any difference that produced a p-value of less than 0.05/28 = 0.0018.

Table 7-6. Summary of multiple comparisons (Bonferroni).

Hypothesis Test	Significance
EPA strip (0.48) versus EPA before (0.10)	S
P.G. strip (0.84) versus P.G. before (0.19)	S
P.G. strip (0.84) versus EPA strip (0.48)	NS
P.G. after (0.16) versus EPA after (0.18)	NS
P.G. after (0.16) versus P.G. before (0.19)	NS
EPA after (0.18) versus EPA before (0.10)	NS

Note: Geometric mean TEM concentrations shown as (s/cc).

Table 7-6 contains a summary of the outcome of the key multiple comparison tests that were examined in this analysis. The table shows the comparison made and whether it was significant or not. A significant difference is denoted with the letter, S, while a finding of no significant difference is labeled, NS. The geometric means in s/cc are also supplied and are shown in parentheses after each of the comparisons is described. The key results are the following:

- There was a significant difference for both the P.G. and EPA wax stripping methods between airborne asbestos levels before and during the wax stripping. This

reflects the existence of the overall significant effect of time period of treatment in the experiment.

- It could not be concluded that there is a significant difference between the P.G. and EPA methods of treatment during stripping. The inability to reach this conclusion for the two comparison tests mirrors the overall situation for the variable, "wax stripping method". The variability between rooms overshadowed the difference in airborne asbestos levels between methods.

- For both the P.G and EPA methods, we could not conclude that there was a difference between airborne asbestos levels from before the experiment to after the process was completed. There is no evidence from this experiment of a residual effect on airborne asbestos levels from either the P.G. or the EPA method.

7.2.4 Other models investigated

Although the above discussion concentrated on the main analysis of the data, a great many different scenarios were examined during the data analysis phase of the project. The multiplicity of analyses derived from the need to investigate an anomaly in the data which occurred in the sixth pair of rooms. This anomaly can best be understood by examining plots of the range of airborne asbestos concentrations which are contained in Appendix B. This appendix contains Figures B-1 through B-6 which graph the arithmetic mean and range of values measured for the six pairs of rooms in the study.

In the first five pairs of rooms, the pattern over time is similar. The range of "before" values is generally below the range of values "during" stripping. The range of values for the "rebuild" period usually is lower than the range of values "during" stripping; and, finally, the range of values for "after" is close to (sometimes higher and sometimes lower than) the "rebuild" values. The picture in the sixth pair of rooms is starkly different, as is apparent from Figure B-6. The "before" values for the rooms in which the P.G. method of wax stripping was applied are the highest set of measurements made over the four time periods. Careful review of the sample traceability documentation maintained during the data collection indicated that there was no mixup of the samples; however it was decided that it was worth performing some exploratory analyses to see whether the sixth pair of rooms needed to be dropped from the study or whether a reclassification of the data would bring a different conclusion to the analysis. To deal with this issue, exploratory analyses were done which looked at the following configuration:

- excluding the sixth pair of rooms from the analysis.
- reclassifying the measurements for the sixth pair of rooms for the P.G. method which were labeled "before" as "during" and vice-versa.

We emphasize there was no intention of reporting reclassified data. Rather, there was a desire to determine whether the conclusions of the study were robust, given the possibility of a problem with the P.G. data from the sixth pair of rooms.

There was a second concern about building an ANOVA model including the "before" measurements. Since the rooms were matched and assigned at random to the EPA and P.G. methods, there is no reason to classify the "before" measurements as being associated with either the EPA or P.G. methods. Therefore, three approaches were suggested:

- leaving out the before data
- analyzing only the "strip" data
- using the "before" data as a covariate in the analysis.

The third approach implements an analysis of covariance model rather than the ANOVA model described above. The idea is that the concentrations during later periods may be modeled as a linear function of the "before" measurements. The factors: method of wax stripping, time period (now excluding the "before" measurement), and, pairs of rooms are still part of the model. Such models can be considered as a combination of a linear regression model which relates the concentration to the "before" measurement and an ANOVA model which relates the concentration to the levels of the various factors in the analysis.

All of the above scenarios were investigated. Although the specific F-ratios and p-values of the various tests varied somewhat, the general findings were the same and the same general conclusions were reached. These consistent results were that no significant difference could be found between levels of airborne asbestos measured during the EPA and the P.G. methods of wax stripping, that there was a significant difference between levels measured during the wax stripping as opposed to other time periods in the wax process, and that the variability of airborne asbestos levels measured between pairs of rooms was large in comparison to the variability between the two methods of wax stripping.

The consistency of results for the various scenarios described above lends credibility to the findings of the study.

7.3 FINDINGS

This section summarizes the results discussed above. The key findings are:

(1) The study data revealed no significant difference between the EPA and P.G. methods of floor wax stripping. This finding is driven by the large variability in airborne asbestos levels between pairs of rooms in the study. It suggests that, if a future study is contemplated, resources be concentrated on increasing the number of rooms included in the study at

the expense of a decrease in the number of measurements per room.

(2) There was a significant difference between measurements observed during the wax stripping process and measurements taken at the three other times in the process. This finding was true for both the P.G. and EPA methods of wax stripping.

(3) Excluding the "during stripping" period, there were no other significant differences between period of measurement within a wax stripping method. In particular, before and after measurements were not significantly different, nor were there significant differences between "during rebuilding" and the "before" and "after" periods. Therefore, the study found no evidence of short term residual effects of the two wax stripping methods.

(4) All 72 of the personal monitoring samples obtained during stripping and rebuilding and analyzed by PCM in the study displayed a concentration lower than the OSHA action level of 0.1 f/cc.

(5) The exposures indicated by the TEM area measurements, as well as by the limited number of TEM personal samples, are considerably higher than those shown by the PCM personal samples. This is because PCM did not measure the smaller fibers which predominated in this experiment.

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APPENDIX A. WAX STRIPPING PROCEDURES

A.1 PRINCE GEORGE'S COUNTY PUBLIC SCHOOLS PROCEDURE FOR REFINISHING (POLISHING) OF ASBESTOS-CONTAINING RESILIENT FLOORS FOLLOWING STRIPPING

1. Equipment and Materials

   Applicator: 24-ounce cotton string mops. All new mops will be washed and dried twice prior to use.

2. Floor Wax

   Metal Cross Linked Floor Polish containing 18% solids.

3. Procedure

   - Dry sweep the stripped floor to remove any settled debris. Do not use a treated mop or sweeping compound.
   - Apply the polish from a mop bucket. Wring the mop out until slow dripping wet.
   - Using a cotton string mop apply the wax as evenly as possibly covering about 100 square feet per 24-ounce mop head.
   - Let each coat dry thoroughly before the next application, typically 20 to 30 minutes or longer depending on temperature and humidity. The polish should be dry to the touch.
   - Apply two uniform coats of polish.

A.2 PRINCE GEORGE'S COUNTY PUBLIC SCHOOLS PROCEDURE FOR STRIPPING OF ASBESTOS-CONTAINING RESILIENT FLOORS

1. Equipment and Materials

   Machine: 300 rpm rotary

   Pad: 3M Black

2. Stripping Solution

   Ammoniated liquid wax stripper. Dilution - 1 part cleaner : 8 parts water.

3. Procedure

   - Sweep floor thoroughly with sweeping compound (for this study completed during room preparation).
   - Mix stripping solution in a bucket of water (dilute 1 part cleaner with 8 parts water).
   - Apply generously with a clean mop and allow to stand on the floor for at least 5 minutes. Check to be sure the solution is still standing on the floor. If not, rewet.
   - Double scrub the floor with a black pad, first in one direction and then in the opposite direction. Do not allow the solution to dry.
   - Use a second bucket and mop with clean water to pickup the spent stripper solution and polish.
   - Use a third bucket and mop with clean water to rinse the floor and remove all residue.
   - Use a fourth bucket and mop with clean water for a second rinse.
   - Repeat the above procedure as necessary on spots where the removal was not adequate.
   - Allow the floor to dry.
   - Check floor. If free from residue, proceed to wax. If not, rerinse, dry, and check again.

A.3 U.S. EPA'S PROCEDURE FOR STRIPPING OF ASBESTOS-CONTAINING RESILIENT FLOORS AT BOWIE HIGH SCHOOL ANNEX IN BOWIE, MARYLAND

1. Equipment and Materials

   Machine: 175 rpm

   Pad: 3M green

2. Stripping Solution

   Ammoniated liquid wax stripper. Dilution - 1 part cleaner : 8 parts water.

3. Procedure

   - Sweep floor thoroughly with sweeping compound (for this study completed during room preparation).
   - Mix stripping solution in a bucket of water (dilute 1 part cleaner with 8 parts water).
   - Apply generously with a clean mop and allow to stand on the floor for at least 5 minutes. Check to be sure the solution is still standing on the floor. If not, rewet.
   - Double scrub the floor with a green pad, first in one direction and then in the opposite direction. Do not allow the solution to dry.
   - Use a second bucket and mop with clean water to pickup the spent stripper solution and polish.
   - Use a third bucket and mop with clean water to rinse the floor and remove all residue.
   - Use a fourth bucket and mop with clean water for a second rinse.
   - Repeat the above procedure as necessary on spots where the removal was not adequate.
   - Allow the floor to dry.
   - Check floor. If free from residue, proceed to wax. If not, rerinse, dry, and check again.

APPENDIX B.

PLOTS OF AIRBORNE ASBESTOS MEASUREMENTS FOR AREA SAMPLES

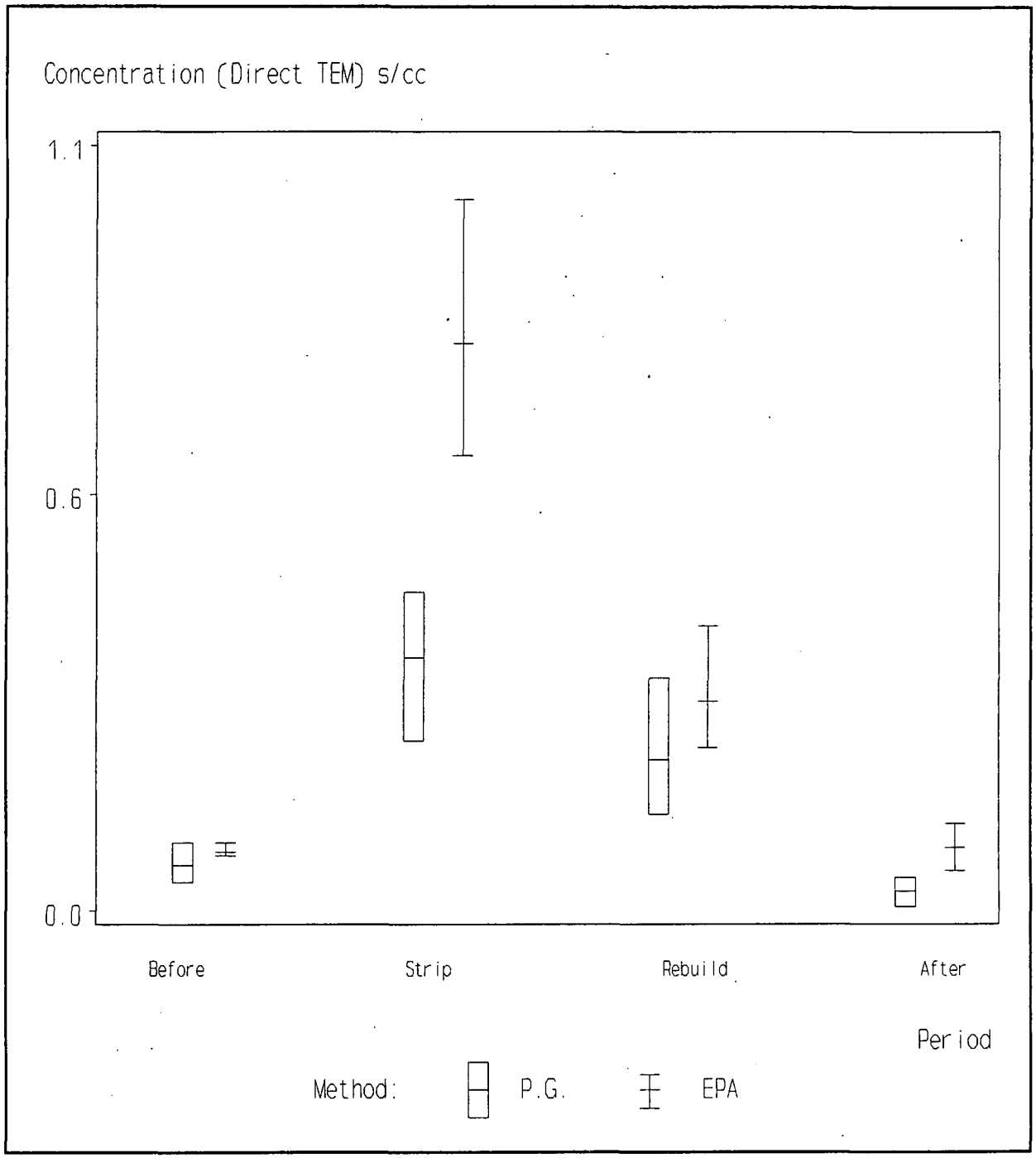


Figure B-1. Maximum, minimum, and arithmetic average airborne asbestos concentrations (TEM) by method and period for the first pair of rooms.

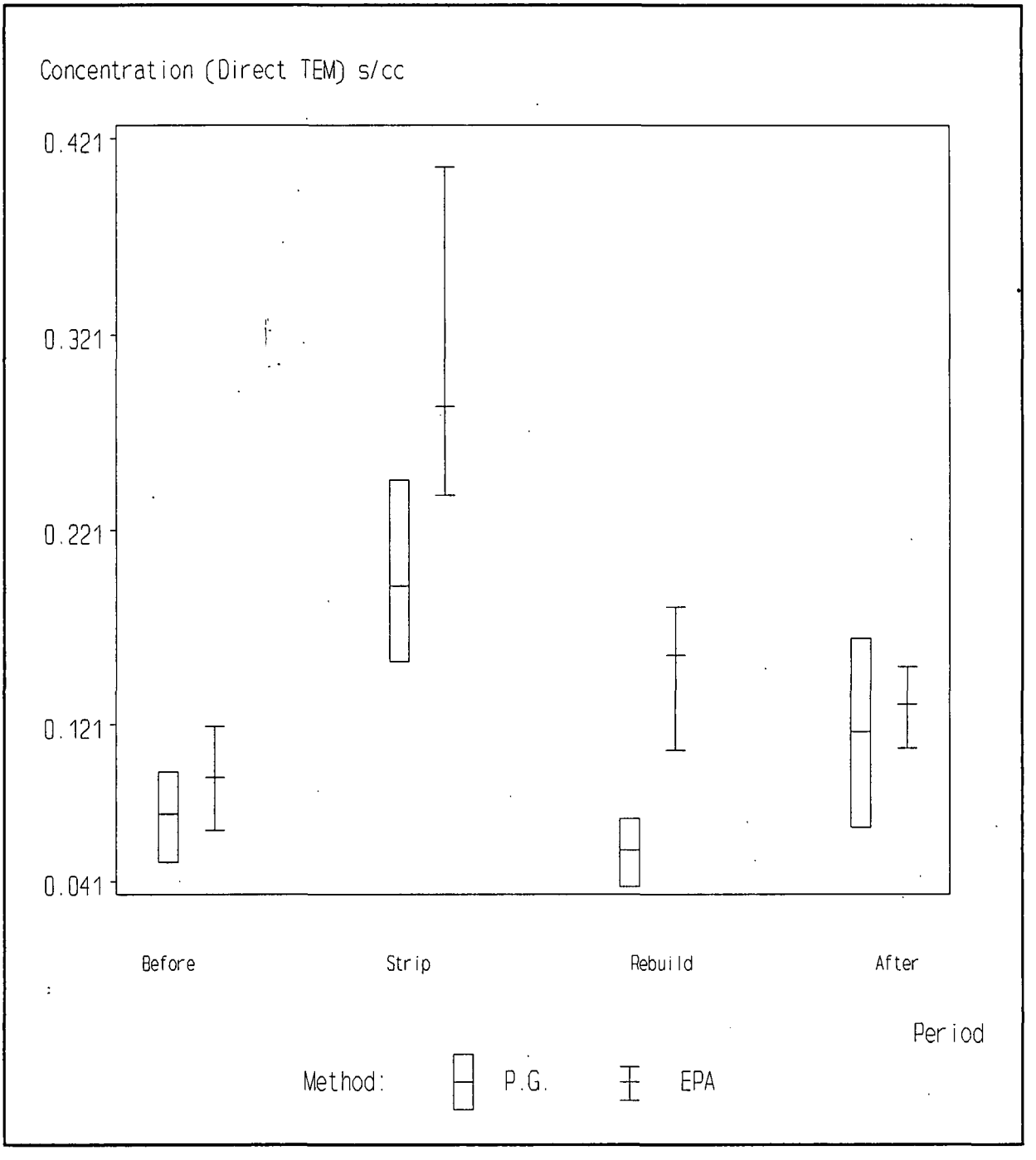


Figure B-2. Maximum, minimum, and arithmetic average airborne asbestos concentrations (TEM) by method and period for the second pair of rooms.

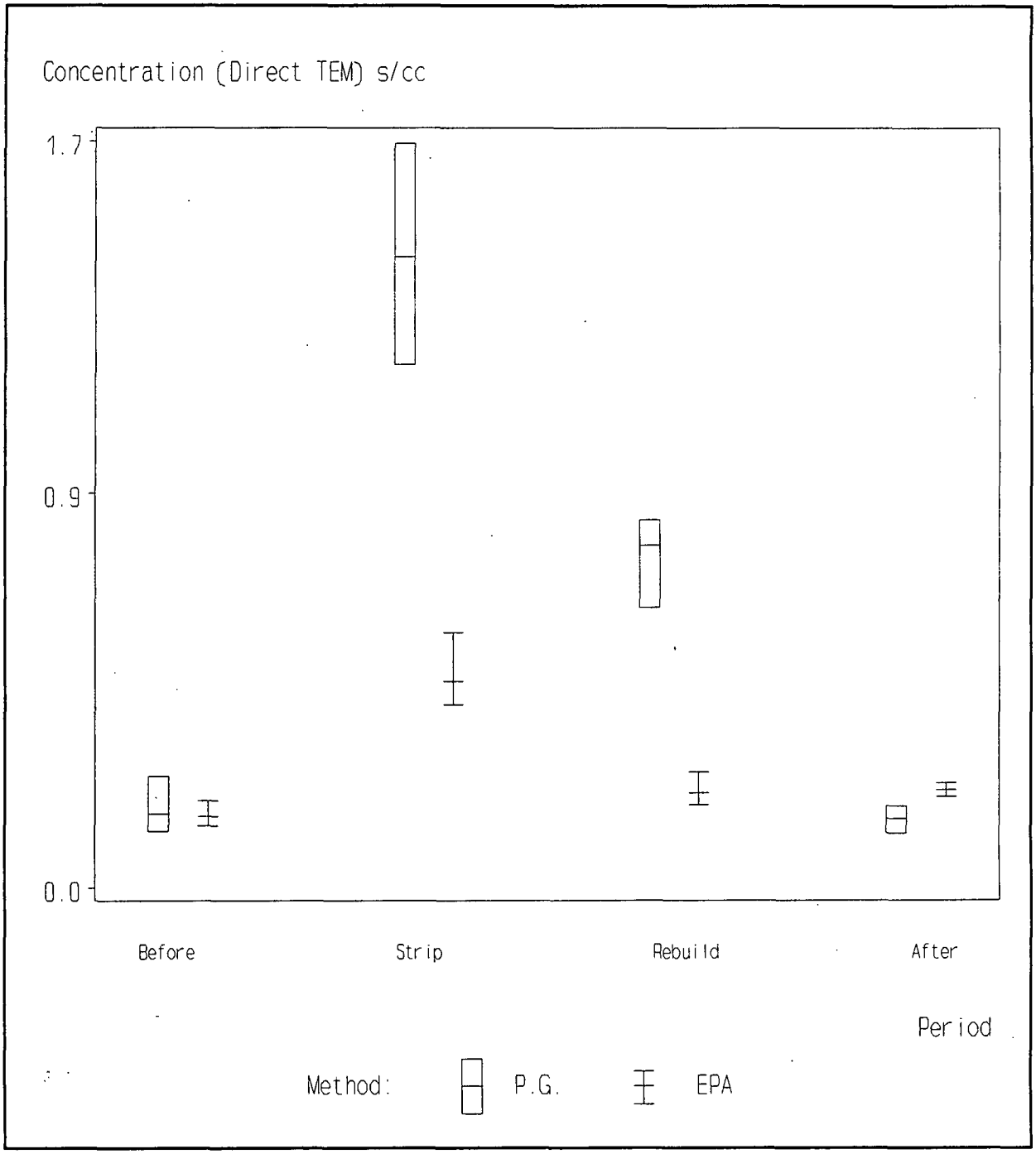


Figure B-3. Maximum, minimum, and arithmetic average airborne asbestos concentrations (TEM) by method and period for the third pair of rooms.

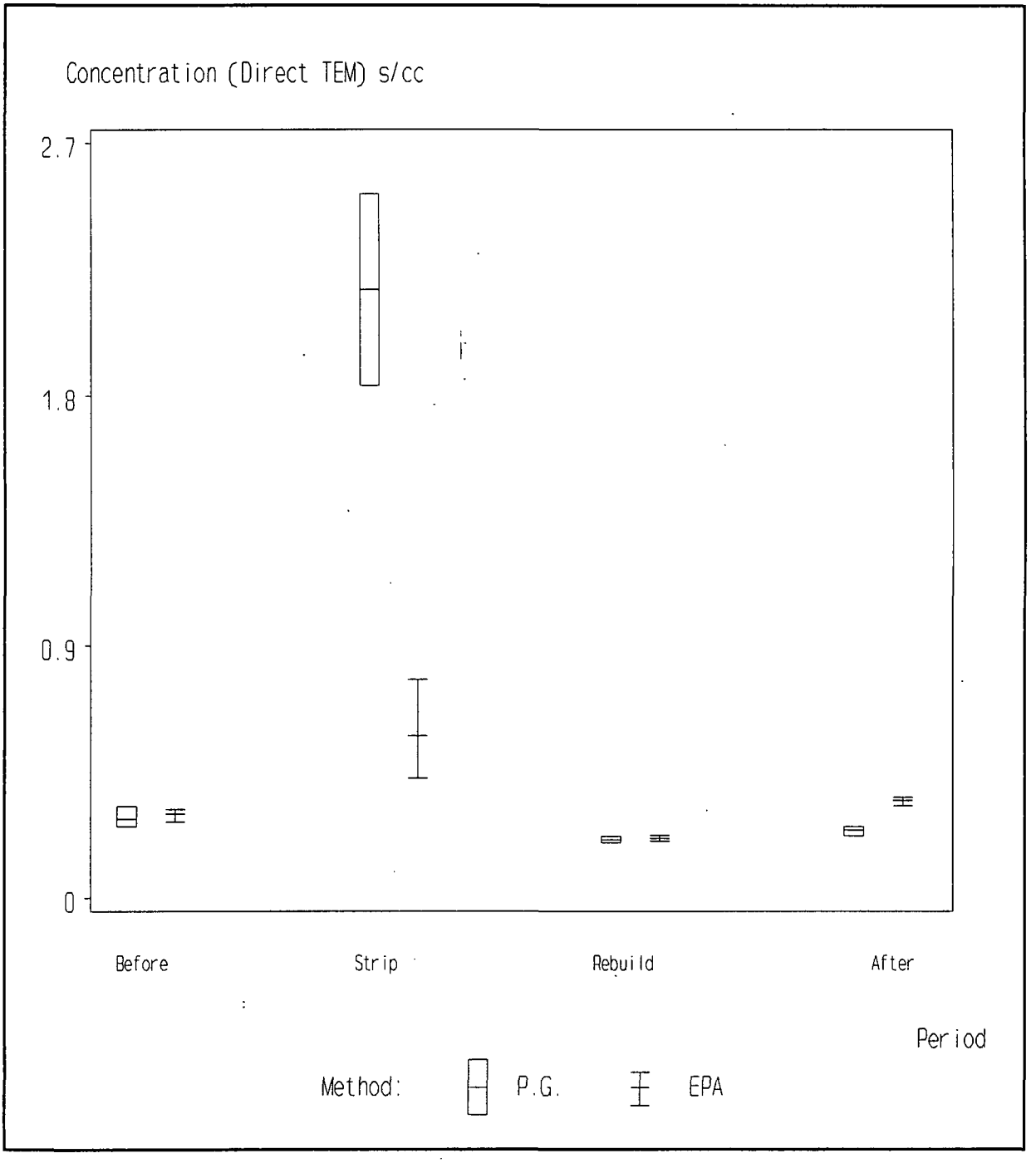


Figure B-4. Maximum, minimum, and arithmetic average airborne asbestos concentrations (TEM) by method and period for the fourth pair of rooms.

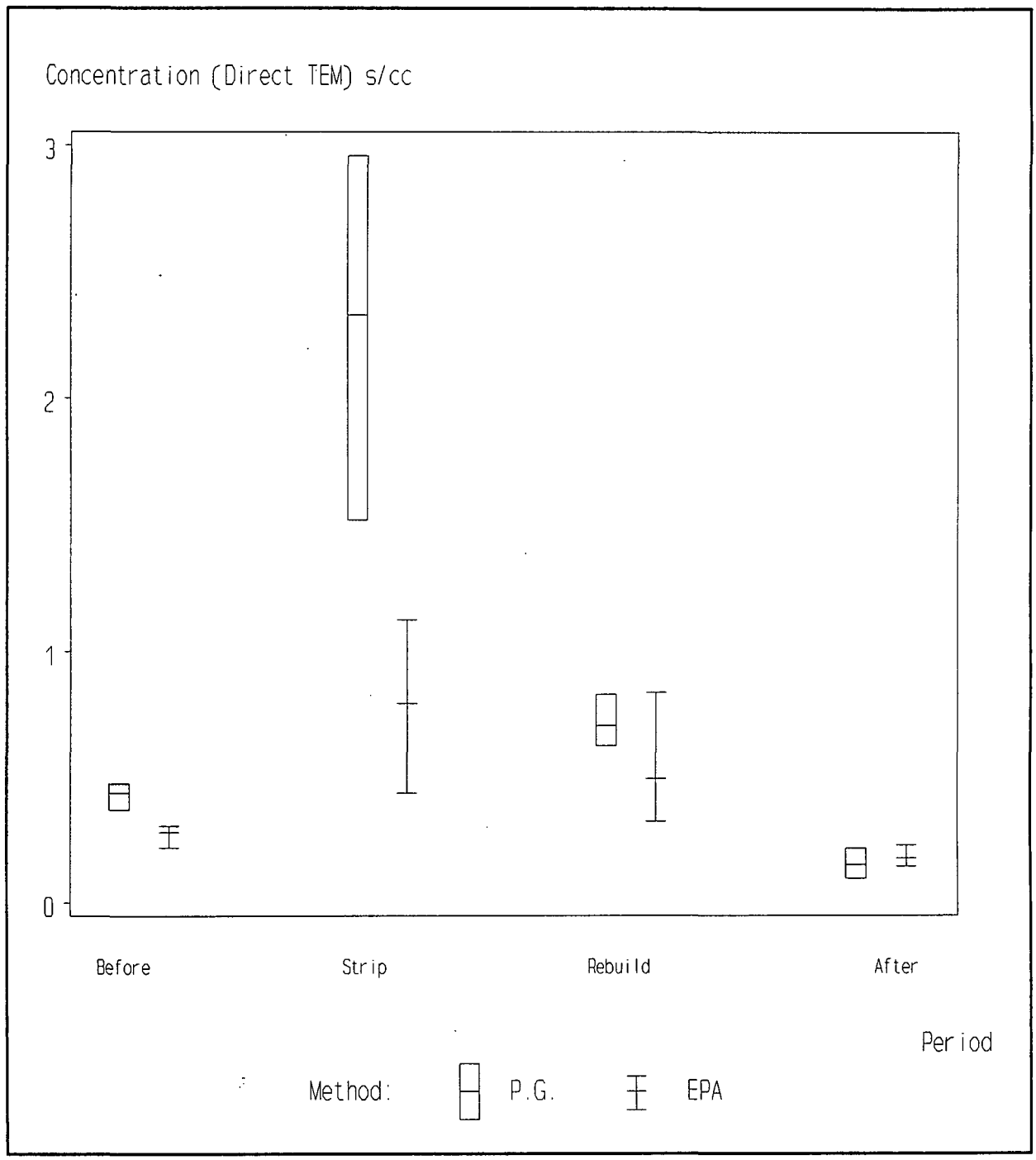


Figure B-5. Maximum, minimum, and arithmetic average airborne asbestos concentrations (TEM) by method and period for the fifth pair of rooms.

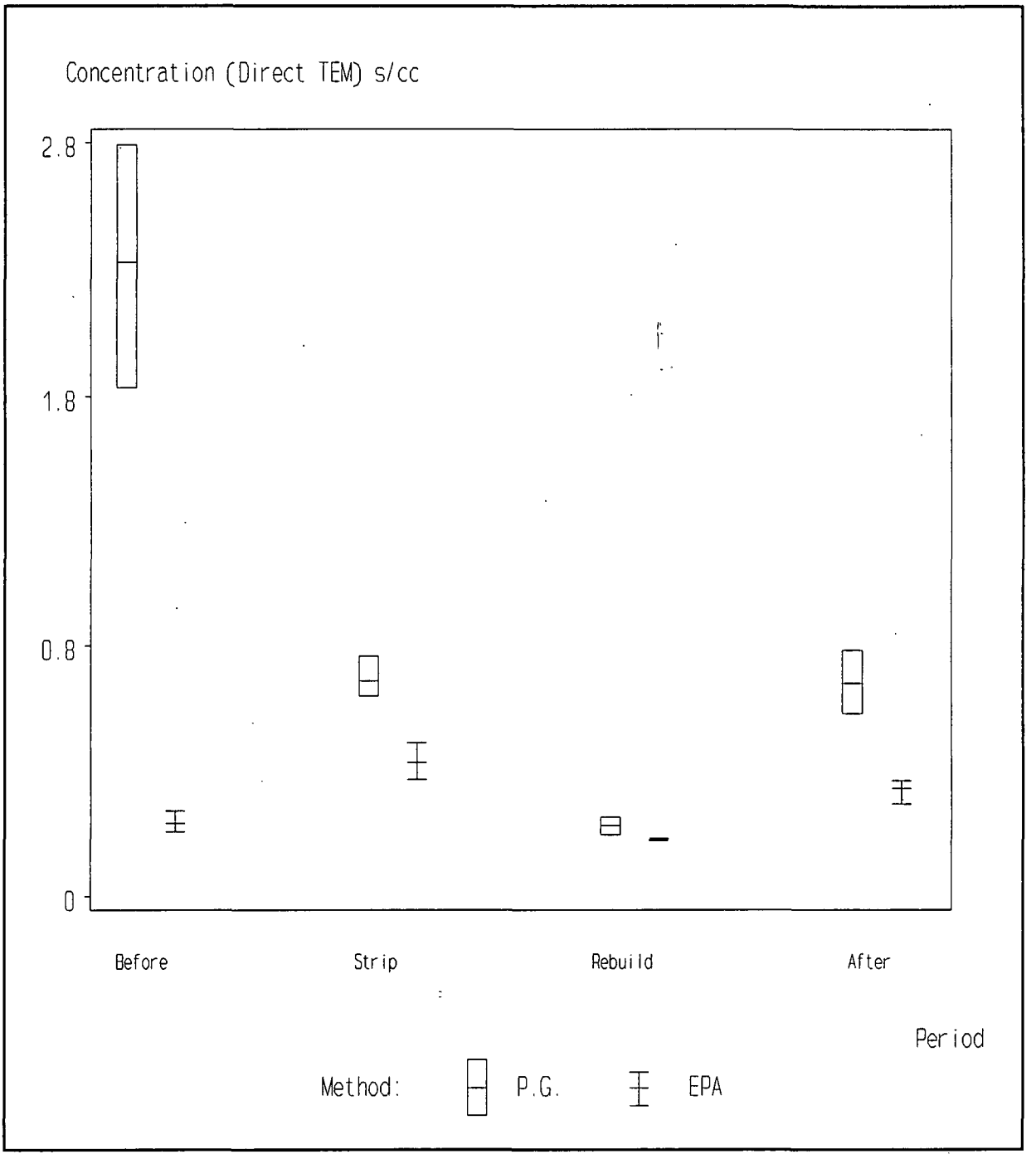


Figure B-6. Maximum, minimum, and arithmetic average airborne asbestos concentrations (TEM) by method and period for the sixth pair of rooms.

APPENDIX C. PCM PERSONAL SAMPLE STUDY DATA

OBS	REPNUM	PERIOD	METHOD	LOCATION	SAMPLE ID	CONC (F/CC)
1	1	STRIP	EPA	ROOM 111	01E-001D2	0.0280
2	1	STRIP	EPA	ROOM 111	01E-002D2	0.0136
3	1	STRIP	EPA	ROOM 111	01E-003D2	0.0000
4	1	STRIP	EPA	ROOM 111	01E-004D2	0.0033
5	1	STRIP	P.G.	ROOM 102	01P-001D2	0.0000
6	1	STRIP	P.G.	ROOM 102	01P-002D2	0.0089
7	1	STRIP	P.G.	ROOM 102	01P-003D2	0.0059
8	1	STRIP	P.G.	ROOM 102	01P-004D2	0.0000
9	1	REBUILD	EPA	ROOM 111	01E-001R2	0.0365
10	1	REBUILD	EPA	ROOM 111	01E-002R2	0.0000
11	1	REBUILD	P.G.	ROOM 102	01P-001R2	0.0000
12	1	REBUILD	P.G.	ROOM 102	01P-002R2	0.0245
13	2	STRIP	EPA	ROOM 113	02E-001D2	0.0298
14	2	STRIP	EPA	ROOM 113	02E-002D2	0.0032
15	2	STRIP	EPA	ROOM 113	02E-003D2	0.0065
16	2	STRIP	EPA	ROOM 113	02E-004D2	0.0000
17	2	STRIP	P.G.	ROOM 101	02P-001D2	0.0000
18	2	STRIP	P.G.	ROOM 101	02P-002D2	0.0213
19	2	STRIP	P.G.	ROOM 101	02P-003D2	0.0000
20	2	STRIP	P.G.	ROOM 101	02P-004D2	0.0109
21	2	REBUILD	EPA	ROOM 113	02E-001R2	0.0000
22	2	REBUILD	EPA	ROOM 113	02E-002R2	0.0082
23	2	REBUILD	P.G.	ROOM 101	02P-001R2	0.0000
24	2	REBUILD	P.G.	ROOM 101	02P-002R2	0.0000
25	3	STRIP	EPA	ROOM 112	03E-001D2	0.0043
26	3	STRIP	EPA	ROOM 112	03E-002D2	0.0000
27	3	STRIP	EPA	ROOM 112	03E-003D2	0.0000
28	3	STRIP	EPA	ROOM 112	03E-004D2	0.0000
29	3	STRIP	P.G.	ROOM 109	03P-001D2	0.0024
30	3	STRIP	P.G.	ROOM 109	03P-002D2	0.0097
31	3	STRIP	P.G.	ROOM 109	03P-003D2	0.0162
32	3	STRIP	P.G.	ROOM 109	03P-004D2	0.0023
33	3	REBUILD	EPA	ROOM 112	03E-001R2	0.0555
34	3	REBUILD	EPA	ROOM 112	03E-002R2	0.0093
35	3	REBUILD	P.G.	ROOM 109	03P-001R2	0.0249
36	3	REBUILD	P.G.	ROOM 109	03P-002R2	0.0249
37	4	STRIP	EPA	ROOM 115	04E-001D2	0.0078
38	4	STRIP	EPA	ROOM 115	04E-002D2	0.0077
39	4	STRIP	EPA	ROOM 115	04E-003D2	0.0000
40	4	STRIP	EPA	ROOM 115	04E-004D2	0.0052
41	4	STRIP	P.G.	ROOM 114	04P-001D2	0.0068
42	4	STRIP	P.G.	ROOM 114	04P-002D2	0.0045
43	4	STRIP	P.G.	ROOM 114	04P-003D2	0.0000
44	4	STRIP	P.G.	ROOM 114	04P-004D2	0.0000
45	4	REBUILD	EPA	ROOM 115	04E-001R2	0.0056
46	4	REBUILD	EPA	ROOM 115	04E-002R2	0.0000

OBS	REPNUM	PERIOD	METHOD	LOCATION	SAMPLE ID	CONC (F/CC)
47	4	REBUILD	P.G.	ROOM 114	04P-001R2	0.0000
48	4	REBUILD	P.G.	ROOM 114	04P-002R2	0.0000
49	5	STRIP	EPA	ROOM 117	05E-001D2	0.0193
50	5	STRIP	EPA	ROOM 117	05E-002D2	0.0000
51	5	STRIP	EPA	ROOM 117	05E-003D2	0.0055
52	5	STRIP	EPA	ROOM 117	05E-004D2	0.0000
53	5	STRIP	P.G.	ROOM 118	05P-001D2	0.0103
54	5	STRIP	P.G.	ROOM 118	05P-002D2	0.0207
55	5	STRIP	P.G.	ROOM 118	05P-003D2	0.0207
56	5	STRIP	P.G.	ROOM 118	05P-004D2	0.0183
57	5	REBUILD	EPA	ROOM 117	05E-001R2	0.0000
58	5	REBUILD	EPA	ROOM 117	05E-002R2	0.0048
59	5	REBUILD	P.G.	ROOM 118	05P-001R2	0.0052
60	5	REBUILD	P.G.	ROOM 118	05P-002R2	0.0051
61	6	STRIP	EPA	ROOM 110	06E-001D2	0.0128
62	6	STRIP	EPA	ROOM 110	06E-002D2	0.0000
63	6	STRIP	EPA	ROOM 110	06E-003D2	0.0124
64	6	STRIP	EPA	ROOM 110	06E-004D2	0.0075
65	6	STRIP	P.G.	ROOM 103	06P-001D2	0.0058
66	6	STRIP	P.G.	ROOM 103	06P-002D2	0.0058
67	6	STRIP	P.G.	ROOM 103	06P-003D2	0.0257
68	6	STRIP	P.G.	ROOM 103	06P-004D2	0.0242
69	6	REBUILD	EPA	ROOM 110	06E-001R2	0.0000
70	6	REBUILD	EPA	ROOM 110	06E-002R2	0.0000
71	6	REBUILD	P.G.	ROOM 103	06P-001R2	0.0000
72	6	REBUILD	P.G.	ROOM 103	06P-002R2	0.0000

APPENDIX D. TEM AREA SAMPLE STUDY DATA

OBS	REPNUM	PERIOD	METHOD	LOCATION	SAMPLE ID	SAMPLE TYPE	TOTAL STRUCTURE CONC (S/CC)	CONC FIBERS > 5 μm (F/CC)
1	1	BEFORE	EPA	ROOM 111	01E-001B	AREA	0.09440	0.000000
2	1	BEFORE	EPA	ROOM 111	01E-002B	AREA	0.10580	0.000000
3	1	BEFORE	EPA	ROOM 111	01E-003B	AREA	0.10160	0.000000
4	1	BEFORE	EPA	ROOM 111	01E-004B	AREA	0.11330	0.000000
5	1	BEFORE	EPA	ROOM 111	01E-005B	AREA	0.09740	0.000000
6	1	BEFORE	P.G.	ROOM 102	01P-001B	AREA	0.06310	0.000000
7	1	BEFORE	P.G.	ROOM 102	01P-002BR	AREA	0.10730	0.000000
8	1	BEFORE	P.G.	ROOM 102	01P-003B	AREA	0.11230	0.000000
9	1	BEFORE	P.G.	ROOM 102	01P-004B	AREA	0.05800	0.000000
10	1	BEFORE	P.G.	ROOM 102	01P-005B	AREA	0.05360	0.000000
11	1	STRIP	EPA	ROOM 111	01E-001D1	AREA	0.71730	0.007102
12	1	STRIP	EPA	ROOM 111	01E-002D1	AREA	1.08450	0.000000
13	1	STRIP	EPA	ROOM 111	01E-003D1	AREA	0.97100	0.000000
14	1	STRIP	EPA	ROOM 111	01E-004D1D	AREA	0.80580	0.011439
15	1	STRIP	EPA	ROOM 111	01E-005D1	AREA	0.81580	0.007921
16	1	STRIP	P.G.	ROOM 102	01P-001D1	AREA	0.52160	0.000000
17	1	STRIP	P.G.	ROOM 102	01P-002D1	AREA	0.49140	0.000000
18	1	STRIP	P.G.	ROOM 102	01P-003D1	AREA	0.39590	0.014846
19	1	STRIP	P.G.	ROOM 102	01P-004D1	AREA	0.42200	0.000000
20	1	STRIP	P.G.	ROOM 102	01P-005D1	AREA	0.30730	0.005038
21	1	REBUILD	EPA	ROOM 111	01E-001R1	AREA	0.47370	0.000000
22	1	REBUILD	EPA	ROOM 111	01E-002R1	AREA	0.38130	0.009778
23	1	REBUILD	EPA	ROOM 111	01E-003R1	AREA	0.34960	0.020265
24	1	REBUILD	EPA	ROOM 111	01E-004R1	AREA	0.32000	0.015000
25	1	REBUILD	EPA	ROOM 111	01E-005R1	AREA	0.29750	0.000000
26	1	REBUILD	P.G.	ROOM 102	01P-001R1	AREA	0.20490	0.000000
27	1	REBUILD	P.G.	ROOM 102	01P-002R1	AREA	0.26320	0.000000
28	1	REBUILD	P.G.	ROOM 102	01P-003R1	AREA	0.33140	0.000000
29	1	REBUILD	P.G.	ROOM 102	01P-004R1	AREA	0.39870	0.000000
30	1	REBUILD	P.G.	ROOM 102	01P-005R1	AREA	0.20240	0.000000
31	1	AFTER	EPA	ROOM 111	01E-001A	AREA	0.18870	0.000000
32	1	AFTER	EPA	ROOM 111	01E-002AR	AREA	0.14860	0.000000
33	1	AFTER	EPA	ROOM 111	01E-003A	AREA	0.17230	0.000000
34	1	AFTER	EPA	ROOM 111	01E-004A	AREA	0.11940	0.000000
35	1	AFTER	EPA	ROOM 111	01E-005A	AREA	0.14460	0.000000
36	1	AFTER	P.G.	ROOM 102	01P-001A	AREA	0.09720	0.000000
37	1	AFTER	P.G.	ROOM 102	01P-002A	AREA	0.10970	0.000000
38	1	AFTER	P.G.	ROOM 102	01P-003A	AREA	0.07630	0.000000
39	1	AFTER	P.G.	ROOM 102	01P-004A	AREA	0.09960	0.000000
40	1	AFTER	P.G.	ROOM 102	01P-005A	AREA	0.06760	0.000000
41	2	BEFORE	EPA	ROOM 113	02E-001B	AREA	0.12250	0.000000
42	2	BEFORE	EPA	ROOM 113	02E-002B	AREA	0.11690	0.000000
43	2	BEFORE	EPA	ROOM 113	02E-003B	AREA	0.06950	0.000000
44	2	BEFORE	EPA	ROOM 113	02E-004B	AREA	0.08060	0.000000
45	2	BEFORE	EPA	ROOM 113	02E-005BR	AREA	0.09265	0.000000
46	2	BEFORE	P.G.	ROOM 101	02P-001B	AREA	0.08690	0.004571

OBS	REPNUM	PERIOD	METHOD	LOCATION	SAMPLE ID	SAMPLE TYPE	TOTAL STRUCTURE CONC (S/CC)	CONC FIBERS > 5 μm (F/CC)
47	2	BEFORE	P.G.	ROOM 101	02P-002B	AREA	0.07630	0.000000
48	2	BEFORE	P.G.	ROOM 101	02P-003B	AREA	0.07400	0.000000
49	2	BEFORE	P.G.	ROOM 101	02P-004B	AREA	0.05330	0.000000
50	2	BEFORE	P.G.	ROOM 101	02P-005B	AREA	0.09930	0.000000
51	2	STRIP	EPA	ROOM 113	02E-001D1	AREA	0.26410	0.000000
52	2	STRIP	EPA	ROOM 113	02E-002D1D	AREA	0.24945	0.000000
53	2	STRIP	EPA	ROOM 113	02E-003D1	AREA	0.24140	0.009468
54	2	STRIP	EPA	ROOM 113	02E-004D1	AREA	0.27040	0.004745
55	2	STRIP	EPA	ROOM 113	02E-005D1	AREA	0.40900	0.000000
56	2	STRIP	P.G.	ROOM 101	02P-001D1	AREA	0.19950	0.000000
57	2	STRIP	P.G.	ROOM 101	02P-002D1	AREA	0.19150	0.000000
58	2	STRIP	P.G.	ROOM 101	02P-003D1	AREA	0.17680	0.000000
59	2	STRIP	P.G.	ROOM 101	02P-004D1	AREA	0.24930	0.000000
60	2	STRIP	P.G.	ROOM 101	02P-005D1	AREA	0.15590	0.000000
61	2	REBUILD	EPA	ROOM 113	02E-001R1	AREA	0.16190	0.000000
62	2	REBUILD	EPA	ROOM 113	02E-002R1	AREA	0.17280	0.000000
63	2	REBUILD	EPA	ROOM 113	02E-003R1	AREA	0.16680	0.000000
64	2	REBUILD	EPA	ROOM 113	02E-004R1	AREA	0.11010	0.000000
65	2	REBUILD	EPA	ROOM 113	02E-005R1	AREA	0.18380	0.000000
66	2	REBUILD	P.G.	ROOM 101	02P-001R1	AREA	0.07540	0.000000
67	2	REBUILD	P.G.	ROOM 101	02P-002R1	AREA	0.04060	0.000000
68	2	REBUILD	P.G.	ROOM 101	02P-003R1	AREA	0.06030	0.000000
69	2	REBUILD	P.G.	ROOM 101	02P-004R1	AREA	0.06400	0.000000
70	2	REBUILD	P.G.	ROOM 101	02P-005R1	AREA	0.05580	0.000000
71	2	AFTER	EPA	ROOM 113	02E-001A	AREA	0.15310	0.000000
72	2	AFTER	EPA	ROOM 113	02E-002A	AREA	0.14250	0.000000
73	2	AFTER	EPA	ROOM 113	02E-003A	AREA	0.11120	0.000000
74	2	AFTER	EPA	ROOM 113	02E-004A	AREA	0.14700	0.000000
75	2	AFTER	EPA	ROOM 113	02E-005A	AREA	0.11420	0.000000
76	2	AFTER	P.G.	ROOM 101	02P-001AR	AREA	0.13000	0.000000
77	2	AFTER	P.G.	ROOM 101	02P-002A	AREA	0.09700	0.000000
78	2	AFTER	P.G.	ROOM 101	02P-003A	AREA	0.13260	0.000000
79	2	AFTER	P.G.	ROOM 101	02P-004A	AREA	0.07090	0.000000
80	2	AFTER	P.G.	ROOM 101	02P-005A	AREA	0.16760	0.000000
81	3	BEFORE	EPA	ROOM 112	03E-001B	AREA	0.17300	0.000000
82	3	BEFORE	EPA	ROOM 112	03E-002B	AREA	0.11730	0.000000
83	3	BEFORE	EPA	ROOM 112	03E-004B	AREA	0.11990	0.000000
84	3	BEFORE	EPA	ROOM 112	03E-005B	AREA	0.14170	0.000000
85	3	BEFORE	P.G.	ROOM 109	03P-001B	AREA	0.10400	0.000000
86	3	BEFORE	P.G.	ROOM 109	03P-002B	AREA	0.22840	0.000000
87	3	BEFORE	P.G.	ROOM 109	03P-003B	AREA	0.12520	0.000000
88	3	BEFORE	P.G.	ROOM 109	03P-004B	AREA	0.11930	0.000000
89	3	BEFORE	P.G.	ROOM 109	03P-005B	AREA	0.14050	0.000000
90	3	STRIP	EPA	ROOM 112	03E-001D1	AREA	0.44490	0.010110
91	3	STRIP	EPA	ROOM 112	03E-002D1	AREA	0.41360	0.004866
92	3	STRIP	EPA	ROOM 112	03E-003D1	AREA	0.38940	0.000000

OBS	REPNUM	PERIOD	METHOD	LOCATION	SAMPLE ID	SAMPLE TYPE	TOTAL STRUCTURE CONC (S/CC)	CONC FIBERS > 5 µm (F/CC)
93	3	STRIP	EPA	ROOM 112	03E-004D1	AREA	0.41020	0.010005
94	3	STRIP	EPA	ROOM 112	03E-005D1	AREA	0.55320	0.000000
95	3	STRIP	P.G.	ROOM 109	03P-001D1	AREA	1.47410	0.026091
96	3	STRIP	P.G.	ROOM 109	03P-002D1	AREA	1.16540	0.000000
97	3	STRIP	P.G.	ROOM 109	03P-003D1R	AREA	1.33385	0.005876
98	3	STRIP	P.G.	ROOM 109	03P-004D1	AREA	1.66830	0.032083
99	3	STRIP	P.G.	ROOM 109	03P-005D1	AREA	1.41060	0.027390
100	3	REBUILD	EPA	ROOM 112	03E-001R1D	AREA	0.23820	0.002481
101	3	REBUILD	EPA	ROOM 112	03E-002R1	AREA	0.18660	0.000000
102	3	REBUILD	EPA	ROOM 112	03E-003R1	AREA	0.17240	0.000000
103	3	REBUILD	EPA	ROOM 112	03E-004R1	AREA	0.19300	0.000000
104	3	REBUILD	EPA	ROOM 112	03E-005R1	AREA	0.16240	0.000000
105	3	REBUILD	P.G.	ROOM 109	03P-001R1	AREA	0.78790	0.000000
106	3	REBUILD	P.G.	ROOM 109	03P-002R1	AREA	0.81190	0.000000
107	3	REBUILD	P.G.	ROOM 109	03P-003R1	AREA	0.78350	0.015514
108	3	REBUILD	P.G.	ROOM 109	03P-004R1	AREA	0.77410	0.000000
109	3	REBUILD	P.G.	ROOM 109	03P-005R1	AREA	0.60950	0.000000
110	3	AFTER	EPA	ROOM 112	03E-001AR	AREA	0.18755	0.000000
111	3	AFTER	EPA	ROOM 112	03E-002A	AREA	0.19180	0.000000
112	3	AFTER	EPA	ROOM 112	03E-003A	AREA	0.21250	0.004620
113	3	AFTER	EPA	ROOM 112	03E-004A	AREA	0.20980	0.000000
114	3	AFTER	EPA	ROOM 112	03E-005A	AREA	0.18170	0.000000
115	3	AFTER	P.G.	ROOM 109	03P-001A	AREA	0.13490	0.004353
116	3	AFTER	P.G.	ROOM 109	03P-002A	AREA	0.15930	0.000000
117	3	AFTER	P.G.	ROOM 109	03P-003A	AREA	0.13350	0.000000
118	3	AFTER	P.G.	ROOM 109	03P-004A	AREA	0.09810	0.003924
119	3	AFTER	P.G.	ROOM 109	03P-005A	AREA	0.12880	0.000000
120	4	BEFORE	EPA	ROOM 115	04E-001B	AREA	0.16770	0.000000
121	4	BEFORE	EPA	ROOM 115	04E-002B	AREA	0.14290	0.000000
122	4	BEFORE	EPA	ROOM 115	04E-003B	AREA	0.16070	0.000000
123	4	BEFORE	EPA	ROOM 115	04E-004B	AREA	0.16180	0.000000
124	4	BEFORE	EPA	ROOM 115	04E-005B	AREA	0.11750	0.000000
125	4	BEFORE	P.G.	ROOM 114	04P-001BR	AREA	0.09875	0.000000
126	4	BEFORE	P.G.	ROOM 114	04P-002B	AREA	0.10460	0.000000
127	4	BEFORE	P.G.	ROOM 114	04P-003B	AREA	0.15930	0.000000
128	4	BEFORE	P.G.	ROOM 114	04P-004B	AREA	0.10680	0.000000
129	4	BEFORE	P.G.	ROOM 114	04P-005B	AREA	0.17960	0.000000
130	4	STRIP	EPA	ROOM 115	04E-001D1	AREA	0.40940	0.000000
131	4	STRIP	EPA	ROOM 115	04E-002D1	AREA	0.29120	0.009870
132	4	STRIP	EPA	ROOM 115	04E-003D1	AREA	0.44930	0.000000
133	4	STRIP	EPA	ROOM 115	04E-004D1	AREA	0.45660	0.010034
134	4	STRIP	EPA	ROOM 115	04E-005D1	AREA	0.68110	0.007095
135	4	STRIP	P.G.	ROOM 114	04P-001D1	AREA	1.85500	0.000000
136	4	STRIP	P.G.	ROOM 114	04P-002D1	AREA	2.19740	0.043513
137	4	STRIP	P.G.	ROOM 114	04P-003D1	AREA	2.28530	0.000000
138	4	STRIP	P.G.	ROOM 114	04P-004D1	AREA	2.21790	0.020924

OBS	REPNUM	PERIOD	METHOD	LOCATION	SAMPLE ID	SAMPLE TYPE	TOTAL STRUCTURE CONC (S/CC)	CONC FIBERS > 5 μm (F/CC)
139	4	STRIP	P.G.	ROOM 114	04P-005D1	AREA	2.61260	0.000000
140	4	REBUILD	EPA	ROOM 115	04E-001R1	AREA	0.04010	0.000000
141	4	REBUILD	EPA	ROOM 115	04E-002R1	AREA	0.06290	0.000000
142	4	REBUILD	EPA	ROOM 115	04E-003R1	AREA	0.04240	0.000000
143	4	REBUILD	EPA	ROOM 115	04E-004R1	AREA	0.06030	0.000000
144	4	REBUILD	EPA	ROOM 115	04E-005R1	AREA	0.05030	0.000000
145	4	REBUILD	P.G.	ROOM 114	04P-001R1	AREA	0.05510	0.000000
146	4	REBUILD	P.G.	ROOM 114	04P-002R1	AREA	0.04520	0.000000
147	4	REBUILD	P.G.	ROOM 114	04P-003R1	AREA	0.06020	0.000000
148	4	REBUILD	P.G.	ROOM 114	04P-004R1	AREA	0.03520	0.000000
149	4	REBUILD	P.G.	ROOM 114	04P-005R1	AREA	0.03510	0.000000
150	4	AFTER	EPA	ROOM 115	04E-001A	AREA	0.18240	0.000000
151	4	AFTER	EPA	ROOM 115	04E-002A	AREA	0.20520	0.000000
152	4	AFTER	EPA	ROOM 115	04E-003AR	AREA	0.21280	0.000000
153	4	AFTER	EPA	ROOM 115	04E-004A	AREA	0.20330	0.000000
154	4	AFTER	EPA	ROOM 115	04E-005A	AREA	0.21610	0.005026
155	4	AFTER	P.G.	ROOM 114	04P-001A	AREA	0.06150	0.000000
156	4	AFTER	P.G.	ROOM 114	04P-002A	AREA	0.09340	0.000000
157	4	AFTER	P.G.	ROOM 114	04P-003AD	AREA	0.09655	0.000000
158	4	AFTER	P.G.	ROOM 114	04P-004A	AREA	0.09850	0.004923
159	4	AFTER	P.G.	ROOM 114	04P-005A	AREA	0.08270	0.000000
160	5	BEFORE	EPA	ROOM 117	05E-001B	AREA	0.02920	0.000000
161	5	BEFORE	EPA	ROOM 117	05E-002B	AREA	0.09820	0.000000
162	5	BEFORE	EPA	ROOM 117	05E-003B	AREA	0.11210	0.000000
163	5	BEFORE	EPA	ROOM 117	05E-004B	AREA	0.11290	0.000000
164	5	BEFORE	EPA	ROOM 117	05E-005B	AREA	0.09500	0.000000
165	5	BEFORE	P.G.	ROOM 118	05P-001B	AREA	0.17060	0.000000
166	5	BEFORE	P.G.	ROOM 118	05P-002B	AREA	0.23590	0.000000
167	5	BEFORE	P.G.	ROOM 118	05P-003B	AREA	0.23970	0.000000
168	5	BEFORE	P.G.	ROOM 118	05P-004B	AREA	0.24290	0.000000
169	5	BEFORE	P.G.	ROOM 118	05P-005B	AREA	0.26440	0.000000
170	5	STRIP	EPA	ROOM 117	05E-001D1	AREA	0.47870	0.005039
171	5	STRIP	EPA	ROOM 117	05E-002D1	AREA	1.09920	0.000000
172	5	STRIP	EPA	ROOM 117	05E-003D1	AREA	0.84880	0.008488
173	5	STRIP	EPA	ROOM 117	05E-004D1R	AREA	0.73755	0.013746
174	5	STRIP	EPA	ROOM 117	05E-005D1	AREA	0.83240	0.016163
175	5	STRIP	P.G.	ROOM 118	05P-001D1	AREA	1.45880	0.014443
176	5	STRIP	P.G.	ROOM 118	05P-002D1	AREA	1.94410	0.000000
177	5	STRIP	P.G.	ROOM 118	05P-003D1	AREA	2.20770	0.000000
178	5	STRIP	P.G.	ROOM 118	05P-004D1R	AREA	2.58075	0.010417
179	5	STRIP	P.G.	ROOM 118	05P-005D1	AREA	2.76640	0.026098
180	5	REBUILD	EPA	ROOM 117	05E-001R1	AREA	0.45670	0.004434
181	5	REBUILD	EPA	ROOM 117	05E-002R1	AREA	0.83770	0.000000
182	5	REBUILD	EPA	ROOM 117	05E-003R1	AREA	0.37640	0.000000
183	5	REBUILD	EPA	ROOM 117	05E-004R1	AREA	0.54440	0.032664
184	5	REBUILD	EPA	ROOM 117	05E-005R1	AREA	0.43530	0.004891

OBS	REPNUM	PERIOD	METHOD	LOCATION	SAMPLE ID	SAMPLE TYPE	TOTAL STRUCTURE CONC (S/CC)	CONC FIBERS > 5 μm (F/CC)
185	5	REBUILD	P.G.	ROOM 118	05P-001R1	AREA	0.83140	0.008151
186	5	REBUILD	P.G.	ROOM 118	05P-002R1	AREA	0.64690	0.006342
187	5	REBUILD	P.G.	ROOM 118	05P-003R1	AREA	0.68880	0.000000
188	5	REBUILD	P.G.	ROOM 118	05P-004R1	AREA	0.74930	0.000000
189	5	REBUILD	P.G.	ROOM 118	05P-005R1	AREA	0.68080	0.000000
190	5	AFTER	EPA	ROOM 117	05E-001A	AREA	0.23650	0.005142
191	5	AFTER	EPA	ROOM 117	05E-002A	AREA	0.20810	0.000000
192	5	AFTER	EPA	ROOM 117	05E-003A	AREA	0.23770	0.010336
193	5	AFTER	EPA	ROOM 117	05E-004AD	AREA	0.21285	0.005314
194	5	AFTER	EPA	ROOM 117	05E-005A	AREA	0.28770	0.005047
195	5	AFTER	P.G.	ROOM 118	05P-001A	AREA	0.22010	0.000000
196	5	AFTER	P.G.	ROOM 118	05P-002A	AREA	0.16370	0.000000
197	5	AFTER	P.G.	ROOM 118	05P-003A	AREA	0.21200	0.005047
198	5	AFTER	P.G.	ROOM 118	05P-004A	AREA	0.19760	0.000000
199	5	AFTER	P.G.	ROOM 118	05P-005A	AREA	0.27390	0.005168
200	6	BEFORE	EPA	ROOM 110	06E-001B	AREA	0.08630	0.000000
201	6	BEFORE	EPA	ROOM 110	06E-002BR	AREA	0.13150	0.000000
202	6	BEFORE	EPA	ROOM 110	06E-003B	AREA	0.06090	0.000000
203	6	BEFORE	EPA	ROOM 110	06E-004B	AREA	0.04830	0.000000
204	6	BEFORE	EPA	ROOM 110	06E-005B	AREA	0.07230	0.000000
205	6	BEFORE	P.G.	ROOM 103	06P-001B	AREA	1.82370	0.000000
206	6	BEFORE	P.G.	ROOM 103	06P-002B	AREA	2.51480	0.000000
207	6	BEFORE	P.G.	ROOM 103	06P-003BD	AREA	2.78080	0.000000
208	6	BEFORE	P.G.	ROOM 103	06P-004B	AREA	2.54110	0.000000
209	6	BEFORE	P.G.	ROOM 103	06P-006B	AREA	1.92950	0.018552
210	6	STRIP	EPA	ROOM 110	06E-001D1	AREA	0.40020	0.004881
211	6	STRIP	EPA	ROOM 110	06E-002D1R	AREA	0.30685	0.004949
212	6	STRIP	EPA	ROOM 110	06E-003D1	AREA	0.35850	0.005272
213	6	STRIP	EPA	ROOM 110	06E-004D1	AREA	0.25530	0.005007
214	6	STRIP	EPA	ROOM 110	06E-005D1	AREA	0.30260	0.004880
215	6	STRIP	P.G.	ROOM 103	06P-001D1	AREA	0.59040	0.000000
216	6	STRIP	P.G.	ROOM 103	06P-002D1	AREA	0.64740	0.000000
217	6	STRIP	P.G.	ROOM 103	06P-003D1	AREA	0.66010	0.000000
218	6	STRIP	P.G.	ROOM 103	06P-004D1	AREA	0.60600	0.000000
219	6	STRIP	P.G.	ROOM 103	06P-005D1	AREA	0.74810	0.000000
220	6	REBUILD	EPA	ROOM 110	06E-001R1	AREA	0.01490	0.000000
221	6	REBUILD	EPA	ROOM 110	06E-003R1	AREA	0.01010	0.000000
222	6	REBUILD	EPA	ROOM 110	06E-004R1	AREA	0.01960	0.000000
223	6	REBUILD	EPA	ROOM 110	06E-005R1	AREA	0.01470	0.000000
224	6	REBUILD	P.G.	ROOM 103	06P-001R1	AREA	0.09630	0.000000
225	6	REBUILD	P.G.	ROOM 103	06P-002R1	AREA	0.05450	0.000000
226	6	REBUILD	P.G.	ROOM 103	06P-003R1	AREA	0.05820	0.000000
227	6	REBUILD	P.G.	ROOM 103	06P-004R1	AREA	0.10550	0.000000
228	6	REBUILD	P.G.	ROOM 103	06P-005R1	AREA	0.03410	0.000000
229	6	AFTER	EPA	ROOM 110	06E-001A	AREA	0.15540	0.000000
230	6	AFTER	EPA	ROOM 110	06E-004A	AREA	0.23900	0.000000

OBS	REPNUM	PERIOD	METHOD	LOCATION	SAMPLE ID	SAMPLE TYPE	TOTAL STRUCTURE CONC (S/CC)	CONC FIBERS > 5 μm (F/CC)
231	6	AFTER	EPA	ROOM 110	06E-005A	AREA	0.2507	0.000000
232	6	AFTER	EPA	ROOM 110	06E-007A	AREA	0.2314	0.000000
233	6	AFTER	P.G.	ROOM 103	06P-001A	AREA	0.5195	0.000000
234	6	AFTER	P.G.	ROOM 103	06P-002A	AREA	0.7073	0.000000
235	6	AFTER	P.G.	ROOM 103	06P-003A	AREA	0.5576	0.000000
236	6	AFTER	P.G.	ROOM 103	06P-004A	AREA	0.7725	0.000000
237	6	AFTER	P.G.	ROOM 103	06P-005A	AREA	0.6458	0.000000

APPENDIX E. PERSONAL TEM SAMPLE STUDY DATA

OBS	REPNUM	PERIOD	METHOD	LOCATION	SAMPLE ID	TOTAL STRUCTURE CONC (S/CC)	FIBERS > 5 μm CONC (F/CC)
1	1	STRIP	EPA	ROOM 111	01E-001D2	0.57292	0.011458
2	2	STRIP	EPA	ROOM 113	02E-001D2	0.26013	0.000000
3	6	STRIP	EPA	ROOM 110	06E-003D2	0.25585	0.000000
4	3	STRIP	P.G.	ROOM 109	03P-003D2	1.43297	0.014188
5	4	STRIP	P.G.	ROOM 114	04P-001D2	1.29861	0.000000
6	5	STRIP	P.G.	ROOM 118	05P-002D2	1.49079	0.014474
7	6	STRIP	P.G.	ROOM 103	06P-001D2	0.52130	0.000000
8	6	STRIP	P.G.	ROOM 103	06P-002D2	0.42346	0.014946
9	6	STRIP	P.G.	ROOM 103	06P-003D2	0.49087	0.000000