AIRBORNE ASBESTOS CONCENTRATIONS DURING BUFFING OF RESILIENT FLOOR TILE

by

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and

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DISCLAIMER

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of materials that, if improperly dealt with, can threaten both public health and the environment. The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. These laws direct the EPA to perform research to define our environmental problems, to measure the impacts, and to search for solutions.

The Risk Reduction Engineering Laboratory is responsible for planning, implementing, and managing research, development, and demonstration programs to provide an authoritative, defensible, engineering basis in support of the policies, programs, and regulations of the EPA with respect to drinking water, wastewater, pesticides, toxic substances, solid and hazardous wastes, and Superfund-related activities. This publication is one of the products of that research and provides a vital communication link between the research and the user community.

This report provides information on airborne asbestos concentrations measured during routine spray buffing of asbestos-containing resilient floor tile in New Jersey schools.

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ABSTRACT

Although asbestos-containing resilient floor tiles are considered nonfriable, the frictional forces exerted on the tile during routine maintenance operations can generate asbestos-containing structures. A study was conducted to determine the level of airborne asbestos concentrations during routine spray buffing of asbestos-containing floor tiles at 17 schools in northern, central, and southern New Jersey. Although the schools selected do not represent a statistical random sample, they do represent a cross section of floor conditions and floor-care maintenance practices.

Increased airborne asbestos levels during spray buffing were measured at 12 of the 17 schools. The increase was statistically significant at 7 of the 17 schools. Overall, the mean relative increase in airborne asbestos concentrations during spray-buffing with the high-speed machines (1000 to 1500 revolutions per minute) was statistically significantly higher than that during buffing with low-speed machines (175 to 330 revolutions per minute). More than 99 percent of the asbestos structures collected before and during spray buffing were chrysotile; less than 1 percent were amphibole. Machine speed appeared to have a significant effect on the structure morphology of the airborne asbestos structures generated during spray-buffing. Results of the study indicate that spray-buffing can generate asbestos-containing particles from the surface of asbestos-containing resilient floor tile. The estimated 8-hour time-weighted average (TWA) of total fiber concentrations (0.093 f/cm^2 maximum) in the breathing zone of the machine operators (as determined by phase contrast microscopy) did not exceed the OSHA action level of 0.1 f/cm^3, 8-hour TWA.

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SECTION 1

INTRODUCTION

Although no longer manufactured in the United States, asbestos-containing resilient floor tiles are installed in residential dwellings, institutions, commercial and public office buildings, and industrial facilities. The organic matrix in floor tiles may be either asphalt or polyvinyl chloride, and their dimensions are either 9 in. by 9 in. or 12 in. by 12 in. The asbestos in nearly all floor tiles is chrysotile, which is dispersed throughout the thickness of the tile. Although these floor tiles are considered nonfriable, the frictional forces exerted on these materials during routine floor-care maintenance operations can generate asbestos-containing particles.

Background

The principal types of maintenance performed routinely on resilient floor tiles include spray buffing and dry burnishing, and wet scrubbing and stripping followed by refinishing. The U.S. Environmental Protection Agency (EPA), school districts, and the Resilient Floor Covering Institute have monitored airborne asbestos levels during wet stripping of asbestos-containing floor tiles.[1,2,3] These studies have shown elevated levels of asbestos structures in the air during the stripping operation (based on transmission electron microscopy), but the 8-hour time-weighted average (TWA) concentrations (based on phase contrast microscopy) were below the Occupational Safety and Health Administration (OSHA) permissible exposure limit and action level of 0.2 and 0.1 fiber per cubic centimeter of air, respectively. If the action level is exceeded, periodic personal air monitoring, employee training, and medical surveillance are required (29 CFR 1910.1001). The results of the two analytical techniques differ mostly because phase contrast microscopy (PCM) does not detect the smaller fibers (<5 μm in length and <0.25 μm in width) as measured by transmission electron microscopy (TEM). Also, the OSHA methodology requires a length to width ratio (aspect ratio) of 3:1 or greater whereas the TEM methodology has an aspect ratio of 5:1 or greater. In response to concerns raised by school districts and building managers regarding the release of asbestos structures during stripping operations, the EPA issued interim guidance on appropriate procedures for the stripping of asbestos-containing floor coverings.[4]

Little data are available for evaluating the extent of asbestos structures released during other floor-care maintenance procedures, such as spray-buffing.[2,3] Spray-buffing is the restorative maintenance of a previously polished floor by use of a suitable floor-polishing machine immediately after the surface has been mist-sprayed with an appropriate product whereby the wet application is buffed to dryness.[5] The levels of airborne asbestos structures released during spray-buffing could be higher than those during wet stripping, especially if the floor has been poorly maintained (i.e., minimal wax layer), is worn, or is otherwise damaged. The Risk Reduction Engineering Laboratory (RREL) of the U.S. EPA and the Environmental Health Service (EHS) of the New Jersey Department of Health (NJDOH) conducted a study to evaluate airborne asbestos concentrations during routine spray-buffing of asbestos-containing floor tile.

Objectives

The objectives of this study were as follows:

1. To determine the airborne asbestos concentrations during routine spray buffing of asbestos-containing resilient floor tile in a cross section of schools in northern, central, and southern New Jersey.

2. To compare the fiber concentrations measured by phase contrast microscopy during routine spray-buffing of asbestos-containing floor tile with the OSHA action level of 0.1 fiber per cubic centimeter of air, 8-hour TWA.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The following are the principal conclusions reached during the study:

- Spray-buffing can cause asbestos structures to be generated from the surface of asbestos-containing resilient floor tile. Increased airborne asbestos concentrations during spray-buffing were measured at 12 of the 17 schools studied. The increase was statistically significant at seven of these schools.

- Overall, the mean relative increase in airborne asbestos concentrations during spray-buffing with the high-speed machines (1000 to 1500 rpm) was significantly higher than the relative increase during spray-buffing with the low-speed machines (175 to 330 rpm). On average, airborne asbestos concentrations were approximately five times higher during than before spray-buffing with the high speed machines, whereas spray-buffing with the low-speed machines showed a two-fold increase during buffing than before.

- Machine speed appears to have a significant effect on the structure morphology of the airborne asbestos structures generated during spray-buffing. The percentage of asbestos fibers observed during high-speed buffing was approximately 2.5 times greater than that before buffing; whereas, the percentage of asbestos fibers observed during low-speed buffing was approximately 1.3 times greater. The percentage of asbestos matrices measured during high-speed buffing were approximately 1.2 times lower than before buffing; whereas the percentage of asbestos matrices measured during low-speed buffing was essentially unchanged (i.e., <0.4 percent lower).

- The estimated 8-hour TWA of total fiber concentrations (0.093 f/cm^3 maximum) in the breathing zone of the machine operators (as determined by phase contrast microscopy) did not exceed the OSHA action level of 0.1 f/cm^3, 8-hour TWA.

Recommendations

Further research is recommended to study the effect of buffing methods on the release of asbestos structures from the surface of asbestos-containing resilient floor tiles. A study should be designed to evaluate the extent of asbestos release during application of the two buffing methods (low-speed spray-buffing and high-speed dry-buffing) on three levels of floor care (poor, intermediate, and good). The results of this study would define the need for and nature of guidance for the buffing of asbestos-containing resilient floor tiles.

SECTION 3

STUDY DESIGN AND METHODS

This study was conducted at 17 schools in northern, central, and southern New Jersey. The selected schools were distributed among eight school districts. Although these schools do not represent a statistical random sample, they do represent a cross section of floor conditions and floor-care maintenance operations.

Access to the schools was coordinated directly by the Environmental Health Service of the New Jersey Department of Health (EHS-NJDOH). The EHS-NJDOH collected bulk samples of all floor tiles, documented floor-care practices, floor conditions, and characteristics of the floor-buffing equipment and materials in each school, as well as other variables that might have an impact on the release of asbestos structures.

In all of the schools, the existing custodial staff performed the floor-care maintenance operations. The floors were prepared (i.e., dry and/or wet-mopped) and spray-buffed in accordance with established practices and procedures at the respective schools.

Sampling Strategy

The first study objective was to determine whether airborne asbestos concentrations increase during the spray-buffing of floor tile. This was addressed by collecting air samples before and during floor-buffing operations. A maximum of two distinct areas were tested in each school studied. Immediately before buffing operations began, three baseline, fixed-station, area air samples were collected in each test area under normal building conditions (i.e., no intentional air disturbance beyond that attributable to normal occupancy activity in the area). Three personal breathing-zone samples were collected during buffing operations for comparison with the baseline samples. These samples also were taken under normal occupancy conditions (i.e., no air disturbance beyond that attributable to the buffing itself). These samples were collected in the breathing zone of the buffing machine operators so they would be representative of airborne asbestos levels during spray-buffing operations. The three baseline and three personal breathing zone samples were analyzed by transmission electron microscopy (TEM).

The second study objective was to compare total fiber concentrations during buffing operations with the OSHA action level of 0.1 fiber per cubic centimeter (f/cm^3), 8-hour TWA (29 CFR 1910.1001). This was achieved by collecting one sample in the breathing zone of the machine operator during the spray-buffing in each area. These samples were collected in accordance with OSHA sampling protocols and analyzed by phase-contrast microscopy (PCM).

Quality assurance/quality control (QA/QC) samples were also collected at each school. These consisted of two field blanks (one open and one closed) at each school. If a second test area was monitored at a school, two additional open field blanks were collected.

Bulk samples of each type of floor tile present in each school were also collected to confirm the percentage and type of asbestos in the floor tile.

Sampling Methods

Fixed-Station Area Air Samples

The baseline, fixed-station, area air samples were collected on open-face, 25-mm-diameter, 0.45-µm-pore-size, mixed cellulose ester (MCE) filters with a 5-µm-pore-size MCE diffusing filter and a cellulose support pad contained in a three-piece cassette. The filter cassettes were positioned on tripods approximately 5 feet above the floor, with the filter face at 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 flow rate of approximately 9 L/min. Air volumes ranged from 564 to

916 L. At the end of the sampling period, the filters were turned upright before being disconnected from the vacuum pump. They were then stored in this position until they were analyzed by TEM.

The sampling pumps were calibrated with a precision rotameter (Manostat Model 36-546-215) both before and after sampling. Because the precision rotameter is a secondary standard, it was calibrated with a primary airflow standard both before and after the study.

Personal Breathing Zone Air Samples

Three personal breathing zone air samples were collected on open-face, 25-mm-diameter, 0.45-µm-pore-size MCE filters with a 5-µm-pore-size MCE diffusing filter and a cellulose support pad contained in a three-piece cassette. These samples were analyzed by TEM. A fourth personal breathing zone sample was collected on a 25-mm-diameter, 0.8-µm-pore-size MCE filter, and a cellulose support pad contained in a three-piece cassette with a 50-mm conductive extension cowl. The fourth personal breathing zone sample was collected in accordance with OSHA protocols and analyzed by PCM.

The four filter cassettes were positioned in the breathing zone of the buffing machine operator. Each filter was attached to approximately 50 ft. of Tygon tubing that was attached to an electric-powered (110 VAC) 1/6-horsepower vacuum pump operating at a flow rate of approximately 9 L per minute. Air volumes ranged from 617 to 970 L. To achieve the target air volume of 600 liters in the time required to spray-buff the test area, traditional battery-powered, personal sampling pumps could not be used because of their limited airflow rates (approximately 2 L/min with the 0.45-µm-pore-size MCE filter).

Bulk Floor Tile Samples

Bulk samples were collected of each type of floor tile present in each school. Each sample consisted of a 2-in. by 2-in. section of floor tile. A 2-in. by 2-in. template was used to delineate the area on the floor tile. A hammer and wood chisel were

Bulk Floor Tile Samples

The type and percentage of asbestos in the floor tile were determined by polarized light microscopy (PLM) analysis in accordance with the EPA test method "Interim Method for Determination of Asbestos in Bulk Insulation Samples" (EPA 600/M4-82-020). A confirmatory analysis was performed on floor tile from eight of the 17 schools. The samples were analyzed by TEM in accordance with Chatfield's Method (SOP-1988-02, Revision No. 1: Analysis of Resilient Floor Tile). Portions of a freshly fractured edge of the bulk samples were analyzed by scanning electron microscopy (SEM) to examine the condition of the floor tile surface.

Statistical Methods

Descriptive statistics were calculated for each school and each area within a school. These descriptive statistics included the sample size; arithmetic mean, minimum, and maximum airborne asbestos concentrations; and the arithmetic standard deviation. All estimated concentrations were based on the number of asbestos structures counted. If no asbestos structures were counted in a sample, a value of 0 s/cm^3 was used as the measured concentration. Results of the quality assurance samples were not included in the statistical analysis of the data.

A two-factor analysis of variance (ANOVA) was used to compare airborne asbestos concentrations before and during floor buffing. Each school was considered separately. The experimental factors in the ANOVA analysis were the sample period (baseline, during) and area within a school (A or B). If only one area was studied at a school, the analysis was reduced to a one-factor ANOVA, which is equivalent to a Student's t-test.

The natural logarithm of each measured concentration was used in the ANOVA analysis. This transformation was used to make variances more equal and to provide data that are better approximated by a normal distribution. This is equivalent to assuming that the data follow a lognormal distribution. If one or more samples showed a measured concentration of 0 s/cm^3 at a given school, the transformation used to remove the tile, which was then placed in a labeled Ziploc plastic bag. The exact location of the sample was recorded on a plan drawing of the building.

Analytical Methods

Air Samples

The 0.45-µm-pore-size MCE filters were prepared and analyzed in accordance with the nonmandatory TEM method specified in the Asbestos Hazard Emergency Response Act (AHERA) Final Rule (October 30, 1987; 40 CFR Part 763). In addition, the specific length and width of each structure were measured and recorded. A sufficient number of grid openings were analyzed to ensure a sensitivity (the concentration represented by the finding of a single structure) of no greater than 0.005 asbestos structure per cubic centimeter of air sampled, unless the degree of loading made this impractical. Samples were analyzed according to AHERA nonmandatory TEM counting rules except that some grid openings with greater than 25 percent particulate matter were analyzed. AHERA specifies that grid openings covered with greater than 25 percent particulate matter should not be analyzed. This exception to the AHERA nonmandatory method was made because of the research nature of this study to obtain additional information.

Each of the 0.8-µm-pore-size MCE membrane filters was analyzed by phase contrast microscopy (PCM). These samples were prepared and analyzed according to the NIOSH 7400 protocol (Revision 3, June 5, 1989, National Institute of Occupational Safety and Health Manual of Analytical Methods). All fibers with a 3:1 (or greater) length-to-width ratio were counted using the A counting rules. The analytical sensitivity was approximately 0.01 f/cm^3 of air sampled. Although the NIOSH 7400 protocol specifies to reject a graticulate field if an agglomerate covers approximately one-sixth or more of the field, an exception to this rule was made on some heavily loaded samples.

ln(x + 0.002), where x is the measured airborne asbestos concentration, was applied to each measurement before the ANOVA was performed. The constant 0.002 was chosen to be smaller than the analytical sensitivity for these measurements and was added to all values (baseline and during) at that school so the comparison would not be biased. The log transformation was used only for the ANOVA tests; it was not used for any other part of the data analysis (e.g., data graphs or descriptive statistics). All statistical comparisons were performed at the 0.05 level of significance.

SECTION 4

QUALITY ASSURANCE

Sample Chain of Custody

During the study, sample chain-of-custody procedures were an integral part of both the sampling and analytical activities and were followed for all air and bulk samples collected. The field custody procedures documented each sample from the time of its collection until its receipt by the analytical laboratory. Internal laboratory records then documented the custody of the sample through its final disposition.

Standard chain-of-custody procedures were used. Each sample was labeled with a unique project identification number, which was recorded on a sample data sheet along with such information as sampling date, location of the sampler, starting/stopping rotameter readings, sampling flow rate, starting/stopping times, and sampling conditions.

Sample Analysis

Specific quality assurance procedures outlined in the AHERA rule were used to ensure the precision of the collection and analysis of air samples; these included filter lot blanks, open and closed field blanks, and repeated sample analyses (replicate and duplicate analyses).

Filter lot blanks, which are samples selected at random from the lot of filters used in this study, were analyzed to determine background asbestos contamination on the filters. Five percent (50 filters) of the total number of filters (2000 filters) from the lot used in this research study were analyzed by the EPA-RREL TEM laboratory. The filters were prepared and analyzed in accordance with the nonmandatory AHERA TEM method. The TEM analysis of the 50 0.45-µm-pore-size MCE filters showed a background contamination level of 0 asbestos structures per 10 grid openings on each filter.

Open field blanks are filter cassettes that have been transported to the sampling site, opened for a short time (<30 sec) without air having passed through the filter, and then sent to the laboratory. Closed field blanks are filter cassettes that have been transported to the sampling site and sent to the laboratory without being opened. Two 0.45-µm-pore-size MCE field blanks (one open and one closed) and two 0.8-µm-pore-size MCE field blanks (one open and one closed) were collected at each school. If a second test area was monitored at a school, two additional open field blanks were collected (one 0.45-µm-pore-size MCE and one 0.8-µm-pore-size MCE). Ten grid openings were examined on each filter. No asbestos structures were found on any of the closed field blanks; three asbestos structures (33 s/mm^2) were found on a 0.45-µm-pore-size MCE open field blank at Site 3.

The reproducibility and precision of the TEM analyses were determined by an evaluation of repeated analyses of randomly selected samples. Repeated analyses included replicate analyses and duplicate analyses. A replicate analysis of 10 samples was performed to assess the uniformity of the distribution of asbestos structures on a single grid preparation. A replicate analysis is a second analysis of the same sample preparation performed by the same microscopist as the original analysis. The microscopist uses the same grid preparation but counts different grid openings from those originally read. Table 1 presents the results of the replicate analyses.

A duplicate sample analysis of 4 samples was performed to assess the reproducibility of the TEM analysis and to quantify any analytical variability resulting from the filter preparation procedure. A duplicate analysis is the analysis of a second TEM grid prepared from a different area of the sample filter but analyzed by the same microscopist who performed the original analysis. Table 2 presents the results of the duplicate analyses.

The coefficient of variation (CV) for the replicate and duplicate analyses was estimated by assuming a lognormal distribution of the data on the original scale and

TABLE 1. DATA SUMMARY FOR REPLICATE ANALYSES[a]

Sample Number	Original Analysis N[b]	Original Analysis s/cm³	Replicate Analysis N	Replicate Analysis s/cm³
02A-02D	1	0.05	5	0.025
04A-03B	0	0	0	0
06A-03D	14	0.065	20	0.093
07B-03B	3	0.014	1	0.005
09A-02D	2	0.009	1	0.005
11A-02B	4	0.020	2	0.010
12A-03D	9	0.043	11	0.052
13B-01D	45	0.225	49	0.245
16A-01D	0	0	0	0
17B-01B	13	0.065	17	0.085

[a] A replicate analysis is a second analysis of the same sample preparation performed by the same microscopist.

[b] Number of asbestos structures.

TABLE 2. DATA SUMMARY FOR DUPLICATE ANALYSES[a]

Sample Number	Original Analysis N[b]	Original Analysis s/cm³	Duplicate Analysis N	Duplicate Analysis s/cm³
05A-03D	23	0.112	31	0.151
08B-01B	21	0.103	11	0.054
10A-03B	53	0.254	62	0.298
17B-03B	5	0.024	8	0.038

[a] A duplicate analysis is the analysis of a second TEM grid preparation by the same microscopist.

[b] Number of asbestos structures.

estimating the variance on the log scale. The variance was estimated by the mean square error obtained from a one-factor ANOVA of the log-transformed data with the sample identification number as the main factor. The CV associated with the replicate analyses was 52 percent, and that associated with the duplicate analyses was 31 percent.

SECTION 5

RESULTS AND DISCUSSION

Study-Site Characteristics

Resilient Floor Tile

Table 3 presents the characteristics of the 28 study sites representing 17 schools. The resilient flooring included mostly 9-in. by 9-in. tiles and some 12-in. by 12-in. tiles. Although the asbestos content of the tiles ranged from 1 to 38 percent, the content of most of the tiles exceeded 10 percent. The areas that were spray-buffed ranged from 727 to 3386 ft^2; the average area was approximately 2150 ft^2. Any floor areas with damaged (e.g., broken) or missing tiles were isolated to prevent their contact with the buffing machine.

Floor Care Maintenance Practices

Table 4 presents the wax-stripping and spray-buffing floor-care maintenance practices at each of the schools. Sixteen of the 17 schools used a black pad for stripping the floors, whereas EPA's interim procedure guidelines for the stripping of resilient floor coverings recommend the use of the "least abrasive pad possible".[4] The schools wet-stripped and refinished the floors one to three times a year (during the summer, winter, or spring breaks).

The floors were dry- and/or wet-mopped before they were spray-buffed. All of the schools dry-mopped the floors, and nine of the schools both dry- and wet-mopped the floors. The floors are typically spray-buffed once a year; however, some schools spray-buffed the floors one to three times each week.

TABLE 3. CHARACTERISTICS OF THE RESILIENT FLOOR TILE AT EACH STUDY SITE

Site	Area Buffed, ft^2	Location	Tile Size, in.	% Asbestos
1A	1480	Classrooms	9 x 9	7
1B	1480	Classrooms	9 x 9	7
2A	1697	Cafeteria	9 x 9	5 - 9
3A	1643	Classrooms	12 x 12	5 - 13
3B	1643	Classrooms	12 x 12	5 - 13
4A	1996	Cafeteria	9 x 9	9 - 12
5A	2171	Cafeteria	9 x 9	19 - 23
6A	2088	Hallway	9 x 9	2 - 10
6B	2088	Hallway	9 x 9	2 - 10
7A	2430	Classrooms	12 x 12	11 - 14
7B	2430	Classrooms	9 x 9	10 - 24
8A	1913	Hallway	9 x 9	10 - 25
8B	1614	Hallway	9 x 9	10 - 25
9A	1590	Hallway	9 x 9	2 - 15
10A	2731	Hallway	9 x 9	12
10B	3386	Hallway	9 x 9	12
11A	2700	Hallway	9 x 9	1.5 - 13
11B	3180	Hallway	9 x 9, 12 x 12	0.5 - 4
12A	1630	Hallway	9 x 9	5 - 10
12B	3185	All-purpose room	9 x 9	15
13A	3230	Hallway	9 x 9	3 - 17
13B	2196	Hallway	9 x 9	10 - 38
14A	1829	All-purpose room	9 x 9	3 - 14
15A	2174	All-purpose room	9 x 9	10 - 15
16A	727	Hallway	12 x 12	1 - 3

(continued)

TABLE 3 (continued)

Site	Area Buffed, ft^2	Location	Tile Size, in.	% Asbestos
16B	908	Cafeteria	9 x 9	10 - 15
17A	2274	Classrooms	9 x 9	10 - 15
17B	1654	Classrooms	9 x 9	10 - 15

TABLE 4. DESCRIPTION OF RESILIENT FLOOR TILE MAINTENANCE PRACTICES

Wax-Stripping/Refinishing Practices			Spray-Buffing Practices			
			Floor Preparation Before Buffing		Frequency of Buffing	
Site	Description	Frequency per year	Dry Mop	Wet Mop	per week	per year
1A, B	Wet stripping with machine and black pad, 2 coats polish, buffing with machine (red pad)	2	Yes	No		2
2A	Wet stripping with machine and black pad, 2 coats polish	2	Yes	Yes		1
3A, B	Wet stripping with machine and black pad, 2 coats polish	2	Yes	Yes		1
4A	Wet stripping with machine and black pad, 2 coats polish	2-3	Yes	Yes		1
5A	Wet stripping with machine and black pad, 1 coat sealer, 2 coats polish	2	Yes	Yes		4
6A, B	Wet stripping with machine and black pad, 2 coats sealer, 2-3 coats polish	1	Yes	No		1
7A, B	Wet stripping with machine and black pad, 3-4 coats polish	1	Yes	No		1
8A,B	Wet stripping with machine and black pad, 2 coats polish	1	Yes	Yes		12
9A	Wet stripping with machine and black pad, 3 coats polish	2	No	No	3	
10A, B	Wet stripping with machine and black pad, 2 coats polish, buffing with machine	2	Yes	No	1	

(continued)

Table 4 (continued)

Wax-Stripping/Refinishing Practices			Spray-Buffing Practices			
			Floor Preparation Before Buffing		Frequency of Buffing	
Site	Description	Frequency per year	Dry Mop	Wet Mop	per week	per year
11A, B	Wet stripping with machine and black pad, 2 coats polish, buffing with machine	2	Yes	Yes	1	
12A, B	Wet stripping with machine and black pad, 2 coats polish, buffing with machine	2	Yes	No	1	
13A, B	Wet stripping with machine and green pad, 2 coats polish, buffing with machine	2	Yes	No	3	
14A	Wet stripping with machine and black pad, 2 coats polish, buffing with machine	3	Yes	Yes	1	
15A	Wet stripping with machine and black pad, 2 coats polish, buffing with machine	2	Yes	No	1	
16A, B	Wet stripping with machine and blue pad, 2 coats polish	1	Yes	No		3-4
	Wet scrubbing with machine, 2 coats polish, machine buffing	3-4				
17A, B	Wet stripping with machine and black pad, 3 coats sealer, 3 coats polish	2	Yes	Yes		1
	Wet scrubbing with machine and red pad, 2 coats polish	2-3				

Buffing Equipment and Materials

Table 5 presents the characteristics of the buffing equipment (e.g., machine speed) and materials (e.g., buffing pad color) used. Twelve of the schools used buffing machines operating at 1000 to 1500 rpm and five used buffing machines operating at 175 to 330 rpm. The speeds are based on information contained on the machines nameplate or that provided by the manufacturer of the machine. The appropriate buffing pad (i.e., a white pad with high-speed machines and a red pad with low-speed machines) was used at all of the schools except two. The two exceptions were at School No. 1 where a red pad was used with a high-speed machine, and at School No. 13 where a green pad (designed for heavy scrubbing and light stripping applications) was used with a low-speed machine.

Airborne Asbestos Concentrations Before and During Spray-Buffing

Three samples were collected before and three during routine spray-buffing of asbestos-containing floor tile in each area within a school. Table 6 presents the descriptive statistics (i.e., mean, minimum, maximum, and standard deviation) separately for each school/area combination and each sampling period (i.e., baseline and during spray-buffing). (Individual airborne asbestos concentrations are presented in Appendix A.) Figure 1 shows the average airborne asbestos concentrations at each area before and during spray-buffing.

Increased airborne asbestos levels during spray-buffing were noted at 12 of the 17 schools. The increase was statistically significant at seven of these schools (Nos. 1, 5, 6, 7, 12, 14, and 17). Compared with baseline measurements taken before buffing, airborne asbestos concentrations were qualitatively the same or lower during buffing at the remaining five schools (Nos. 2, 4, 9, 10, and 16).

Overall, the mean relative increase in airborne asbestos concentrations during spray-buffing with the high-speed machines (1000 to 1500 rpm) was significantly higher ($p=0.0326$) than the relative increase during spray-buffing with the low-speed machines (175 to 330 rpm). On average, airborne asbestos concentrations were

TABLE 5. CHARACTERISTICS OF FLOOR BUFFING EQUIPMENT AND MATERIALS

Site	Machine Speed, rpm	Machine Manufacturer	Pad Color	Pad Manufacturer	Polish Used ml/ft^2	Polish Name	Polish Manufacturer	% Solids in Polish
1A	1000	Kent	Red[a]	Norton	1.92	Flashback Spray Buff	Misco Products	Not Available
1B	1000	Kent	Red[a]	Norton	1.28	Flashback Spray Buff	Misco Products	Not Available
2A	175	Hild	Red	Glit	0.28	Appearance Plus	Fuller Brush	6.3
3A	175	Hild	Red	Norton	0.43	Appearance Plus	Fuller Brush	6.3
3B	175	Hild	Red	Norton	0.58	Appearance Plus	Fuller Brush	6.3
4A	175	Clark	Red	Glit	0.53	Earl's 4018M	John A. Earl, Inc.	Not Available
5A	1500	Mastercraft	White	Glit	0.14	Primero	Chemsearch	Not Available
6A	1500	Floorcraft	White	3M	0.20	Appearance Plus	Fuller Brush	6.3
6B	1500	Floorcraft	White	3M	0.30	Appearance Plus	Fuller Brush	6.3
7A	1100	Hild	White	3M	0.44	Gloss Spray Buff	Banner Chemical	9.5-10.5
7B	1100	Hild	White	3M	0.44	Gloss Spray Buff	Banner Chemical	9.5-10.5
8A	300	Hild	Red	3M	0.25	Dyna Spray	Halbro Control Ind.	Not Available

(continued)

TABLE 5 (continued)

Site	Machine Speed, rpm	Machine Manufacturer	Pad Color	Pad Manufacturer	Polish Used ml/ft^2	Polish Name	Polish Manufacturer	% Solids in Polish
8B	300	Hild	Red	3M	0.15	Dyna Spray	Halbro Control Ind.	Not Available
9A	300	Advance	Red	3M	0.33	Floor Gloss Restorer	Professional Products	Not Available
10A	1500	Tornado	White	3M	0.13	Super Spray Buff	Spartan Chemical	5
10B	1500	Tornado	White	3M	0.14	Super Spray Buff	Spartan Chemical	5
11A	330	Tornado	White	Microtron	0.09	Super Spray Buff	Spartan Chemical	5
11B	330	Tornado	White	Microtron	0.02	Super Spray Buff	Spartan Chemical	5
12A	330	Tornado	White	Glit	0.15	Super Spray Buff	Spartan Chemical	5
12B	330	Tornado	White	Glit	0.07	Super Spray Buff	Spartan Chemical	5
13A	330	Tornado	Green[a]	Norton	0.09	Super Spray Buff	Spartan Chemical	5
13B	330	Tornado	Green[a]	Norton	0.14	Super Spray Buff	Spartan Chemical	5
14A	175	Kent	White	Glit	0.32	Super Spray Buff	Spartan Chemical	5

(continued)

TABLE 5 (continued)

Site	Machine Speed, rpm	Machine Manufacturer	Pad Color	Pad Manufacturer	Polish Used ml/ft^2	Polish Name	Polish Manufacturer	% Solids in Polish
15A	330	Tornado	White	3M	0.11	Super Spray Buff	Spartan Chemical	5
16A	175	Hild	White	Norton	0.33	Renovator Solution	State Chemical	Confidential
16B	175	Hild	White	Norton	0.26	Renovator Solution	State Chemical	Confidential
17A	175	Kent	Red	Microtron	0.13	Major Wax	Butcher Polish Co.	Confidential
17B	175	Kent	Red	Microtron	0.18	Major Wax	Butcher Polish Co.	Confidential

[a] Designed for low-speed buffing machines.

[b] Designed for heavy-duty scrubbing and light-stripping applications.

TABLE 6. SUMMARY OF AIRBORNE ASBESTOS CONCENTRATIONS MEASURED BY TEM BEFORE AND DURING BUFFING OF FLOOR TILE

	Asbestos Concentration, s/cm³ (N = 3)							
	Baseline				During Buffing			
Site	Mean	Minimum	Maximum	Standard Deviation	Mean	Minimum	Maximum	Standard Deviation
1A	0.004	0	0.009	0.005	0.014	0.010	0.019	0.005
1B	0.001	0	0.005	0.003	0.013	0.005	0.019	0.007
2A	0.006	0	0.010	0.006	0.003	0	0.005	0.003
3A	0.001	0	0.005	0.003	0.011	0	0.025	0.013
3B	0	0	0	0	0.003	0	0.009	0.005
4A[a]	0	0	0	0	0	0	0	0
5A	0.009	0.005	0.014	0.005	0.107	0.088	0.123	0.018
6A	0.030	0	0.076	0.040	0.163	0.065	0.302	0.123
6B	0.029	0.015	0.054	0.021	0.205	0.137	0.291	0.078
7A	0.003	0	0.010	0.006	0.145	0.097	0.179	0.043
7B	0.008	0.005	0.014	0.005	0.414	0.379	0.464	0.044
8A	0.011	0.005	0.020	0.008	0.025	0.015	0.030	0.009
8B[b]	0.041	0	0.103	0.055	-	-	-	-
9A	0.010	0	0.020	0.010	0.003	0	0.009	0.005
10A	0.086	0	0.254	0.145	0.067	0.033	0.094	0.031
10B	0.038	0.030	0.045	0.008	0.032	0.029	0.035	0.003
11A	0.033	0.020	0.054	0.018	0.056	0.015	0.097	0.058

(continued)

TABLE 6 (continued)

Site	Asbestos Concentration, s/cm^3 (N = 3)							
	Baseline				During Buffing			
	Mean	Minimum	Maximum	Standard Deviation	Mean	Minimum	Maximum	Standard Deviation
11B	0.029	0.005	0.069	0.034	0.077	0.067	0.090	0.012
12A	0.012	0.009	0.014	0.003	0.067	0.043	0.113	0.039
12B	0.065	0.029	0.113	0.043	0.096	0.062	0.151	0.048
13A	0.015	0	0.040	0.022	0.082	0.015	0.206	0.040
13B	0.194	0.051	0.390	0.175	0.290	0.225	0.329	0.057
14A	0.006	0.005	0.010	0.003	0.052	0.020	0.087	0.034
15A	0.094	0.058	0.126	0.034	0.151	0.102	0.216	0.059
16A	0.001	0	0.005	0.003	0.001	0	0.004	0.002
16B	0.003	0	0.005	0.003	0	0	0	0
17A	0.001	0	0.005	0.003	0.056	0.052	0.059	0.004
17B	0.050	0.024	0.065	0.023	0.114	0.035	0.189	0.077

[a] Summary statistics are based on two samples (N = 2).
[b] The samples collected during spray-buffing were too heavily loaded with particulate to count.

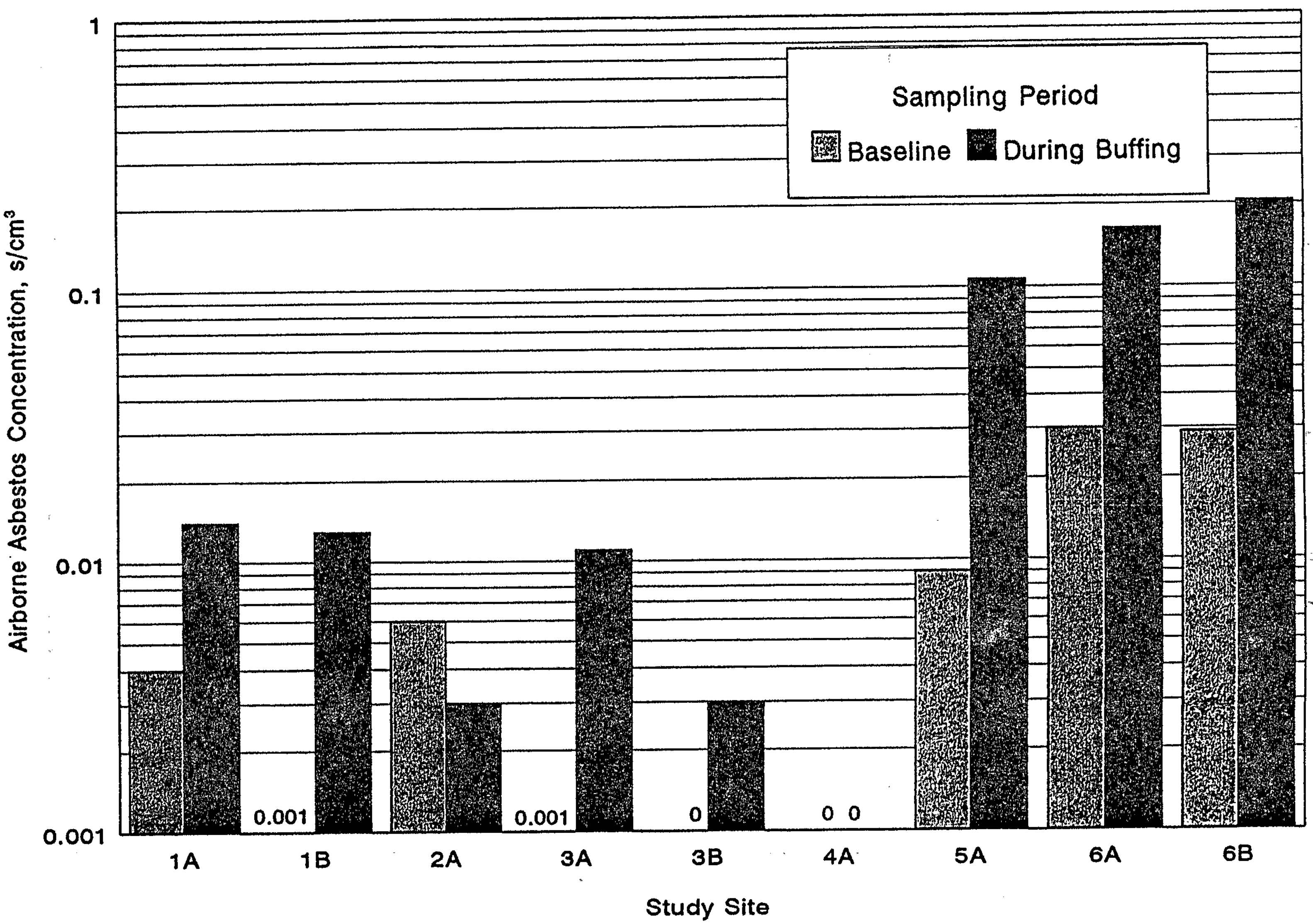

Figure 1. Average airborne asbestos concentrations (measured by TEM) before and during buffing of asbestos-containing resilient floor tile (continued).

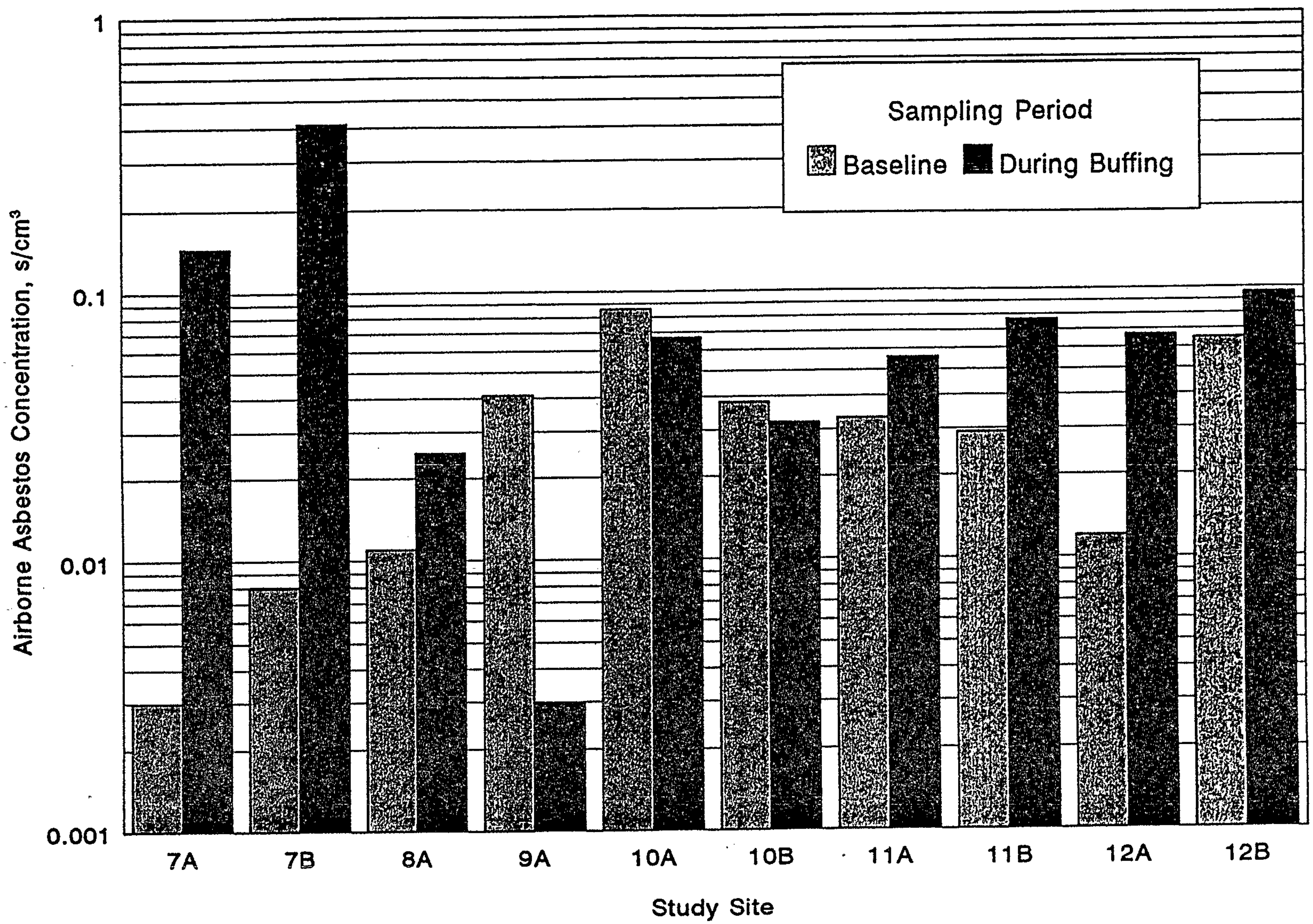

Figure 1. Average airborne asbestos concentrations (measured by TEM) before and during buffing of asbestos-containing resilient floor tile (continued).

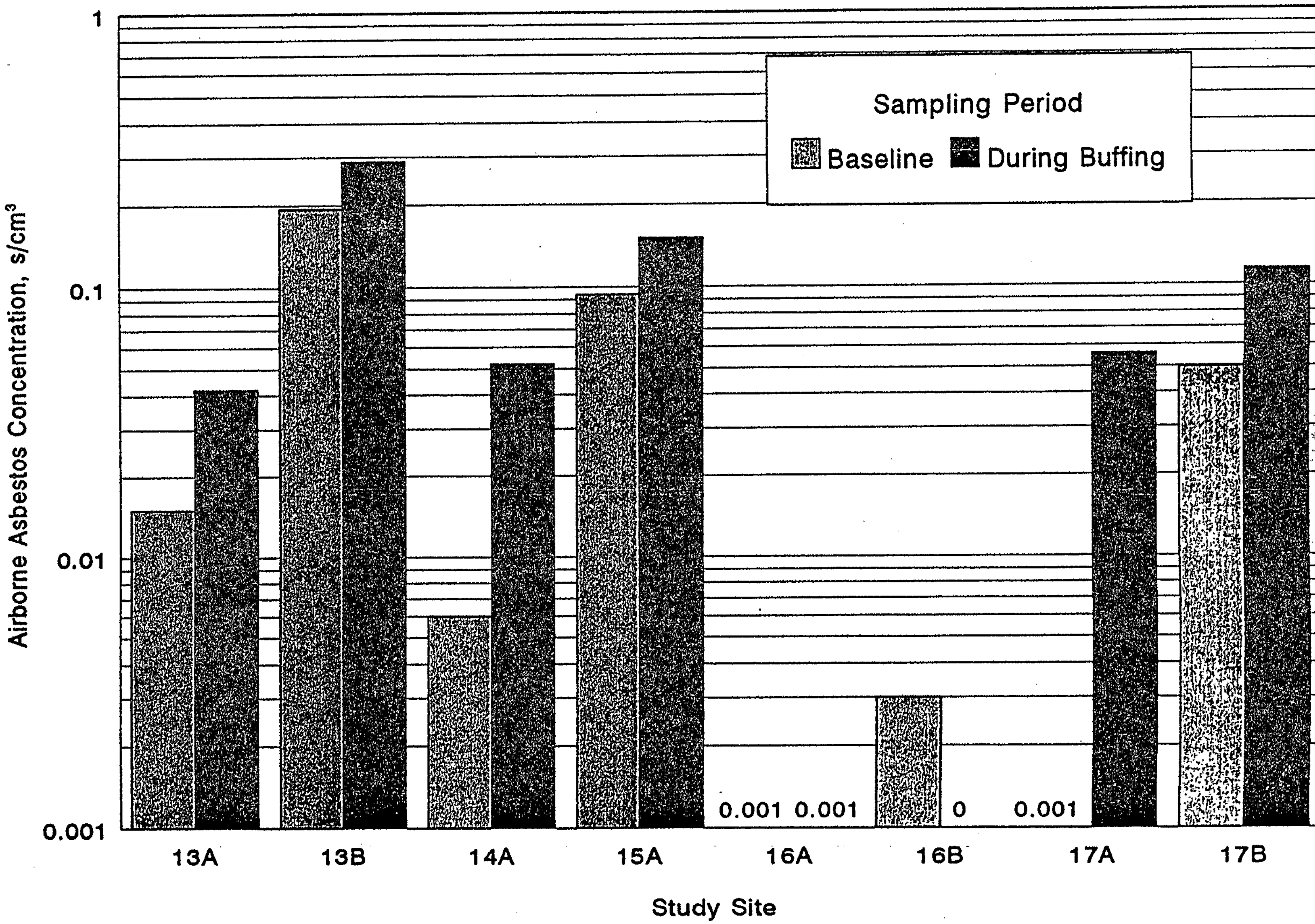

Figure 1. Average airborne asbestos concentrations (measured by TEM) before and during buffing of asbestos-containing resilient floor tile.

approximately five times higher during spray-buffing than before spray-buffing with the higher speed machines, whereas spray-buffing with the lower-speed machines showed a two-fold increase during buffing than before.

Airborne Asbestos Concentrations Based on Frequency of Spray-Buffing

Table 4 presents the frequency at which spray-buffing is performed at each school. Spray-buffing is routinely performed (one or more times weekly) at seven schools, whereas spray-buffing is performed less frequently (once per month to once per year) at the remaining ten schools. The mean airborne asbestos concentrations measured before buffing at the schools in which spray-buffing is routinely performed (0.035 s/cm^3) was significantly greater ($p=0.0004$) than the mean baseline concentration measured at schools in which spray-buffing is performed less frequently (0.007 s/cm^3).

Personal Breathing Zone Concentrations of Total Fibers

Table 7 presents total fiber concentrations in the machine operator's breathing zone during spray buffing, as measured by PCM. The actual time spent buffing the floors ranged from 64 to 97 minutes.

School maintenance workers do not typically spray-buff floors for a full 8-hour work shift. According to school custodians at the five sites (Nos. 6A, 10A, 11A, 13B, and 16B) that showed measured levels above 0.1 f/cm^3, the average time spent buffing floors on a typical day ranges from 1.5 to 2.5 hours. Assuming that a maintenance worker spends no more than 2.5 hours a day buffing the floor and has no additional exposure to asbestos for the remainder of the day, the predicted 8-hour time-weighted average (TWA) concentrations for all of these sites would be less than the OSHA action level of 0.1 f/cm^3, 8-hour TWA. The maximum estimated 8-hour TWA exposure concentration (0.093 f/cm^3, 8-hour TWA) was measured at Site 11A. On July 20, 1990, OSHA proposed to lower the permissible exposure limit to 0.1 f/cm^3 (55 CFR 29722).

TABLE 7. TOTAL FIBER CONCENTRATIONS DURING BUFFING OF RESILIENT FLOOR TILE (AS MEASURED BY PCM)

Site	Total Fiber Concentration, f/cm^3
1A	0.033
1B	0.034
2A	0.078
3A	0.077
3B	0.076
4A	0.024
5A[a]	-
6A	0.130
6B[a]	-
7A	0.048
7B[a]	-
8A[a]	-
8B[a]	-
9A	0.030
10A	0.133
10B	0.061
11A	0.295
11B	0.065
12A	0.067
12B	0.070
13A	0.085
13B	0.220
14A	0.042
15A	0.076
16A	0.080
16B	0.104
17A	0.027
17B	0.055

[a] Samples were all too heavily loaded with particulate to count.

Paired TEM and PCM Analyses

Four of the personal breathing zone samples collected for PCM analysis were also analyzed by TEM. Table 8 presents the concentrations associated with these paired analyses. The PCM concentrations were higher than the corresponding TEM concentrations in two of the four samples; the TEM concentrations were higher in the other two samples. Typically, concentrations determined by TEM are consistently higher than those determined by PCM, primarily because of the inability of PCM to detect fibers less than 5 µm in length and less than 0.25 µm in width. Because PCM analysis does not distinguish asbestos fibers from nonasbestos fibers and the TEM concentrations are based solely on asbestos structures, finding higher levels with PCM than with TEM is not unreasonable. This is especially true if the sample's environment was fraught with settled particulate and debris.

TABLE 8. PAIRED PCM AND TEM ANALYSES FOR SELECTED SAMPLES

	Concentration	
Sample Number	PCM, f/cm³	TEM, s/cm³
06A-01D2	0.130	0.277
11A-01D2	0.295	0.178
13A-01D2	0.085	0.262
16A-01D2	0.080	0.005

Characterization of Bulk Floor Tile Surface

The bulk samples of floor tile collected at each site to confirm the presence and approximate percentage of asbestos content were also analyzed by scanning electronic microscopy (SEM). Portions of a freshly fractured edge of each bulk sample were carbon coated and analyzed by SEM to examine the condition of the floor tile surface and to confirm the asbestos content determined by PLM. Surface conditions varied from extremely pitted with large numbers of asbestos bundles exposed on the surface (Figure 2) to excellent (i.e., no pitting or exposed asbestos

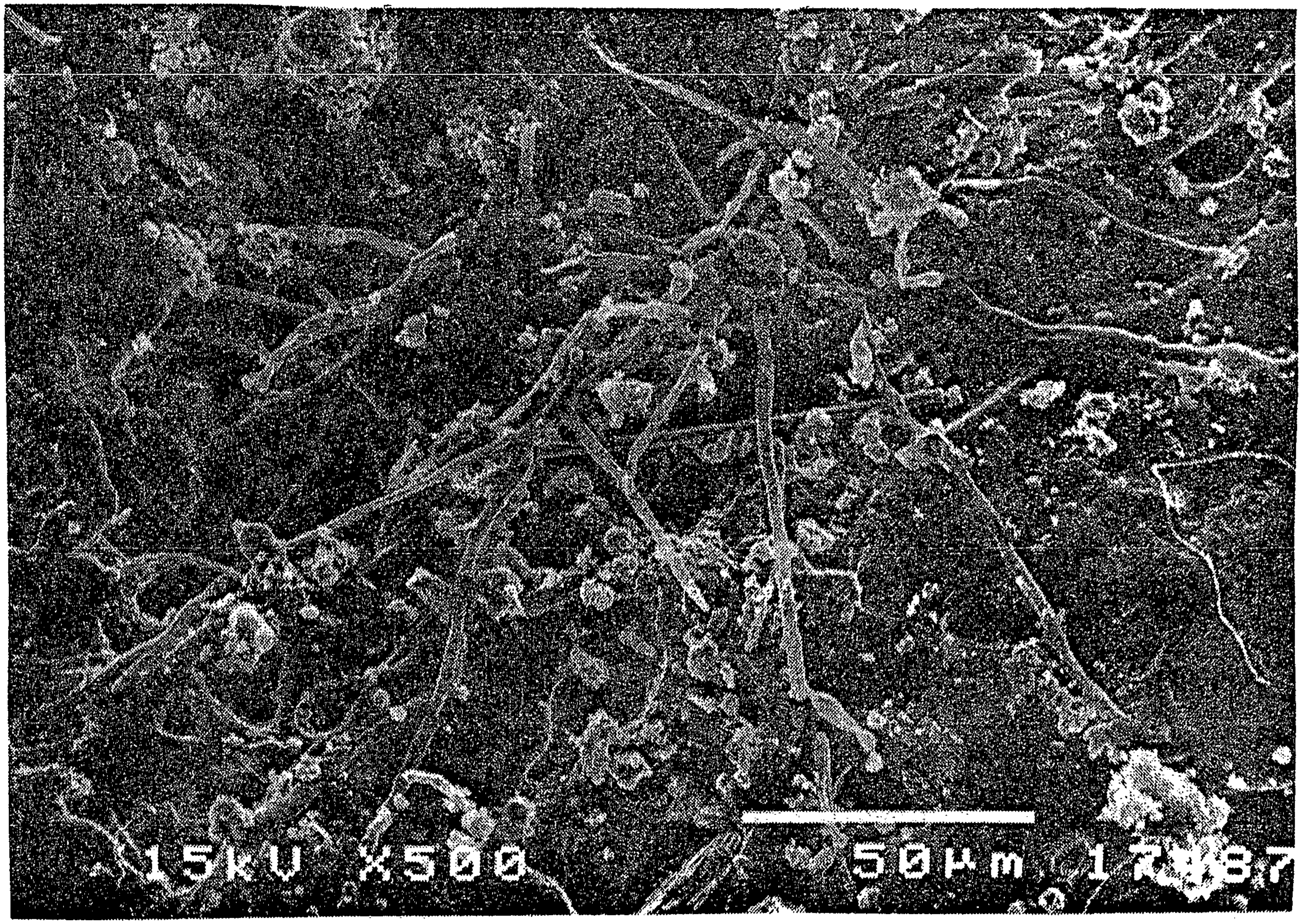

Figure 2. Scanning electron micrograph of bulk floor tile surface from an area in poor condition. The surface of the tile is coarsely pitted and covered by exposed asbestos bundles. Original magnification = 500X.

fibers) condition (Figure 3). The wax coating on the surface of the floor tile could be characterized as having a sponge-like or honeycomb appearance due to the presence of circular pores of varying diameters (Figure 3). Energy dispersive x-ray analysis (EDXA) of the bulk floor tile samples revealed a tile matrix characterized by a distinct chlorine peak and the presence of titanium and other metallic elements commonly used in the formulation of pigments.

Characterization of Surficial Asbestos Structures

Surface samples were collected from some of the floor tile before and after spray-buffing by using a proprietary tape-lift sampling method developed by the R. J. Lee Group, Inc., and analyzed by TEM. The tape-lift samples provide a record of the surficial material which was easily removable from the floor tile prior to buffing. One advantage of this sampling protocol is that no solvents are used which could dissolve or otherwise alter the vinyl or asphalt floor tile matrix. Figure 4 illustrates a typical tape-lift sample collected from floor tile before spray-buffing. The structures resembled a web-like network of surface wax material similar to the surface seen in the bulk samples analyzed by SEM. The edges of the pores are readily visible, and the wax matrix between the pores contains large numbers of asbestos-containing structures with sizes ranging from less than 1 µm to several micrometers in length. These networks often extended over several grid openings representing structures that approached 0.2 to 0.5 mm in length. Particulate structures embedded in the matrices were analyzed by energy dispersive x-ray analysis. The majority of particles containing asbestos displayed matrix materials similar to the bulk floor tile samples. Some particles produced EDXA spectra containing large amounts of calcium and/or calcium sulfate, probably due to either cementitious mortar or gypsum binders from a non-tile source which had become entrapped in the wax.

Morphology and Size Distributions of Asbestos Structures

The TEM analysis of the 163 air samples collected before and during spray-buffing yielded a total of 4598 asbestos structures, of which more than 99 percent

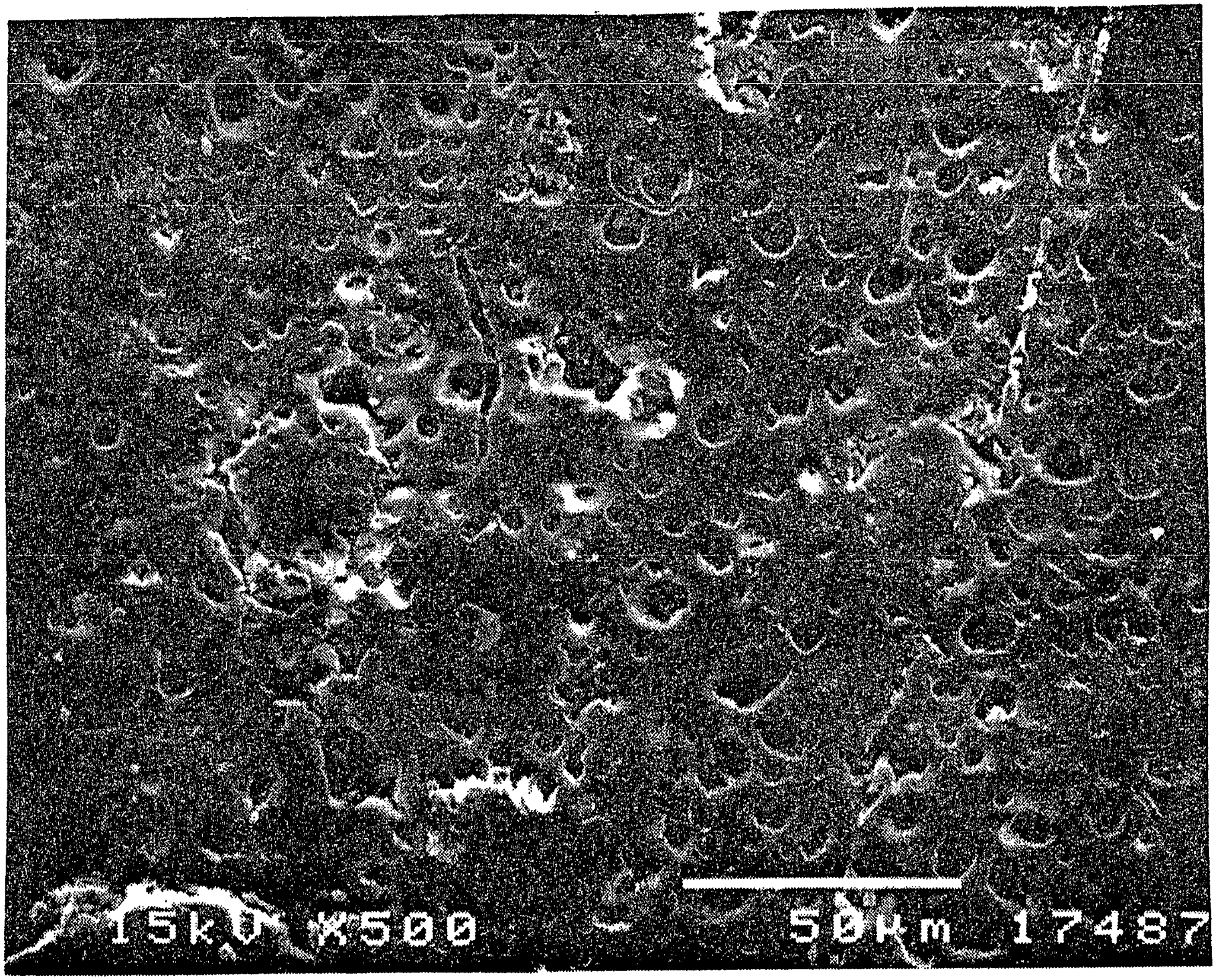

Figure 3. Scanning electron micrograph of a bulk floor tile surface from an area in good condition. The surface of the tile is covered by a coat of wax penetrated by pores of varying sizes. Original magnification = 500X.

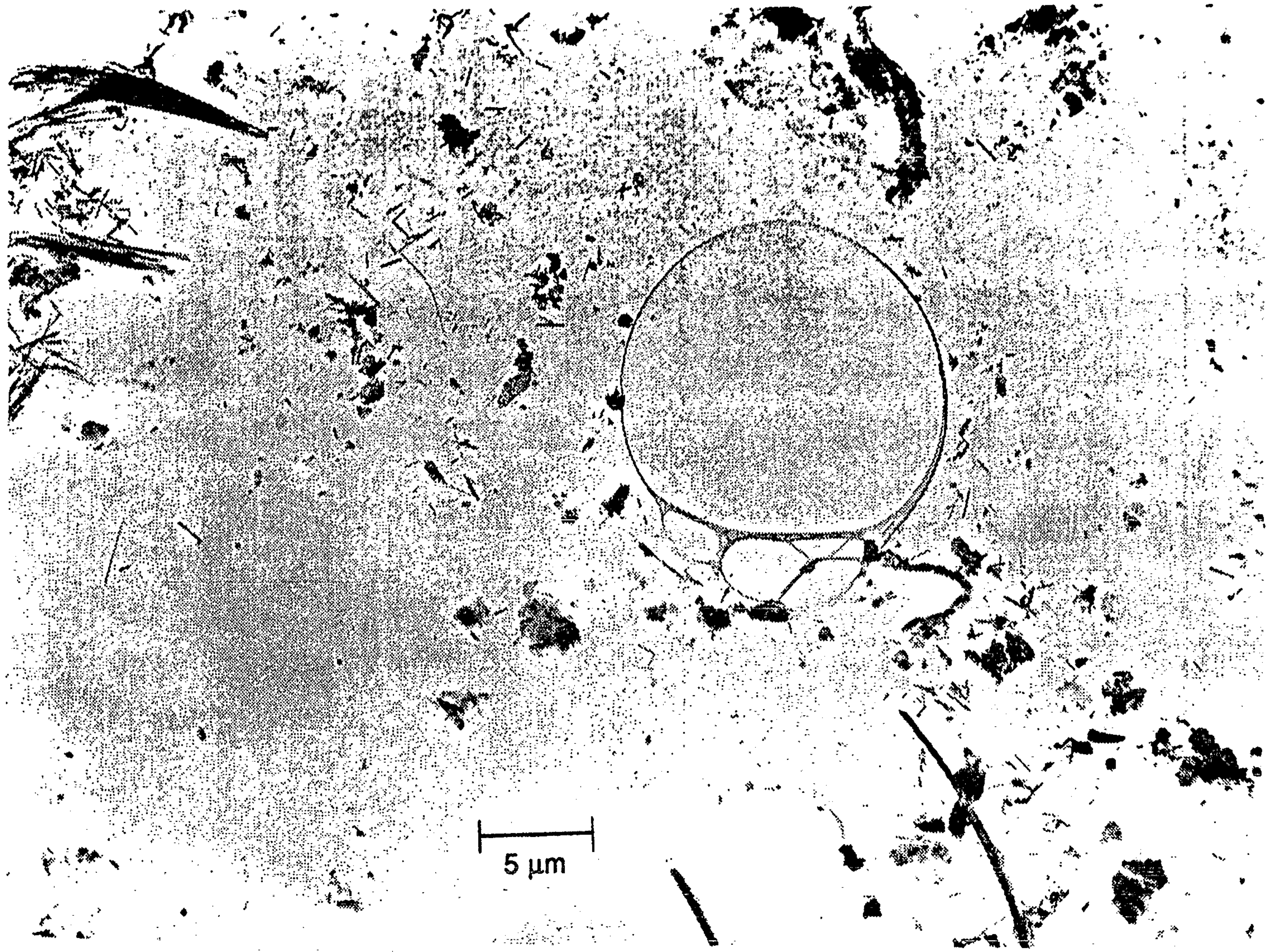

Figure 4. Transmission electron micrograph of tape lift sample taken before buffing. Circular structure in the right half of the field is a pore in the wax similar to those seen in the scanning electron microscope analysis of the bulk tile surface. Surrounding wax matrix contains large numbers of asbestos fibers, bundles, and matrices. Original magnification = 2500X.

were chrysotile and less than 1 percent were amphibole. This proportion of chrysotile and amphibole existed both before and during spray-buffing. The asbestos in nearly all floor tiles is chrysotile. Table 9 summarizes the overall structure morphology distribution separately for each sampling period. Overall, the asbestos structures were primarily matrices (approximately 80 percent) and to a lesser extent, fibers, clusters, and bundles. (Appendix B presents a summary of the structure morphology distributions observed at each study site.)

TABLE 9. OVERALL DISTRIBUTION OF ASBESTOS STRUCTURES MEASURED BEFORE AND DURING BUFFING OF RESILIENT FLOOR TILE (PERCENTAGES)

	Type of Asbestos		Structure Morphology			
Sampling Period	Chrysotile	Amphibole	Fibers	Bundles	Clusters	Matrices
Baseline	99.8	0.2	9.3	2.1	4.2	84.4
During Buffing	99.7	0.3	18.8	1.6	2.5	77.1

Table 10 presents the structure morphology distribution separately for each machine speed and sampling period (i.e., baseline and during spray-buffing). The structure morphology for asbestos structures observed before (i.e., baseline) low-speed buffing was comparable to that observed during low-speed buffing. That is, similar percentages of fibers, bundles, clusters, and matrices were observed both before and during low-speed buffing. The structure morphologies for asbestos structures observed during high-speed buffing, however, were distinctly different. The morphologies for asbestos structures observed during high-speed buffing showed that the percentage of asbestos fibers observed during high-speed buffing was approximately 2.5 times greater than the percentage of fibers observed before buffing. In contrast, the percentage of asbestos matrices were greater before high-speed buffing than during buffing. One possible explanation for a decrease in the number of asbestos matrices during buffing is that the high speed buffing pulverizes any asbestos-containing particles lying on the surface of the floor and/or any particles contained in the wax layer on the floor tile. This could also explain the increase in the percentage of asbestos fibers during high speed buffing. Another possible explanation for the increase in the percentage of asbestos fibers during high-speed buffing could be the abrasion of surficial fibers from the floor tile.

TABLE 10. DISTRIBUTION OF ASBESTOS STRUCTURES MEASURED BEFORE AND DURING LOW AND HIGH SPEED BUFFING OF RESILIENT FLOOR TILE (PERCENTAGES)

		Type of Asbestos		Structure Morphology			
Machine Speed	Sampling Period	Chrysotile	Amphibole	Fibers	Bundles	Clusters	Matrices
Low	Baseline	99.8	0.20	8.9	1.8	4.5	84.8
	During Buffing	99.9	0.10	12.3	1.3	2.0	84.4
High	Baseline	100	0	10.2	3.1	3.4	83.4
	During Buffing	99.6	0.40	25.5	1.9	3.0	69.6

Figure 5 illustrates a typical airborne asbestos-containing matrix observed during buffing. In general, the airborne matrices had an appearance similar to the bulk floor tile surface and the tape-lift samples, but much smaller in size. This observation appears to support the possibility that the buffing activity caused a mechanical shearing of the surface material and consequent release of the surface material into the surrounding air.

Table 11 presents the overall cumulative size distributions of asbestos structures in the air before and during spray-buffing. Overall, there does not appear to be any significant difference in the cumulative size distributions before and during buffing. Table 12 presents the overall structure size and fiber size distributions separately for each machine speed and sampling period. Overall, less than 1 percent of the asbestos fibers measured before and during were greater than 5 μm in length.

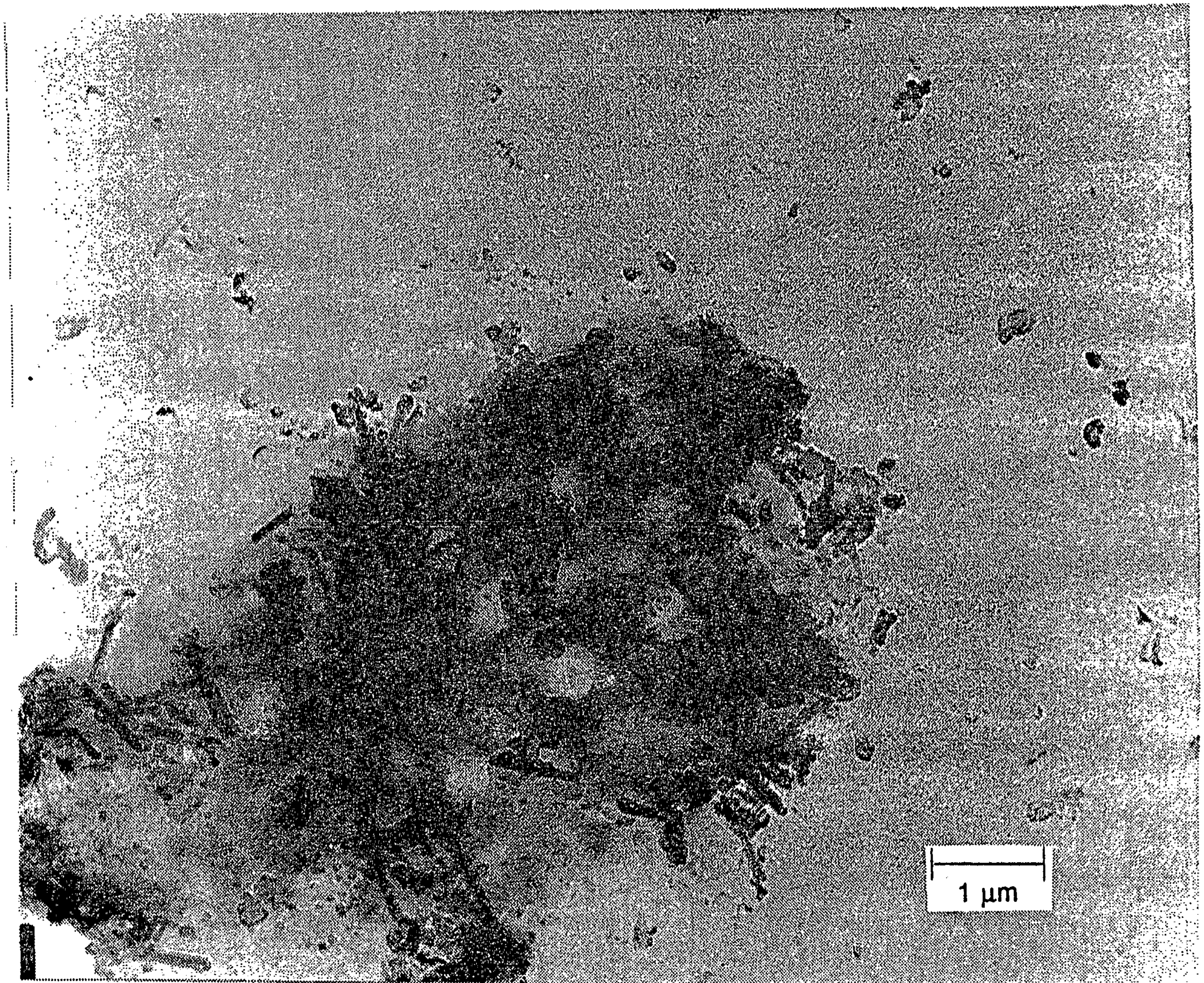

Figure 5. Airborne matrix observed on a sample collected during buffing. Note the pores present in the matrix as well as the entrapped asbestos fibers and matrices. Structure is similar in morphology to tape lift sample, only reduced in size. Transmission electron micrograph, original magnification = 20,000X.

TABLE 11. CUMULATIVE SIZE DISTRIBUTION OF ASBESTOS STRUCTURES MEASURED BEFORE AND DURING BUFFING OF RESILIENT FLOOR TILE (CUMULATIVE PERCENTAGES)

	Structure Length, µm					
Sampling Period	≤1	≤2	≤3	≤4	≤5	≤10
Baseline	34.7	49.4	59.3	64.4	71.0	89.8
During Buffing	40.2	52.8	61.3	65.7	71.2	88.2

TABLE 12. SIZE DISTRIBUTION OF ASBESTOS STRUCTURES MEASURED BEFORE AND DURING LOW AND HIGH SPEED BUFFING (PERCENTAGES)

		Structure length, µm			Fiber length, µm		
Machine Speed	Sampling Period	≤1	≤5	>5	≤1	≤5	>5
Low	Baseline	35	68	32	84	100	0
	During Buffing	32	66	34	80	100	0
High	Baseline	34	80	29	70	97	3
	During Buffing	49	77	23	94	100	0

Although Table 12 shows comparable structure morphologies before and during low-speed buffing, the structure morphologies for high-speed buffing were different for structures less than 1 µm in length. Specifically, a larger percentage of the structures observed during high-speed buffing were less than 1 µm compared to structures observed before high-speed buffing. The increased number of structures less than 1 µm in length could be due to (1) the pulverization of asbestos structures on the floor surface and/or asbestos structures contained in the wax layer, and/or (2) the abrasion of surficial fibers from the floor tile.

Appendix C presents the cumulative size distributions measured at each study site. Appendix D contains a series of particle graphs showing the structure lengths and widths measured at each study site. Each particle graph contains a "PCM window" that delineates the area on the graph where structures would be large enough to be detected by PCM.

Particulate Loading on Filters

Twenty of the 194 samples were heavily loaded with particulate matter. Five of the 28 personal breathing zone samples analyzed by PCM and three of the 166 samples analyzed by TEM were too heavily loaded to count. Four personal breathing zone samples analyzed by PCM were counted despite having graticulate fields with more than 1/6 of the field covered by particulate; eight of the personal breathing zone samples analyzed by TEM were counted despite having grid openings with more than 25 percent of the opening covered by particulate matter. Excessive particulate loading on filters results in overlapping structures that were likely individual structures in the air, but are counted as single structures according to AHERA nonmandatory TEM Method and NIOSH 7400 counting rules. Hence, on overloaded samples, the resulting concentrations could actually be underestimating the true airborne asbestos level.

The four personal breathing zone samples that were analyzed by PCM despite having graticulate fields with slightly more than 1/6 of the field covered by particulate showed total fiber concentrations ranging from 0.048 to 0.133 f/cm^3. The corresponding estimated 8-hour TWA concentrations ranged from 0.015 to 0.042 f/cm^3. Although these concentrations are below the OSHA action level (0.1 f/cm^3), they should be considered the minimum exposure concentrations during spray-buffing for these workers and an underestimation of the true levels.

The eight TEM samples having grid openings with more than 25 percent of the opening covered by particulate matter were all samples collected during buffing. The samples were collected at five different sites, all of which showed elevated airborne asbestos concentrations during spray-buffing. Therefore, if the measured levels underestimate the actual airborne concentrations during buffing at these sites, then the relative magnitude of the increase may also be underestimated.

Appendix E contains information on the degree of overloading for each of the samples collected during this study. The percentage of particulate in each grid opening is estimated for each of the samples.

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APPENDIX A. INDIVIDUAL AIRBORNE ASBESTOS CONCENTRATIONS (DETERMINED BY TEM) BEFORE AND DURING BUFFING OF ASBESTOS-CONTAINING RESILIENT FLOOR TILE

Site Number	Sample Number	Sampling Period	Concentration, s/cm^2
1A	01A-01D	During Buffing	0.019
1A	01A-02D	During Buffing	0.014
1A	01A-03D	During Buffing	0.010
1A	01A-01B	Baseline	0.009
1A	01A-02B	Baseline	0.005
1A	01A-03B	Baseline	0
1B	01B-01D	During Buffing	0.015
1B	01B-02D	During Buffing	0.019
1B	01B-03D	During Buffing	0.005
1B	01B-01B	Baseline	0
1B	01B-02B	Baseline	0
1B	01B-03B	Baseline	0.005
2A	02A-01D	During Buffing	0
2A	02A-02D	During Buffing	0.005
2A	02A-02DR	Replicate of 02A-02D	0.024
2A	02A-03D	During Buffing	0.005
2A	02A-01B	Baseline	0
2A	02A-02B	Baseline	0.010
2A	02A-03B	Baseline	0.010
3A	03A-01D	During Buffing	0.025
3A	03A-02D	During Buffing	0.010
3A	03A-03D	During Buffing	0
3A	03A-01B	Baseline	0
3A	03A-02B	Baseline	0.005
3A	03A-03B	Baseline	0
3B	03B-01D	During Buffing	0
3B	03B-02D	During Buffing	0.009
3B	03B-03D	During Buffing	0
3B	03B-01B	Baseline	0
3B	03B-02B	Baseline	0
3B	03B-03B	Baseline	0
4A	04A-01D	During Buffing	0
4A	04A-02D	During Buffing	0
4A	04A-01B	Baseline	0
4A	04A-02B	Baseline	0
4A	04A-03B	Baseline	0
4A	04A-03BR	Replicate of 04A-03B	0

(continued)

APPENDIX A (continued)

Site Number	Sample Number	Sampling Period	Concentration, s/cm²
5A	05A-01D	During Buffing	0.088
5A	05A-02D	During Buffing	0.123
5A	05A-03D	During Buffing	0.112
5A	05A-03DD	Duplicate Analysis of 05A-03D	0.151
5A	05A-01B	Baseline	0.014
5A	05A-02B	Baseline	0.010
5A	05A-03B	Baseline	0.005
6A	06A-01D	During Buffing	0.124
6A	06A-02D	During Buffing	0.302
6A	06A-03D	During Buffing	0.065
6A	06A-03DR	Replicate of 06A-03DR	0.093
6A	06A-01B	Baseline	0.076
6A	06A-02B	Baseline	0
6A	06A-03B	Baseline	0.015
6B	06B-01D	During Buffing	0.291
6B	06B-02D	During Buffing	0.137
6B	06B-03D	During Buffing	0.189
6B	06B-01B	Baseline	0.018
6B	06B-02B	Baseline	0.015
6B	06B-03B	Baseline	0.053
7A	07A-01D	During Buffing	0.161
7A	07A-02D	During Buffing	0.179
7A	07A-03D	During Buffing	0.097
7A	07A-01B	Baseline	0
7A	07A-02B	Baseline	0
7A	07A-03B	Baseline	0.010
7B	07B-01D	During Buffing	0.400
7B	07B-02D	During Buffing	0.379
7B	07B-03D	During Buffing	0.464
7B	07B-01B	Baseline	0.005
7B	07B-02B	Baseline	0.005
7B	07B-03B	Baseline	0.014
7B	07B-03BR	Replicate of 07B-03B	0.005
8A	08A-01D	During Buffing	0.030
8A	08A-02D	During Buffing	0.030
8A	08A-03D	During Buffing	0.015
8A	08A-01B	Baseline	0.005
8A	08A-02B	Baseline	0.010

(continued)

APPENDIX A (continued)

Site Number	Sample Number	Sampling Period	Concentration, s/cm²
8A	08A-03B	Baseline	0.020
8B	08B-01B	Baseline	0.103
8B	08B-01BD	Duplicate Analysis of 08B-01B	0.054
8B	08B-02B	Baseline	0
8B	08B-03B	Baseline	0.020
9A	09A-01D	During Buffing	0
9A	09A-02D	During Buffing	0.009
9A	09A-02DR	Replicate of 09A-02D	0.005
9A	09A-03D	During Buffing	0
9A	09A-01B	Baseline	0
9A	09A-02B	Baseline	0.020
9A	09A-03B	Baseline	0.010
10A	10A-01D	During Buffing	0.094
10A	10A-02D	During Buffing	0.033
10A	10A-03D	During Buffing	0.076
10A	10A-01B	Baseline	0.005
10A	10A-02B	Baseline	0
10A	10A-03B	Baseline	0.254
10A	10A-03BD	Duplicate Analysis of 10A-03B	0.297
10B	10B-01D	During Buffing	0.035
10B	10B-02D	During Buffing	0.029
10B	10B-03D	During Buffing	0.034
10B	10B-01B	Baseline	0.030
10B	10B-02B	Baseline	0.040
10B	10B-03B	Baseline	0.045
11A	11A-01D	During Buffing	0.097
11A	11A-03D	During Buffing	0.015
11A	11A-01B	Baseline	0.053
11A	11A-02B	Baseline	0.020
11A	11A-02BR	Replicate of 11A-02B	0.010
11A	11A-03B	Baseline	0.025
11B	11B-01D	During Buffing	0.075
11B	11B-02D	During Buffing	0.090
11B	11B-03D	During Buffing	0.067
11B	11B-01B	Baseline	0.069
11B	11B-02B	Baseline	0.015
11B	11B-03B	Baseline	0.005

(continued)

APPENDIX A (continued)

Site Number	Sample Number	Sampling Period	Concentration, s/cm^2
12A	12A-01D	During Buffing	0.113
12A	12A-02D	During Buffing	0.047
12A	12A-03D	During Buffing	0.043
12A	12A-03DR	Replicate of 12A-03D	0.052
12A	12A-01B	Baseline	0.014
12A	12A-02B	Baseline	0.009
12A	12A-03B	Baseline	0.014
12B	12B-01D	During Buffing	0.062
12B	12B-02D	During Buffing	0.150
12B	12B-03D	During Buffing	0.075
12B	12B-01B	Baseline	0.054
12B	12B-02B	Baseline	0.113
12B	12B-03B	Baseline	0.029
13A	13A-01D	During Buffing	0.206
13A	13A-02D	During Buffing	0.015
13A	13A-03D	During Buffing	0.025
13A	13A-01B	Baseline	0.040
13A	13A-02B	Baseline	0
13A	13A-03B	Baseline	0.005
13B	13B-01D	During Buffing	0.225
13B	13B-01DR	Replicate of 13B-01D	0.245
13B	13B-02D	During Buffing	0.329
13B	13B-03D	During Buffing	0.318
13B	13B-01B	Baseline	0.051
13B	13B-02B	Baseline	0.143
13B	13B-03B	Baseline	0.390
14A	14A-01D	During Buffing	0.050
14A	14A-02D	During Buffing	0.020
14A	14A-03D	During Buffing	0.087
14A	14A-01B	Baseline	0.005
14A	14A-02B	Baseline	0.005
14A	14A-03B	Baseline	0.010
15A	15A-01D	During Buffing	0.102
15A	15A-02D	During Buffing	0.216
15A	15A-03D	During Buffing	0.135
15A	15A-01B	Baseline	0.098
15A	15A-02B	Baseline	0.126
15A	15A-03B	Baseline	0.058

(continued)

APPENDIX A (continued)

Site Number	Sample Number	Sampling Period	Concentration, s/cm^2
16A	16A-01D	During Buffing	0
16A	16A-01DR	Replicate of 16A-01D	0
16A	16A-02D	During Buffing	0
16A	16A-03D	During Buffing	0.004
16A	16A-01B	Baseline	0.005
16A	16A-02B	Baseline	0
16A	16A-03B	Baseline	0
16B	16B-01D	During Buffing	0
16B	16B-02D	During Buffing	0
16B	16B-03D	During Buffing	0
16B	16B-01B	Baseline	0
16B	16B-02B	Baseline	0.005
16B	16B-03B	Baseline	0.005
17A	17A-01D	During Buffing	0.059
17A	17A-02D	During Buffing	0.052
17A	17A-03D	During Buffing	0.057
17A	17A-01B	Baseline	0
17A	17A-02B	Baseline	0
17A	17A-03B	Baseline	0.005
17B	17B-01D	During Buffing	0.119
17B	17B-02D	During Buffing	0.035
17B	17B-03D	During Buffing	0.189
17B	17B-01B	Baseline	0.065
17B	17B-01BR	Replicate of 17B-01B	0.085
17B	17B-02B	Baseline	0.061
17B	17B-03B	Baseline	0.024
17B	17B-03BD	Duplicate Analysis of 17B-03B	0.038

APPENDIX B. DISTRIBUTION OF AIRBORNE ASBESTOS STRUCTURES MEASURED AT EACH SCHOOL (PERCENTAGES OF TOTAL NUMBER OF ASBESTOS STRUCTURES)

Sample Type	Type of Asbestos		Structure Morphology			
	Chrysotile	Amphibole	Fibers	Bundles	Clusters	Matrices
Site 1A						
Baseline (N=7)	100	0	14.3	0	0	85.7
During Buffing (N=10)	100	0	80	0	0	20
Site 1B						
Baseline (N=2)	100	0	0	0	0	100
During Buffing (N=8)	100	0	75	25	0	0
Site 2A						
Baseline (N=5)	100	0	60	0	0	40
During Buffing (N=2)	100	0	100	0	0	0
Site 3A						
Baseline (N=2)	100	0	0	0	0	100
During Buffing (N=18)	100	0	22.2	0	27.8	50
Site 3B						
Baseline (N=0)	0	0	0	0	0	0
During Buffing (N=2)	100	0	100	0	0	0
Site 4A						
Baseline (N=0)	0	0	0	0	0	0
During Buffing (N=0)	0	0	0	0	0	0
Site 5A						
Baseline (N=7)	100	0	71.4	0	0	28.6
During Buffing (N=245)	98.4	1.6	15.9	2.0	0.8	81.2
Site 6A						
Baseline (N=54)	100	0	3.7	1.9	9.3	85.2
During Buffing (N=291)	99.7	0.3	18.6	1	1	79.4
Site 6B						
Baseline (N=59)	100	0	8.5	0	0	91.5
During Buffing (N=376)	99.5	0.5	12.8	3.5	2.7	81.1

(continued)

APPENDIX B (continued)

Sample Type	Type of Asbestos		Structure Morphology			
	Chrysotile	Amphibole	Fibers	Bundles	Clusters	Matrices
Site 7A						
Baseline (N=3)	100	0	33.3	0	0	66.7
During Buffing (N=143)	100	0	51	0	1.4	47.6
Site 7B						
Baseline (N=9)	100	0	22.2	11.1	0	66.7
During Buffing (N=430)	100	0	44	1.4	7.7	47
Site 8A						
Baseline (N=13)	100	0	30.8	7.7	0	61.5
During Buffing (N=48)	97.9	2.1	18.8	4.2	0	77.1
Site 8B						
Baseline (N=59)	98.3	1.7	15.3	3.4	18.6	62.7
During Buffing[a]	-	-	-	-	-	-
Site 9A						
Baseline (N=8)	100	0	50	12.5	0	37.5
During Buffing (N=4)	100	0	25	0	0	75
Site 10A						
Baseline (N=116)	100	0	12.1	6.0	3.4	78.4
During Buffing (N=124)	100	0	5.6	1.6	0	92.7
Site 10B						
Baseline (N=68)	100	0	4.4	1.5	2.9	91.2
During Buffing (N=53)	100	0	9.4	1.9	0	88.7
Site 11A						
Baseline (N=48)	100	0	2.1	2.1	12.5	83.3
During Buffing (N=111)	100	0	6.3	0	0	93.7
Site 11B						
Baseline (N=51)	100	0	5.9	0	7.8	86.3
During Buffing (N=146)	100	0	8.2	0.7	3.4	87.7

(continued)

APPENDIX B (continued)

Sample Type	Type of Asbestos		Structure Morphology			
	Chrysotile	Amphibole	Fibers	Bundles	Clusters	Matrices
Site 12A						
Baseline (N=25)	100	0	4.0	8.0	0	88.0
During Buffing (N=149)	100	0	7.4	2	4.0	86.6
Site 12B						
Baseline (N=102)	100	0	11.8	0	4.9	83.3
During Buffing (N=183)	100	0	5.5	1.6	4.9	88
Site 13A						
Baseline (N=32)	100	0	0	3.1	3.1	93.7
During Buffing (N=165)	99.4	0.6	7.3	0.6	0	92.1
Site 13B						
Baseline (N=273)	99.6	0.4	7.3	1.1	1.5	90.1
During Buffing (N=425)	100	0	14.8	1.6	0.5	83.1
Site 14A						
Baseline (N=20)	100	0	0	0	0	100
During Buffing (N=74)	100	0	18.9	0	2.7	78.4
Site 15A						
Baseline (N=132)	100	0	4.5	3.0	5.3	87.1
During Buffing (N=205)	100	0	20.5	1.5	2.9	75.1
Site 16A						
Baseline (N=1)	100	0	100	0	0	0
During Buffing (N=3)	100	0	0	0	0	100
Site 16B						
Baseline (N=4)	100	0	0	0	0	100
During Buffing (N=0)	0	0	0	0	0	0
Site 17A						
Baseline (N=3)	100	0	0	0	0	100
During Buffing (N=70)	100	0	20	0	0	80

(continued)

APPENDIX B (continued)

Sample Type	Type of Asbestos		Structure Morphology			
	Chrysotile	Amphibole	Fibers	Bundles	Clusters	Matrices
Site 17B						
Baseline (N=64)	100	0	17.2	0	0	82.8
During Buffing (N=146)	100	0	9.6	0.7	0	89.7

[a] The samples collected during spray-buffing were too heavily loaded with particulate to count.

APPENDIX C. CUMULATIVE SIZE DISTRIBUTIONS OF ASBESTOS STRUCTURES MEASURED BEFORE AND DURING BUFFING AT EACH SCHOOL (CUMULATIVE PERCENTAGES)

Sample Type	Structure Length, µm ≤1	≤2	≤3	≤4	≤5	≤10
Site 1A						
Baseline (N=7)	42.9	42.9	42.9	42.9	42.9	100
During Buffing (N=10)	50	70	90	90	100	100
Site 1B						
Baseline (N=5)	50	50	50	50	50	100
During Buffing (N=8)	87.5	100	100	100	100	100
Site 2A						
Baseline (N=2)	80	100	100	100	100	100
During Buffing (N=2)	100	100	100	100	100	100
Site 3A						
Baseline (N=2)	50	100	100	100	100	100
During Buffing (N=18)	55.6	72.2	77.8	83.3	83.3	100
Site 3B						
Baseline (N=0)	0	0	0	0	0	0
During Buffing (N=2)	100	100	100	100	100	100
Site 4A						
Baseline (N=0)	0	0	0	0	0	0
During Buffing (N=0)	0	0	0	0	0	0
Site 5A						
Baseline (N=7)	57.1	100	100	100	100	100
During Buffing (N=245)	36.3	46.1	51.4	55.5	61.6	82.4
Site 6A						
Baseline (N=54)	31.5	50	61.1	63.0	77.8	92.6
During Buffing (N=291)	43.6	55.3	64.9	68.7	73.5	92.4
Site 6B						
Baseline (N=59)	25.4	35.6	55.9	61.0	66.1	89.8
During Buffing (N=376)	40.4	50.8	59.0	62.0	69.1	86.4
Site 7A						
Baseline (N=3)	33.3	33.3	33.3	33.3	33.3	100
During Buffing (N=143)	65.7	75.5	83.2	86	88.8	96.5

(continued)

APPENDIX C (continued)

Sample Type	Structure Length, µm					
	≤1	≤2	≤3	≤4	≤5	≤10
Site 7B						
Baseline (N=9)	44.4	44.4	55.6	88.9	88.9	100
During Buffing (N=430)	69.5	80.7	86	88.6	90.5	96.7
Site 8A						
Baseline (N=13)	38.5	53.8	61.5	61.5	69.2	92.3
During Buffing (N=48)	25	35.4	37.5	39.6	50	66.7
Site 8B						
Baseline (N=59)	44.1	52.5	64.4	67.8	79.7	98.3
During Buffing[a]	-	-	-	-	-	-
Site 9A						
Baseline (N=8)	75	75	75	75	87.5	100
During Buffing (N=4)	0	25	50	75	75	100
Site 10A						
Baseline (N=116)	33.8	60.3	69.8	77.6	87.9	98.3
During Buffing (N=124)	26.6	46.8	55.6	63.7	76.6	93.5
Site 10B						
Baseline (N=68)	30.9	52.9	69.1	76.5	82.4	98.5
During Buffing (N=53)	26.4	50.9	67.9	69.8	75.5	92.5
Site 11A						
Baseline (N=48)	37.5	52.1	68.7	70.8	85.4	97.9
During Buffing (N=111)	22.5	31.5	48.6	55.9	68.5	85.6
Site 11B						
Baseline (N=51)	31.4	51	60.8	70.6	74.5	94.1
During Buffing (N=146)	28.8	41.1	54.8	60.3	66.4	85.6

(continued)

APPENDIX C (continued)

Sample Type	Structure Length, µm					
	≤1	≤2	≤3	≤4	≤5	≤10
Site 12A						
Baseline (N=25)	16	36	56	56	64	96
During Buffing (N=149)	23.5	32.9	46.3	51.7	59.1	86.6
Site 12B						
Baseline (N=102)	34.3	54.9	57.8	60.8	66.7	89.2
During Buffing (N=183)	23.5	36.6	48.1	57.4	63.4	85.8
Site 13A						
Baseline (N=32)	18.8	34.4	37.5	43.7	46.9	78.1
During Buffing (N=165)	28.5	44.8	48.5	52.7	57.6	84.8
Site 13B						
Baseline (N=273)	36.3	44.3	50.2	54.6	57.9	79.1
During Buffing (N=425)	36	45.9	51.3	54.6	58.6	80.2
Site 14A						
Baseline (N=20)	15	40	65	75	80	100
During Buffing (N=74)	28.4	55.4	64.9	70.3	73.0	82.4
Site 15A						
Baseline (N=132)	33.3	47.7	58.3	64.4	74.2	88.6
During Buffing (N=205)	35.6	54.1	64.9	69.8	76.6	88.8
Site 16A						
Baseline (N=1)	100	100	100	100	100	100
During Buffing (N=3)	33.3	33.3	33.3	33.3	33.3	100
Site 16B						
Baseline (N=4)	50	50	75	100	100	100
During Buffing (N=0)	0	0	0	0	0	0
Site 17A						
Baseline (N=3)	0	0	100	100	100	100
During Buffing (N=70)	54.3	64.3	70	75.7	81.4	94.3

(continued)

APPENDIX C (continued)

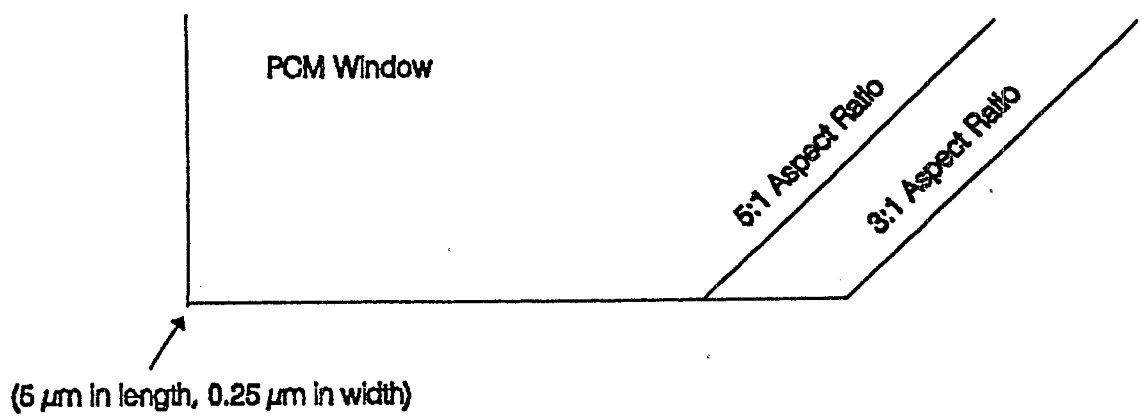
Sample Type	Structure Length, µm					
	≤1	≤2	≤3	≤4	≤5	≤10
			Site 17B			
Baseline (N=64)	37.5	51.6	60.9	64.1	64.1	85.9
During Buffing (N=146)	37.7	54.1	66.4	73.3	78.1	93.2

[a] The samples collected during spray buffing were too heavily loaded with particulate to count.

APPENDIX D

SIZE DISTRIBUTION OF ASBESTOS STRUCTURES IN AIR SAMPLES COLLECTED BEFORE AND DURING BUFFING OF ASBESTOS-CONTAINING FLOOR TILES IN EACH OF THE 28 STUDY AREAS AT 17 SITES

The figures contained in this appendix illustrate the size of the asbestos structures measured by TEM on the samples collected before and during spray-buffing. Structure lengths and widths are illustrated for each study site in Figures D-1 through D-28. Each figure contains a "PCM window" (see below) which delineates the area on the graph where structures would be large enough to be detected by PCM (i.e., structures greater than 5 μm in length and greater than 0.25 μm in width). The PCM window also shows structures with length-to-width aspect ratios of 3 to 1 and 5 to 1. These aspect ratios relate to the A and B counting rules in NIOSH Method 7400.



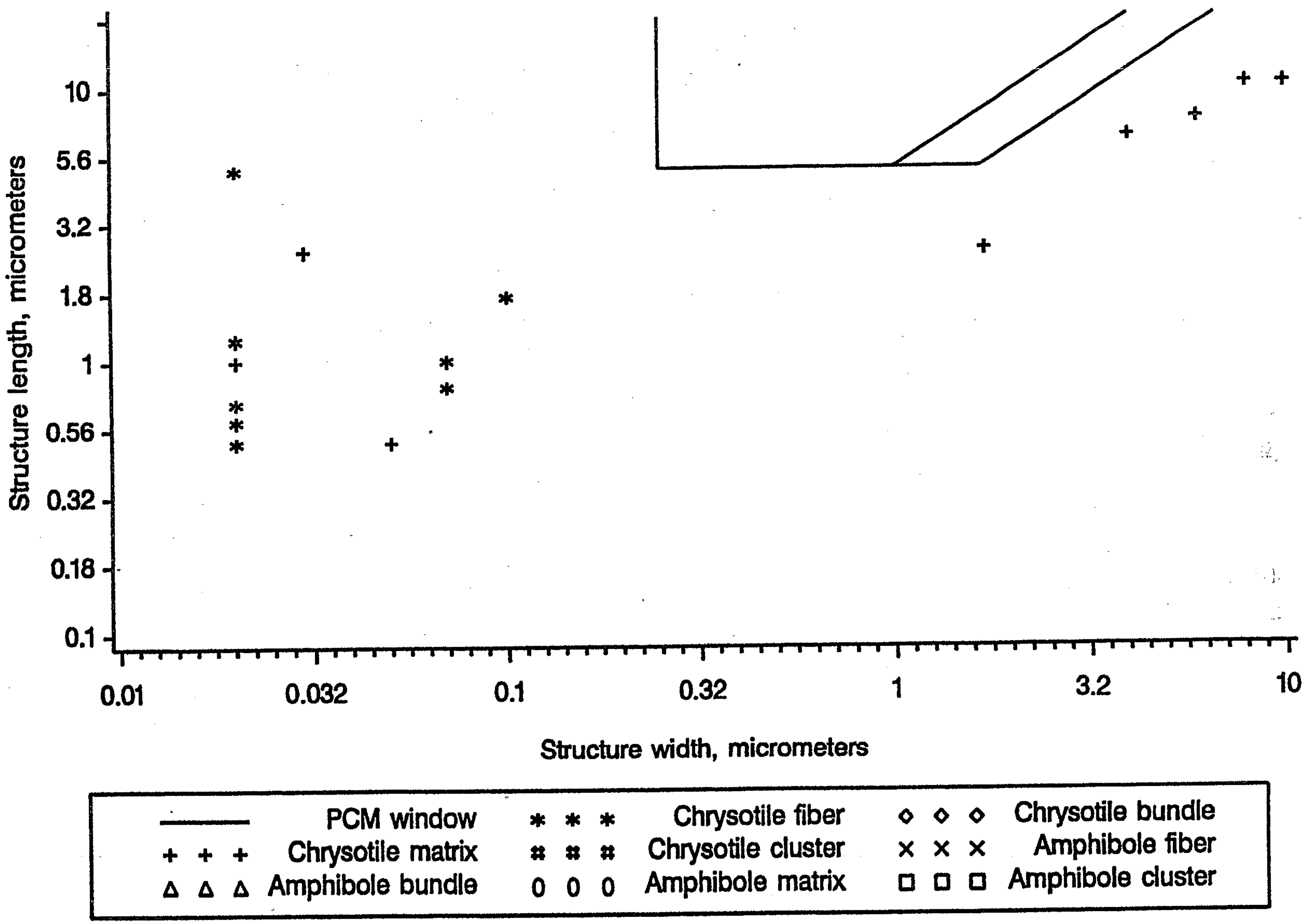


Figure D–1. Size distribution of asbestos structures in air samples collected before and during buffing of asbestos–containing floor tile at Site 1A.

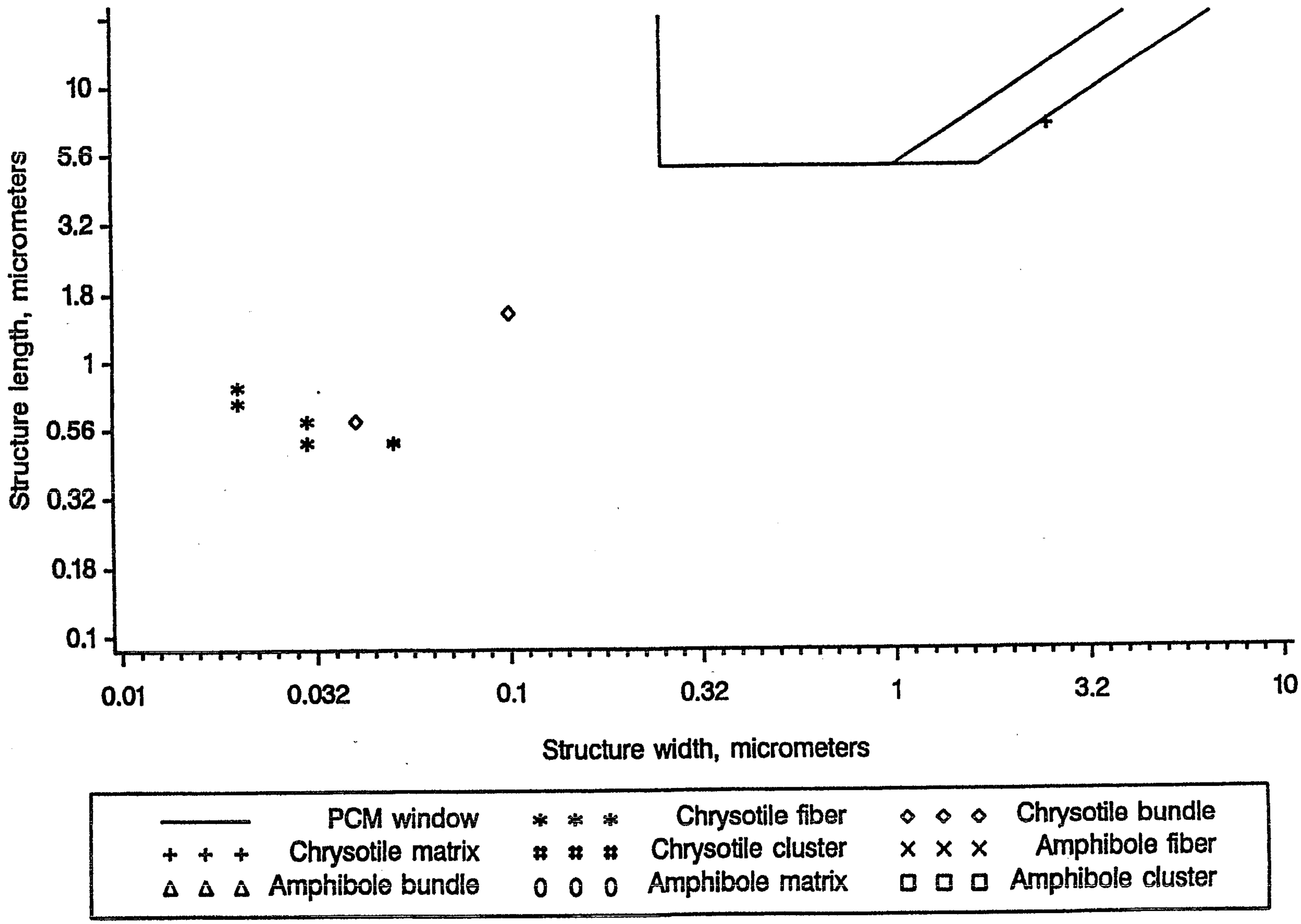


Figure D–2. Size distribution of asbestos structures in air samples collected before and during buffing of asbestos–containing floor tile at Site 1B.

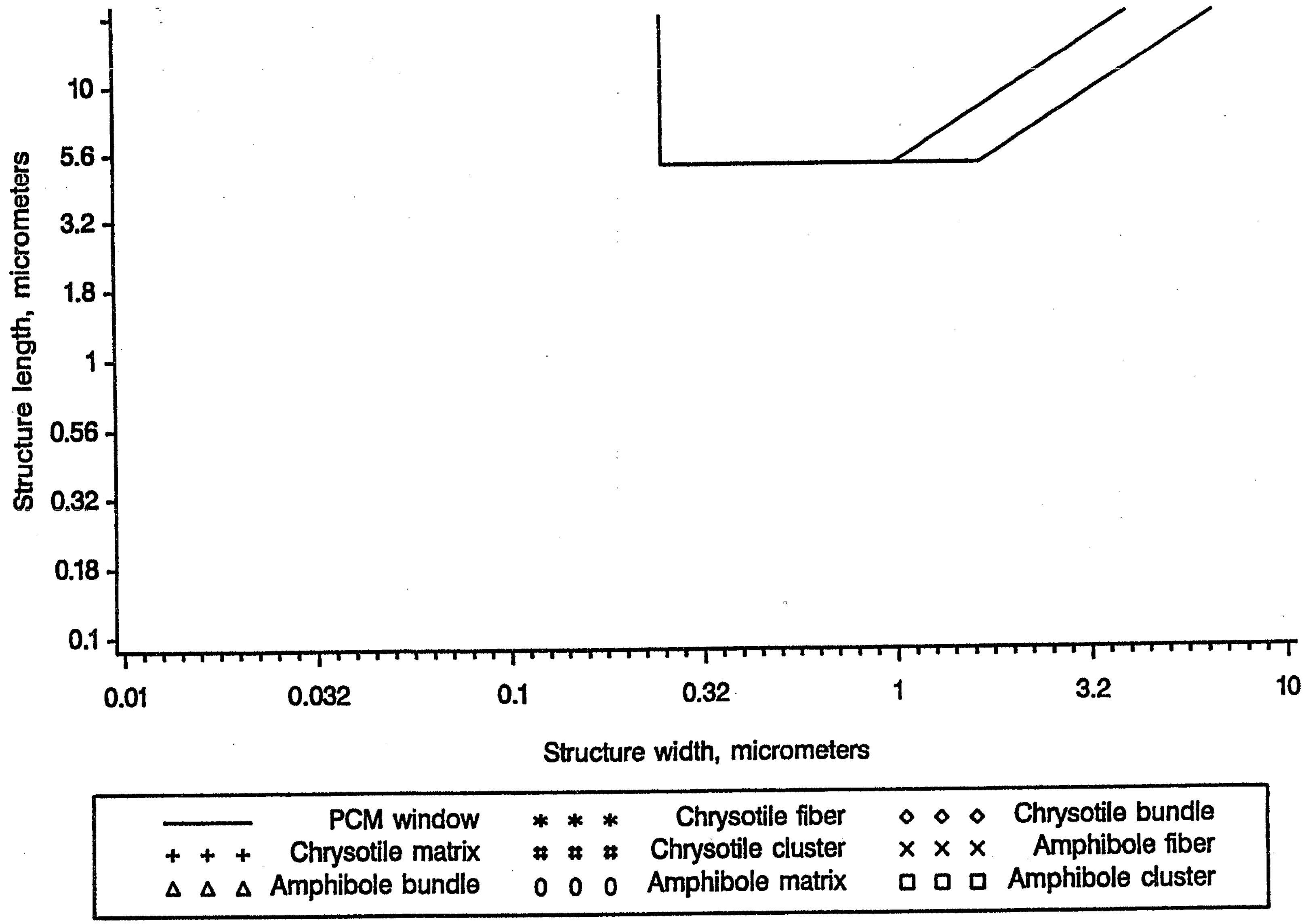


Figure D–3. Size distribution of asbestos structures in air samples collected before and during buffing of asbestos–containing floor tile at Site 2A.

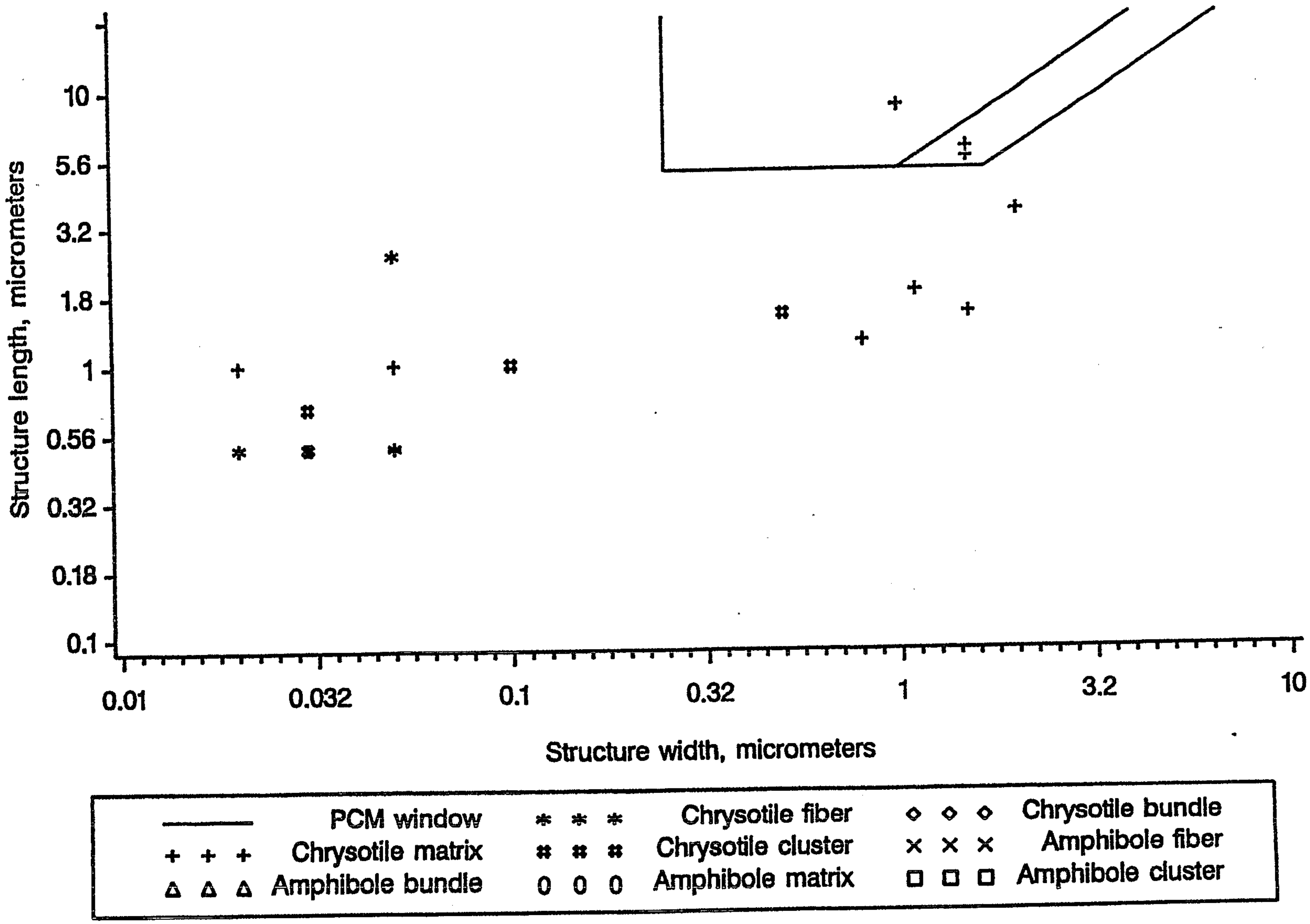


Figure D–4. Size distribution of asbestos structures in air samples collected before and during buffing of asbestos–containing floor tile at Site 3A.

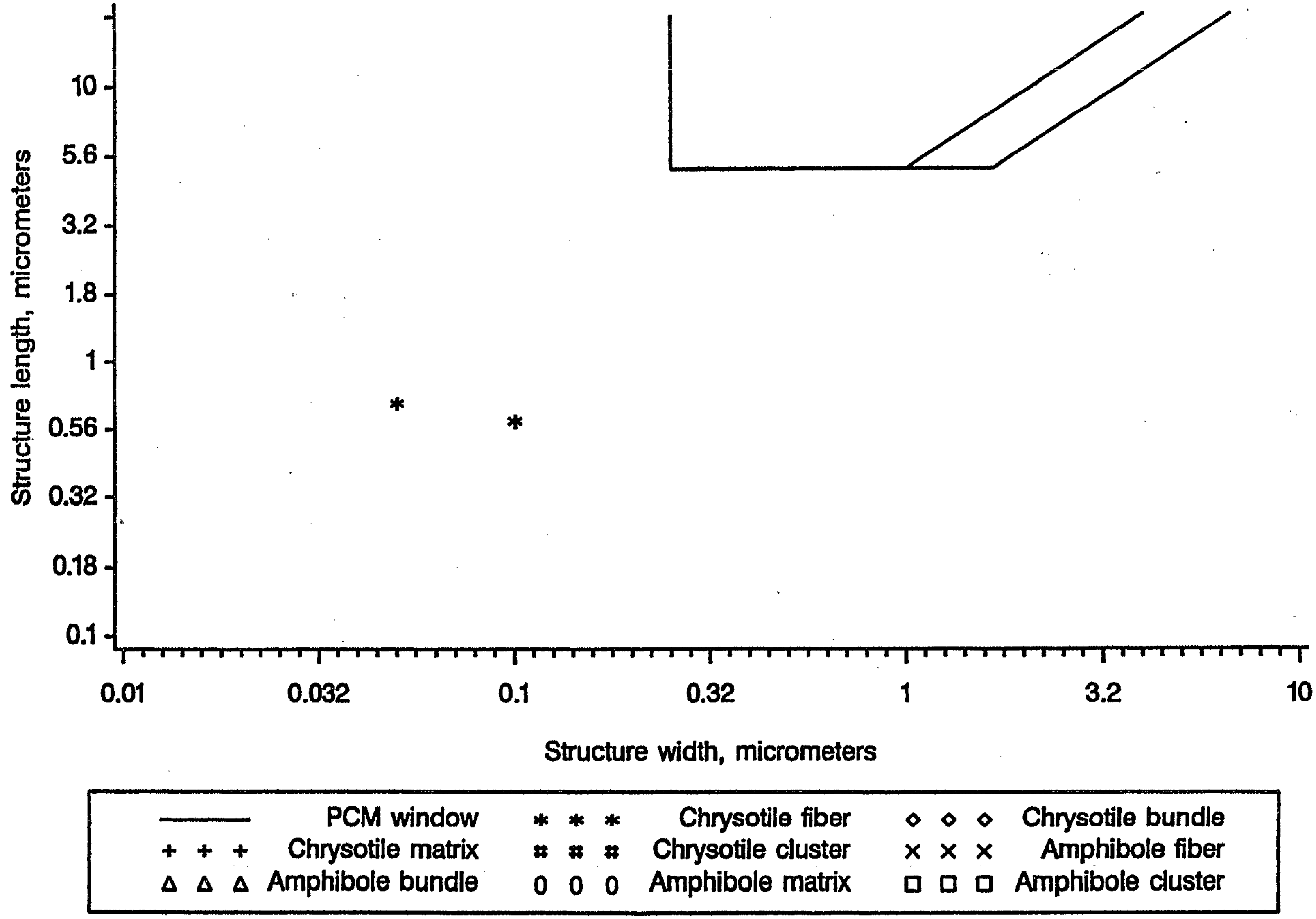


Figure D–5. Size distribution of asbestos structures in air samples collected before and during buffing of asbestos–containing floor tile at Site 3B.

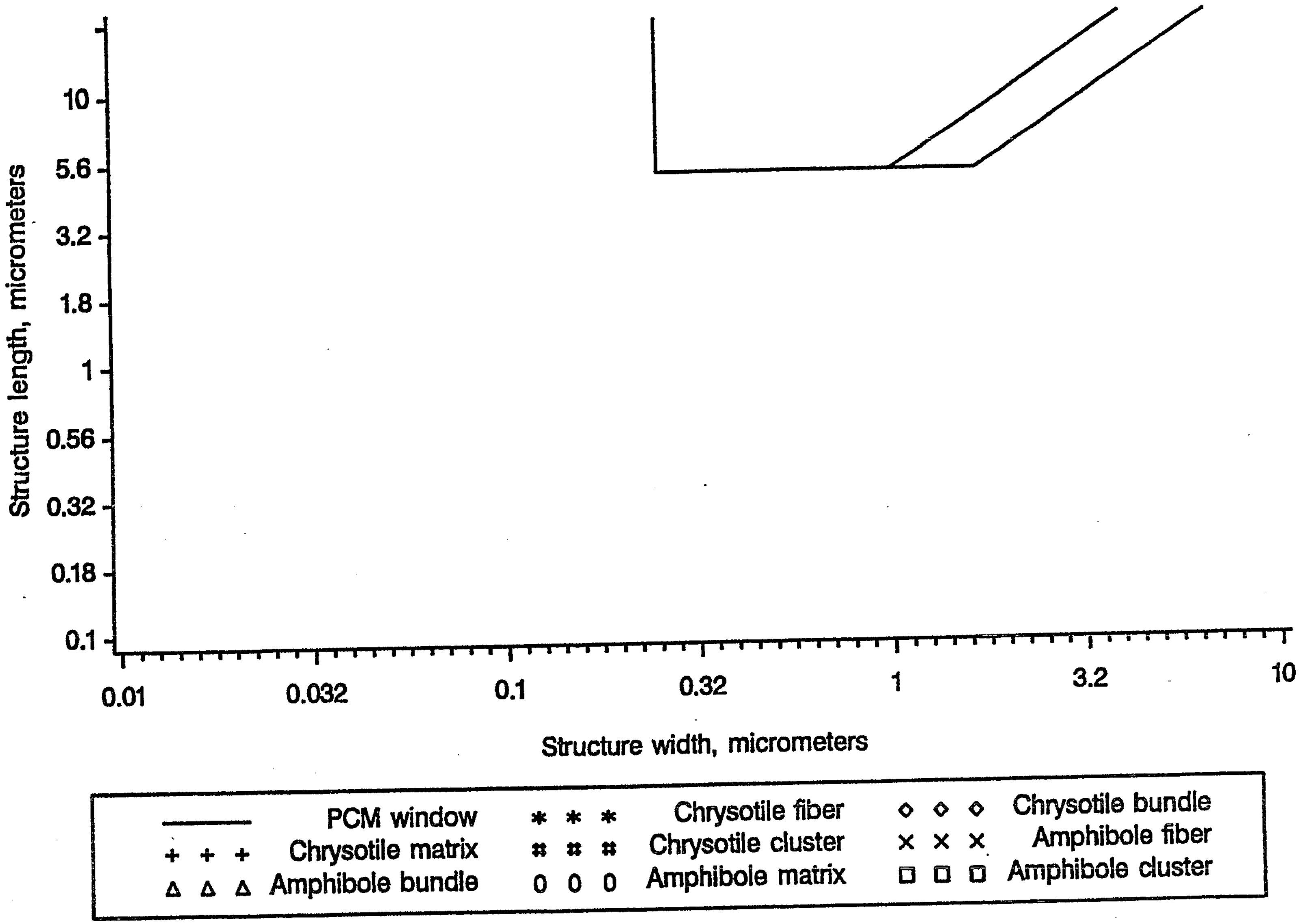


Figure D–6. Size distribution of asbestos structures in air samples collected before and during buffing of asbestos–containing floor tile at Site 4A.

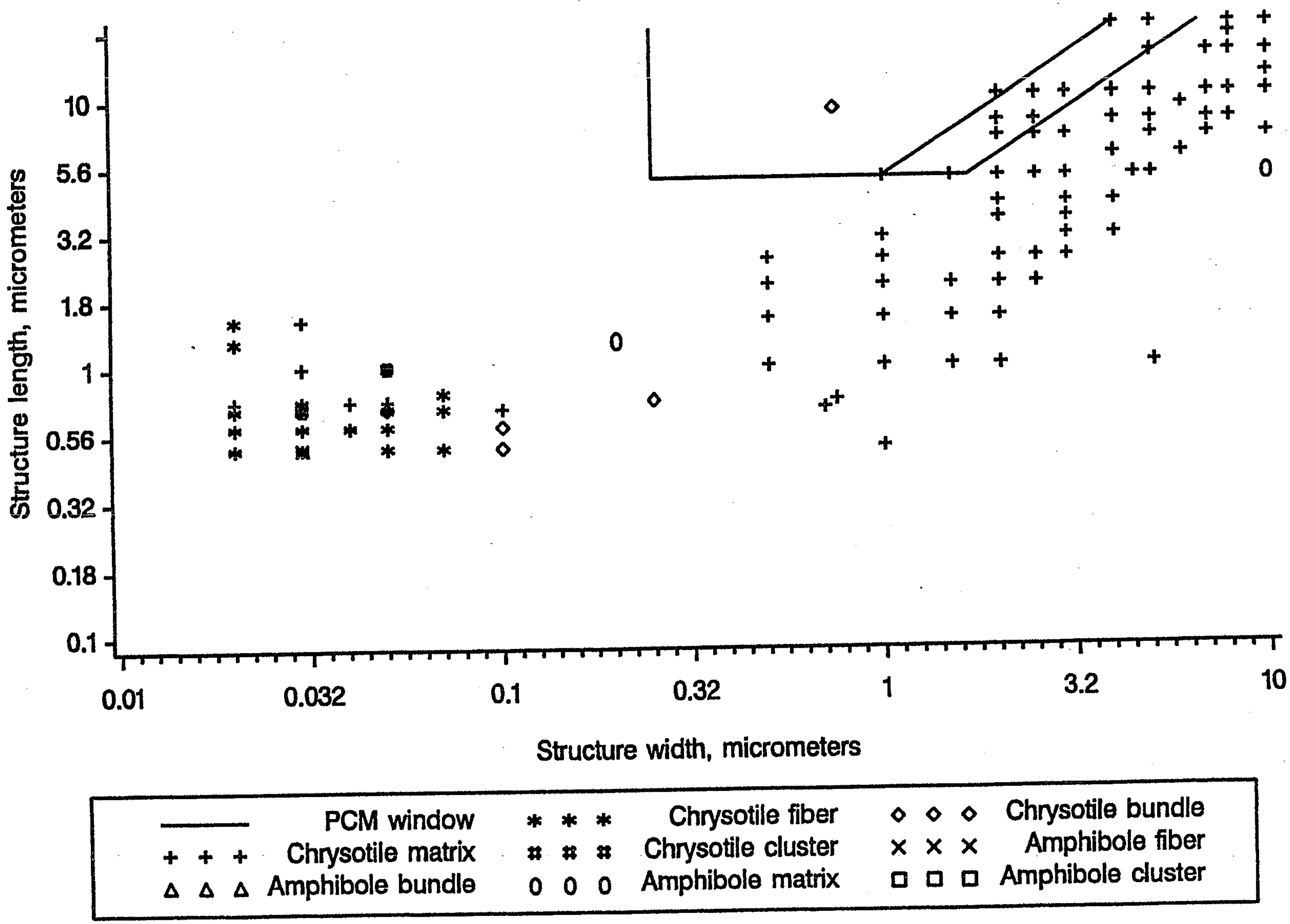


Figure D–7. Size distribution of asbestos structures in air samples collected before and during buffing of asbestos–containing floor tile at Site 5A.

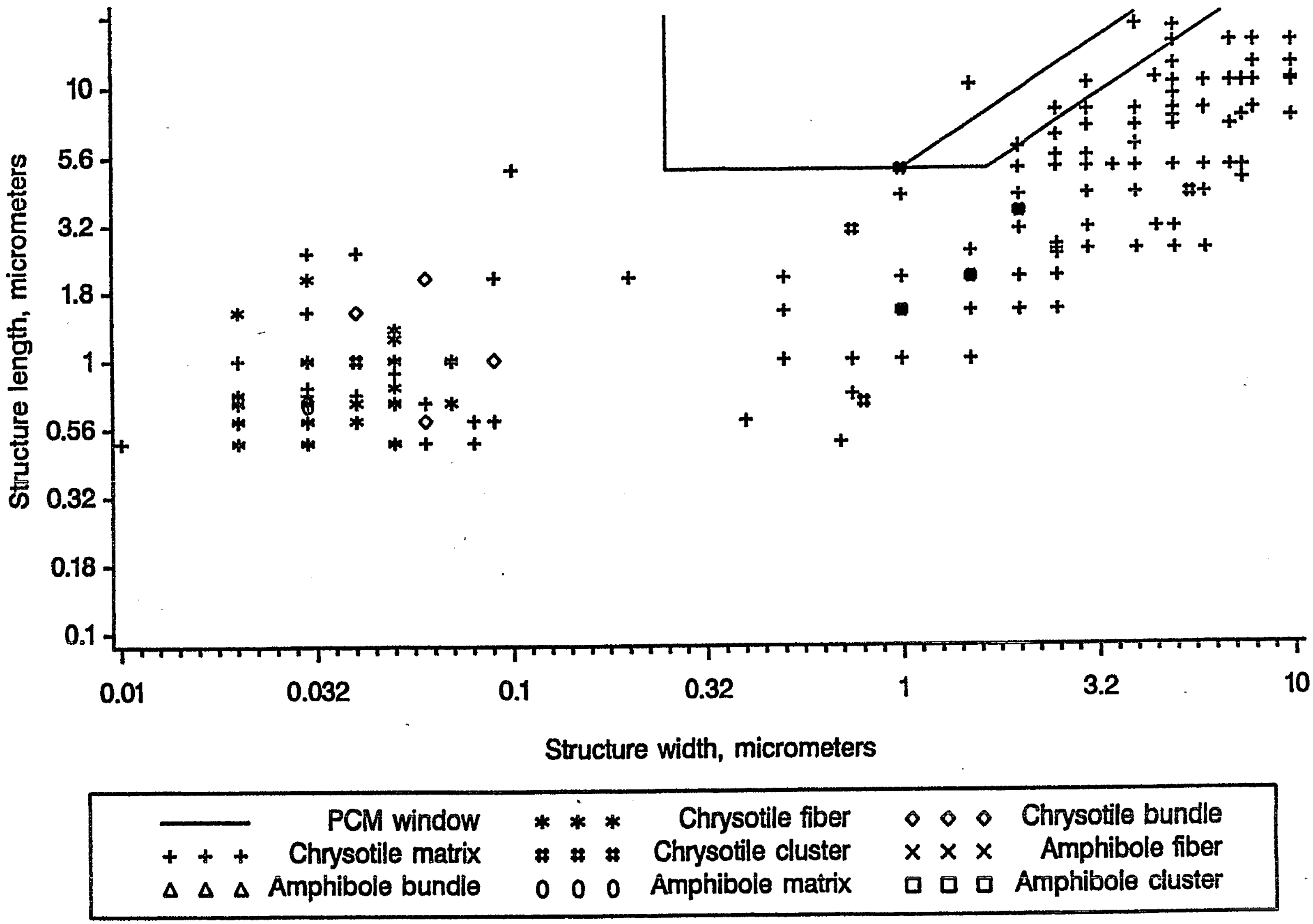


Figure D—8. Size distribution of asbestos structures in air samples collected before and during buffing of asbestos—containing floor tile at Site 6A.

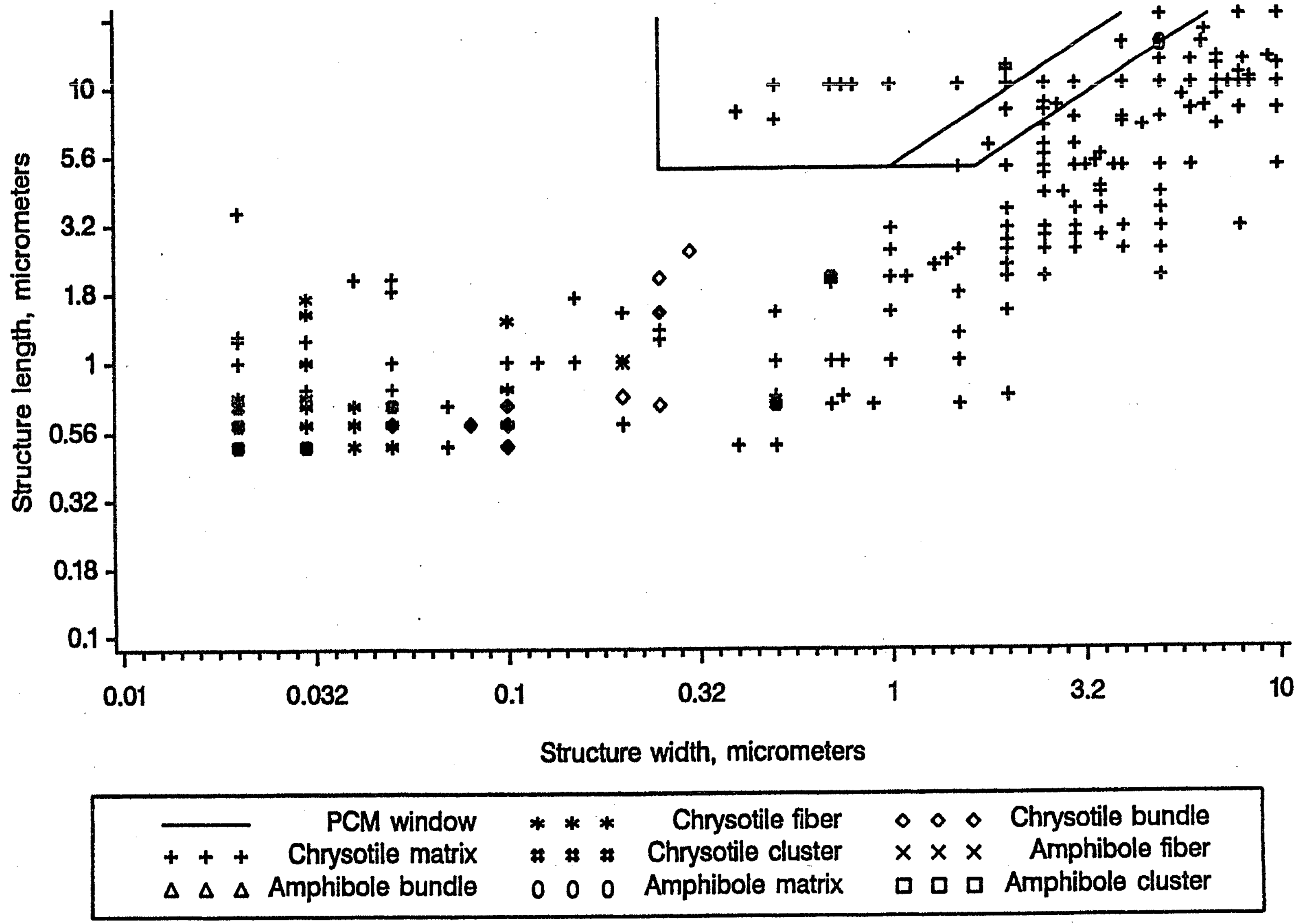


Figure D–9. Size distribution of asbestos structures in air samples collected before and during buffing of asbestos–containing floor tile at Site 6B.

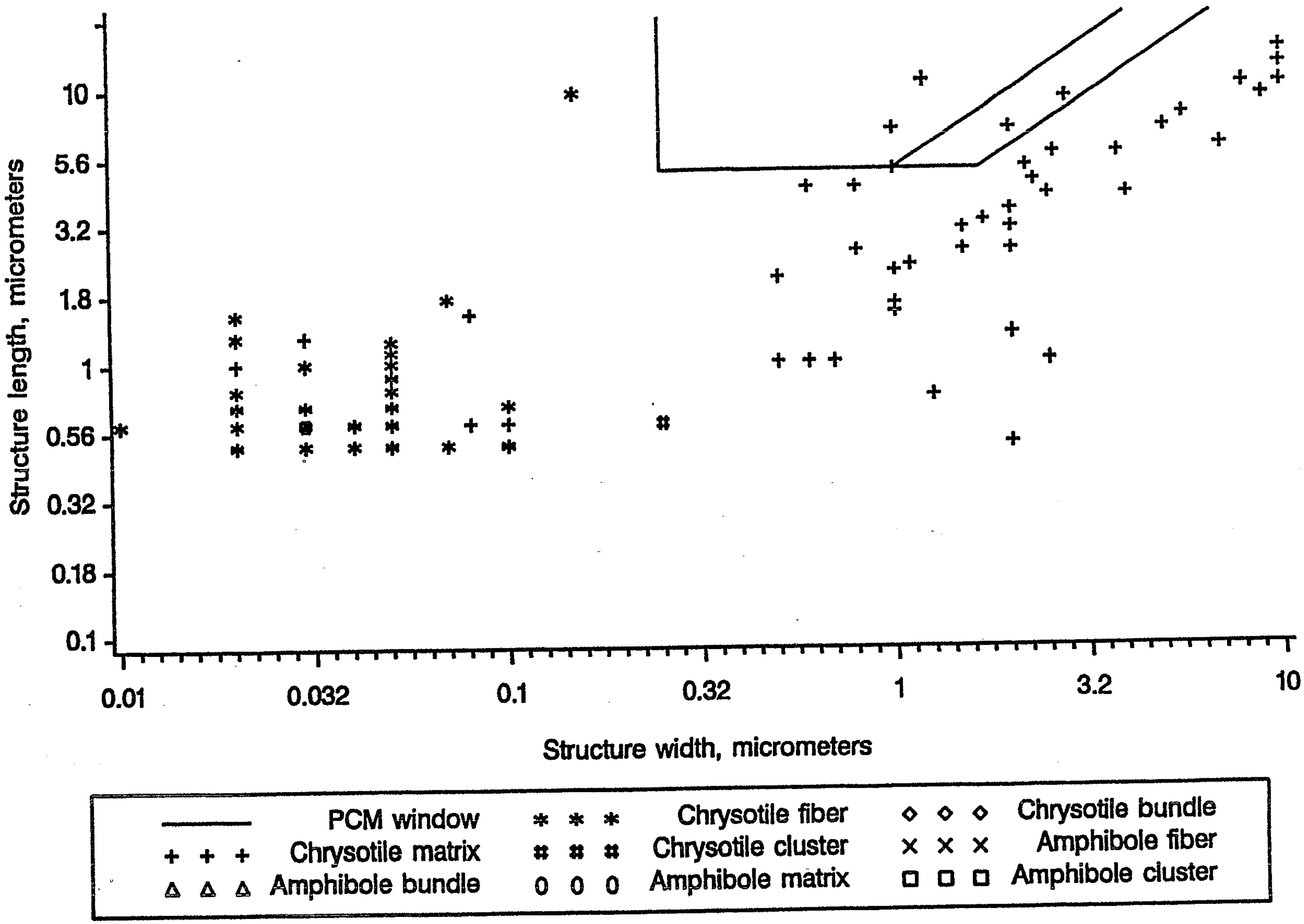


Figure D–10. Size distribution of asbestos structures in air samples collected before and during buffing of asbestos–containing floor tile at Site 7A.

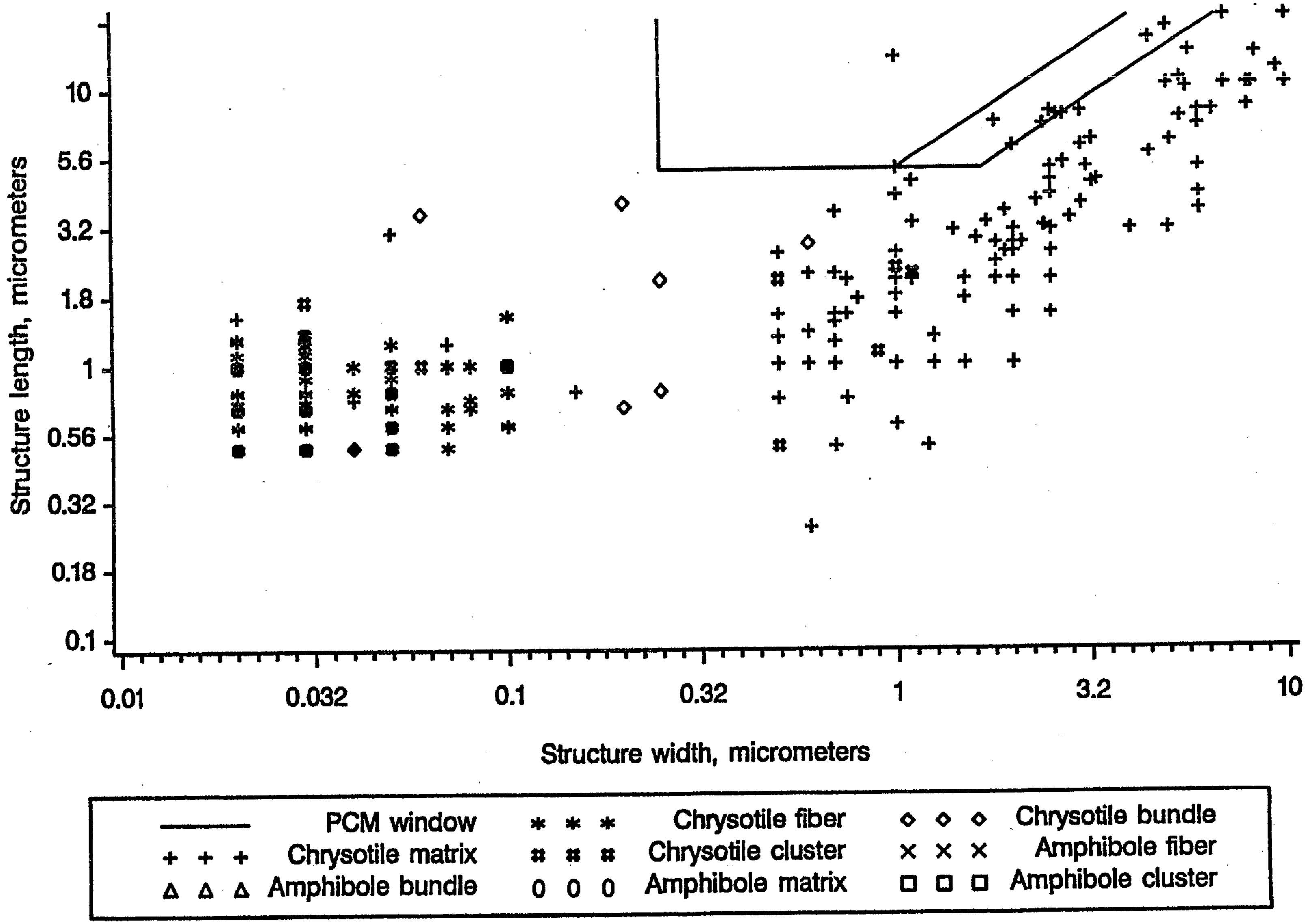


Figure D–11. Size distribution of asbestos structures in air samples collected before and during buffing of asbestos–containing floor tile at Site 7B.

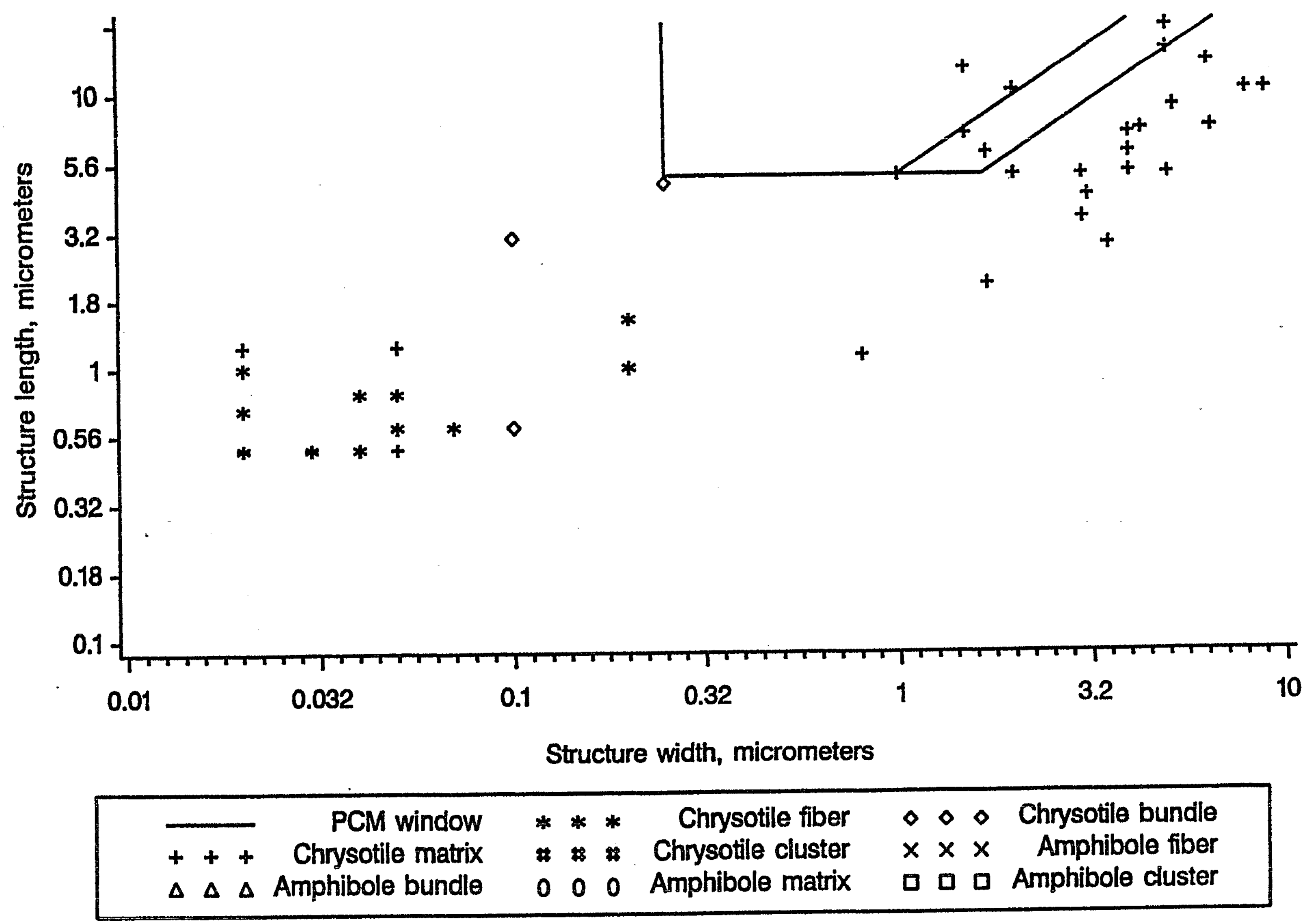


Figure D-12. Size distribution of asbestos structures in air samples collected before and during buffing of asbestos-containing floor tile at Site 8A.

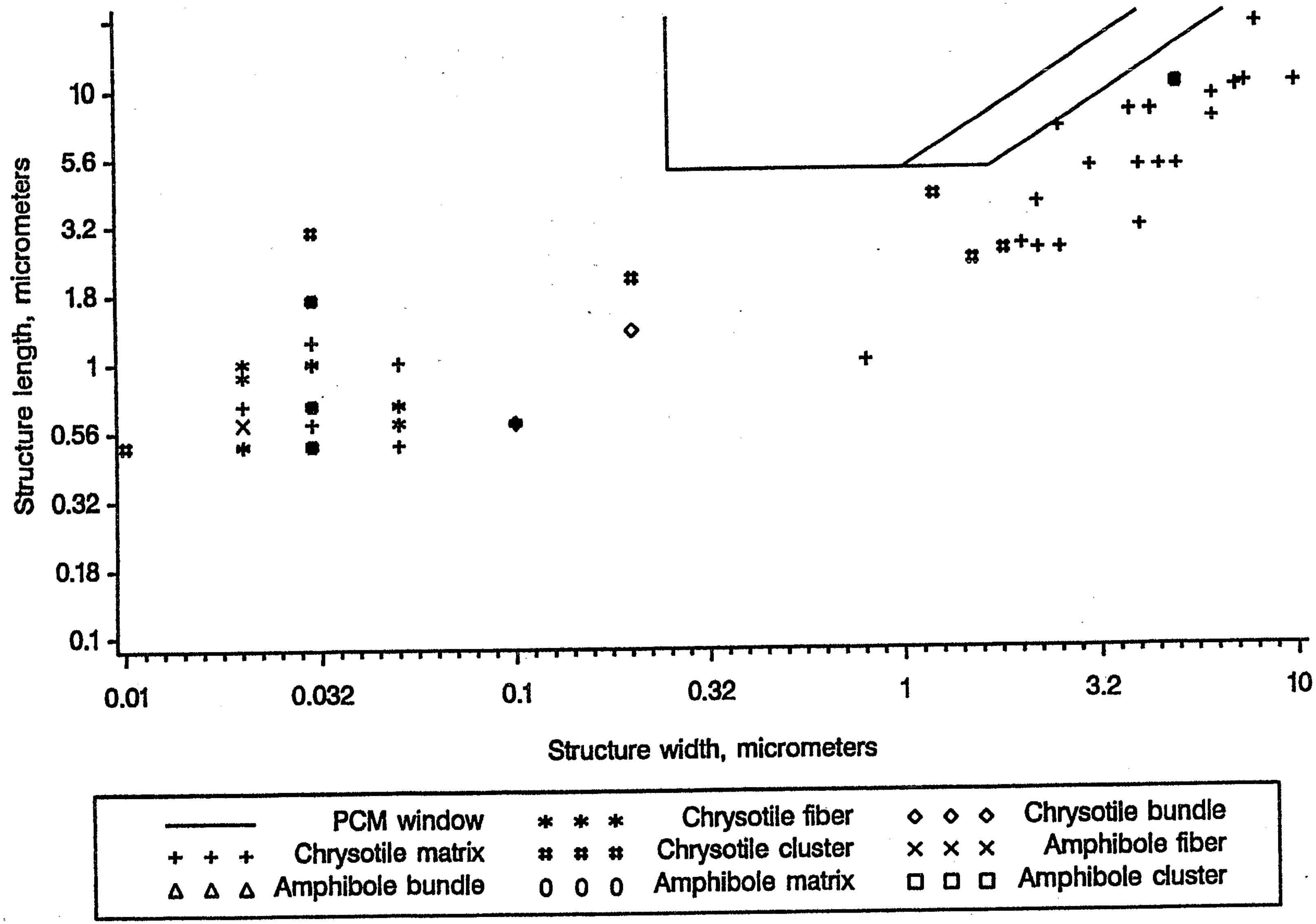


Figure D–13. Size distribution of asbestos structures in air samples collected before and during buffing of asbestos–containing floor tile at Site 8B.

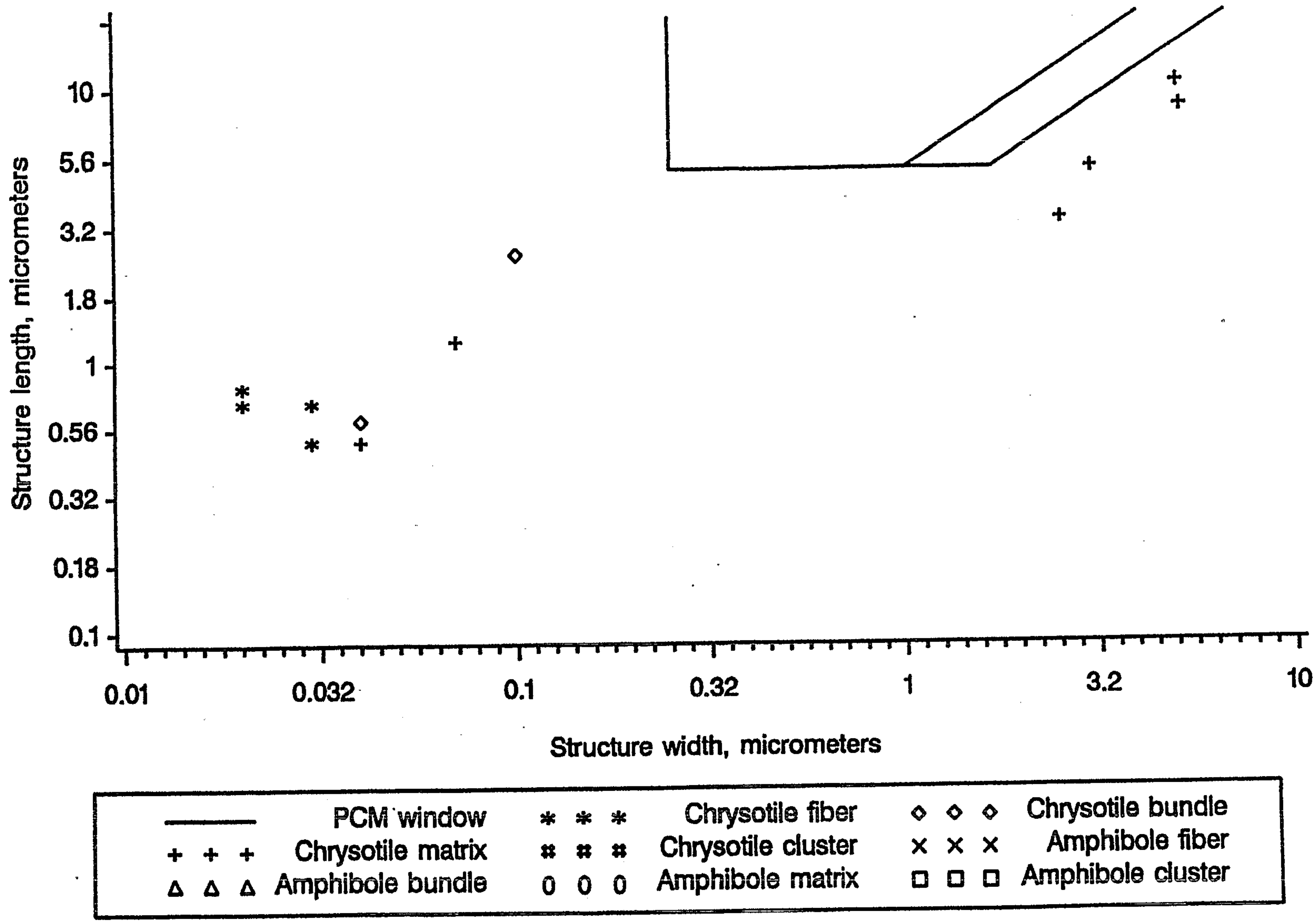


Figure D–14. Size distribution of asbestos structures in air samples collected before and during buffing of asbestos–containing floor tile at Site 9A.

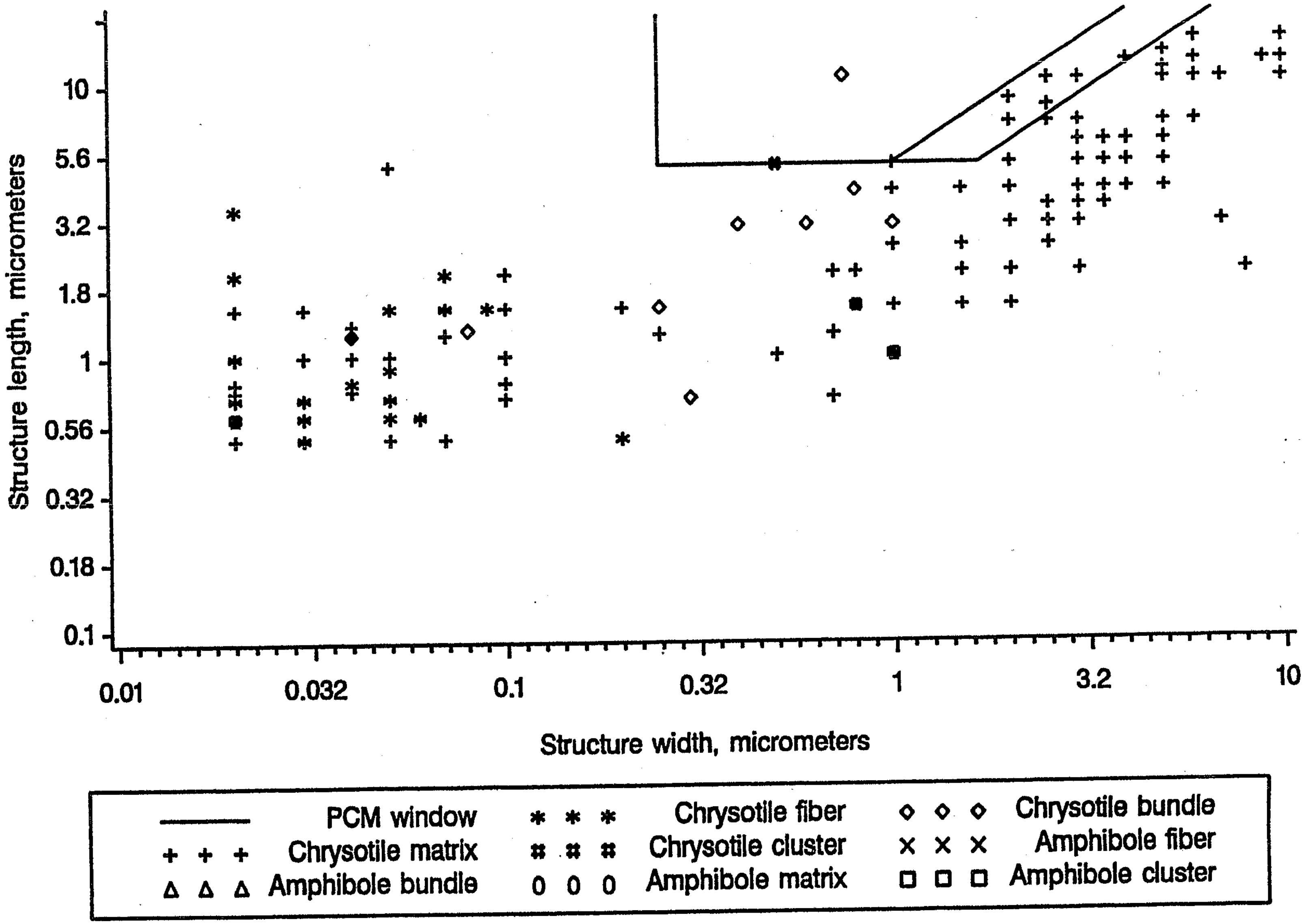


Figure D–15. Size distribution of asbestos structures in air samples collected before and during buffing of asbestos–containing floor tile at Site 10A.

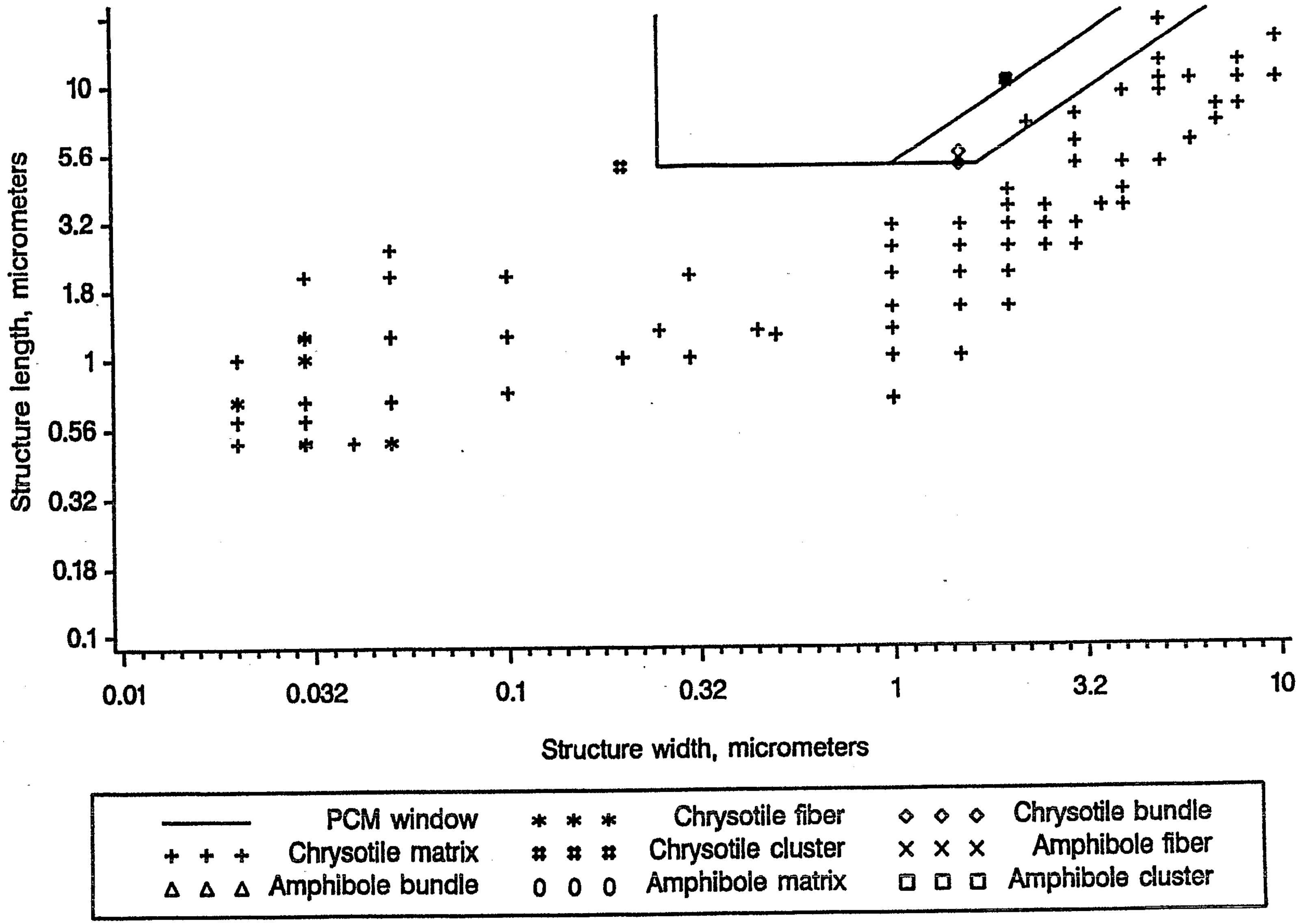


Figure D–16. Size distribution of asbestos structures in air samples collected before and during buffing of asbestos–containing floor tile at Site 10B.

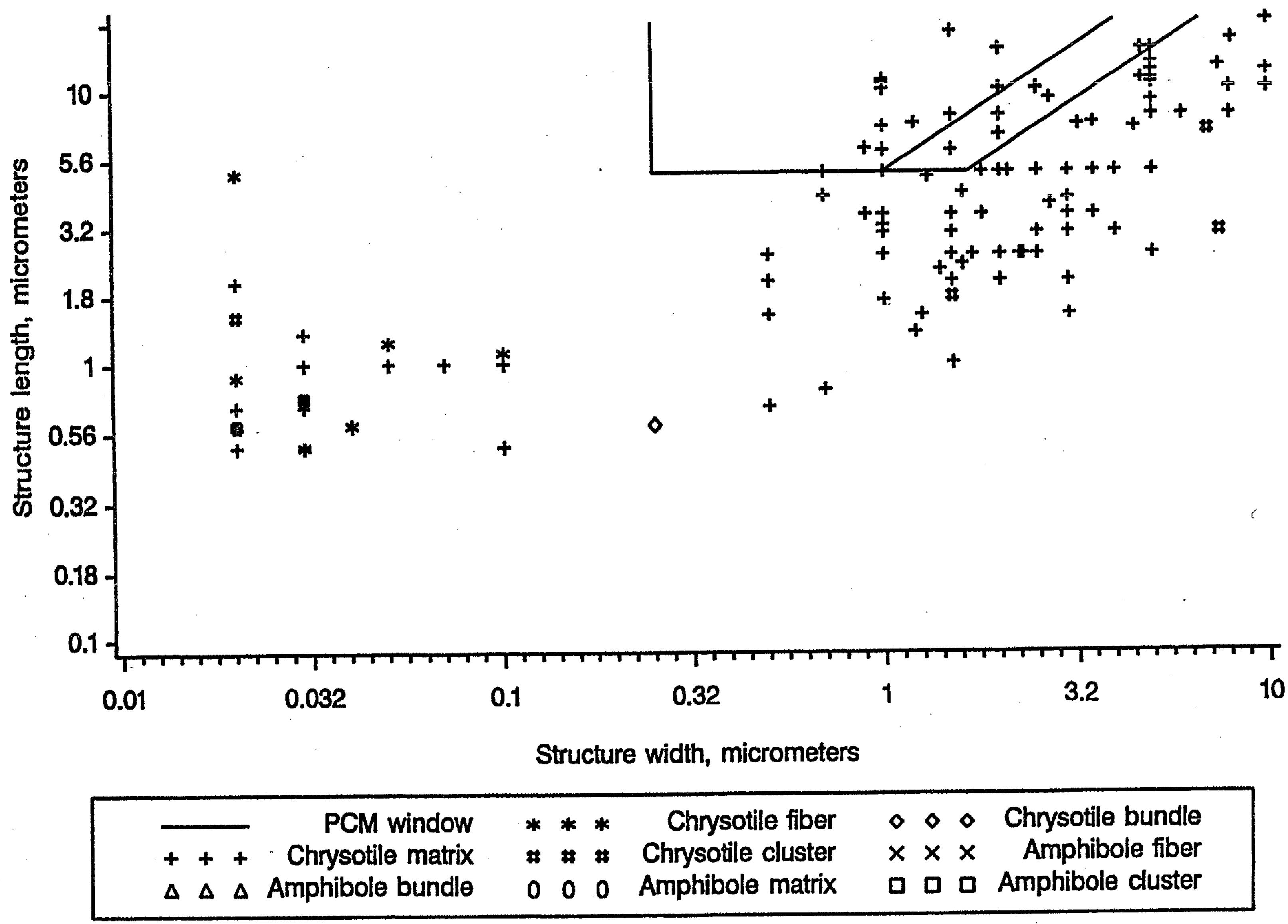


Figure D–17. Size distribution of asbestos structures in air samples collected before and during buffing of asbestos–containing floor tile at Site 11A.

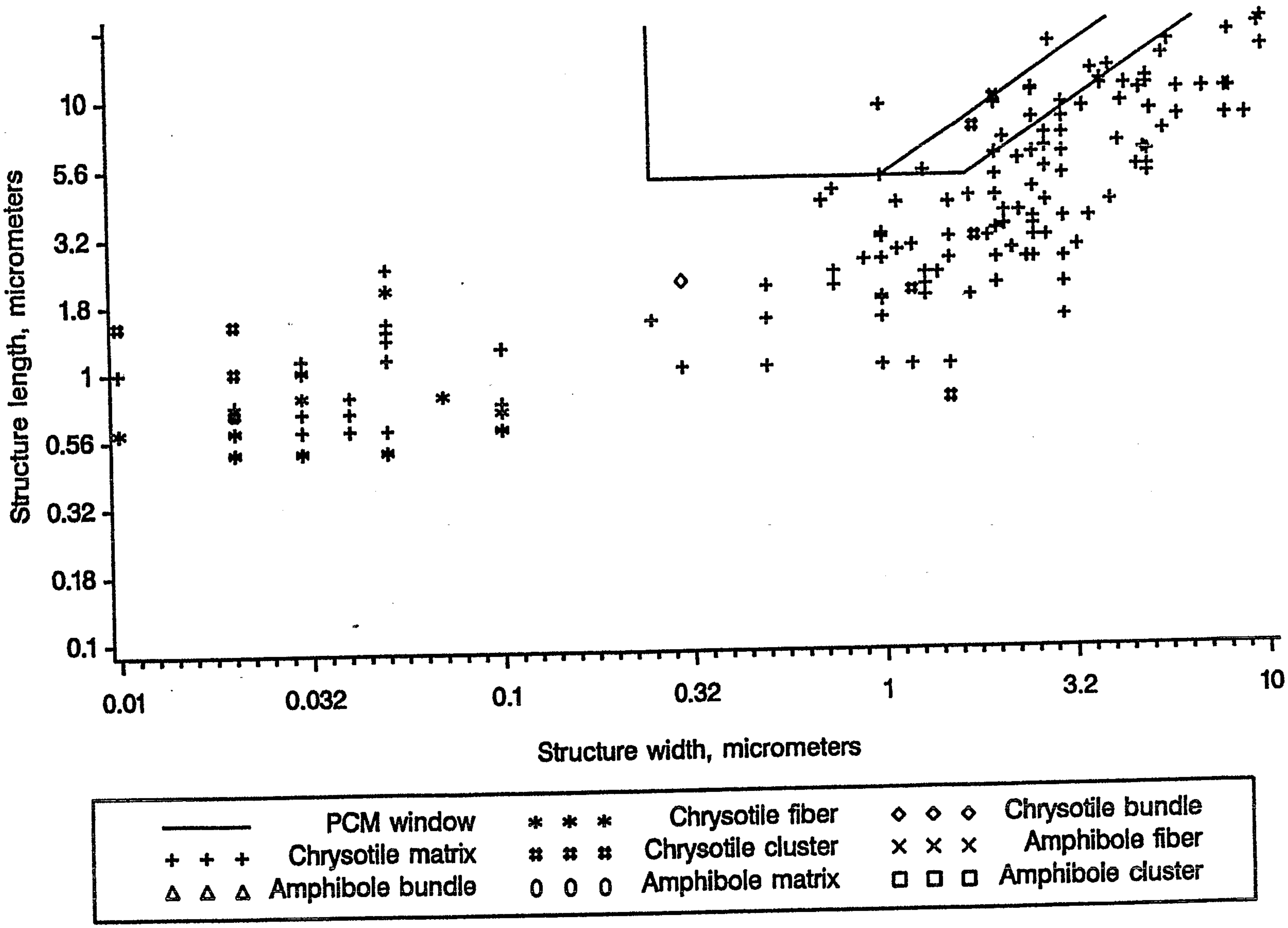


Figure D—18. Size distribution of asbestos structures in air samples collected before and during buffing of asbestos—containing floor tile at Site 11B.

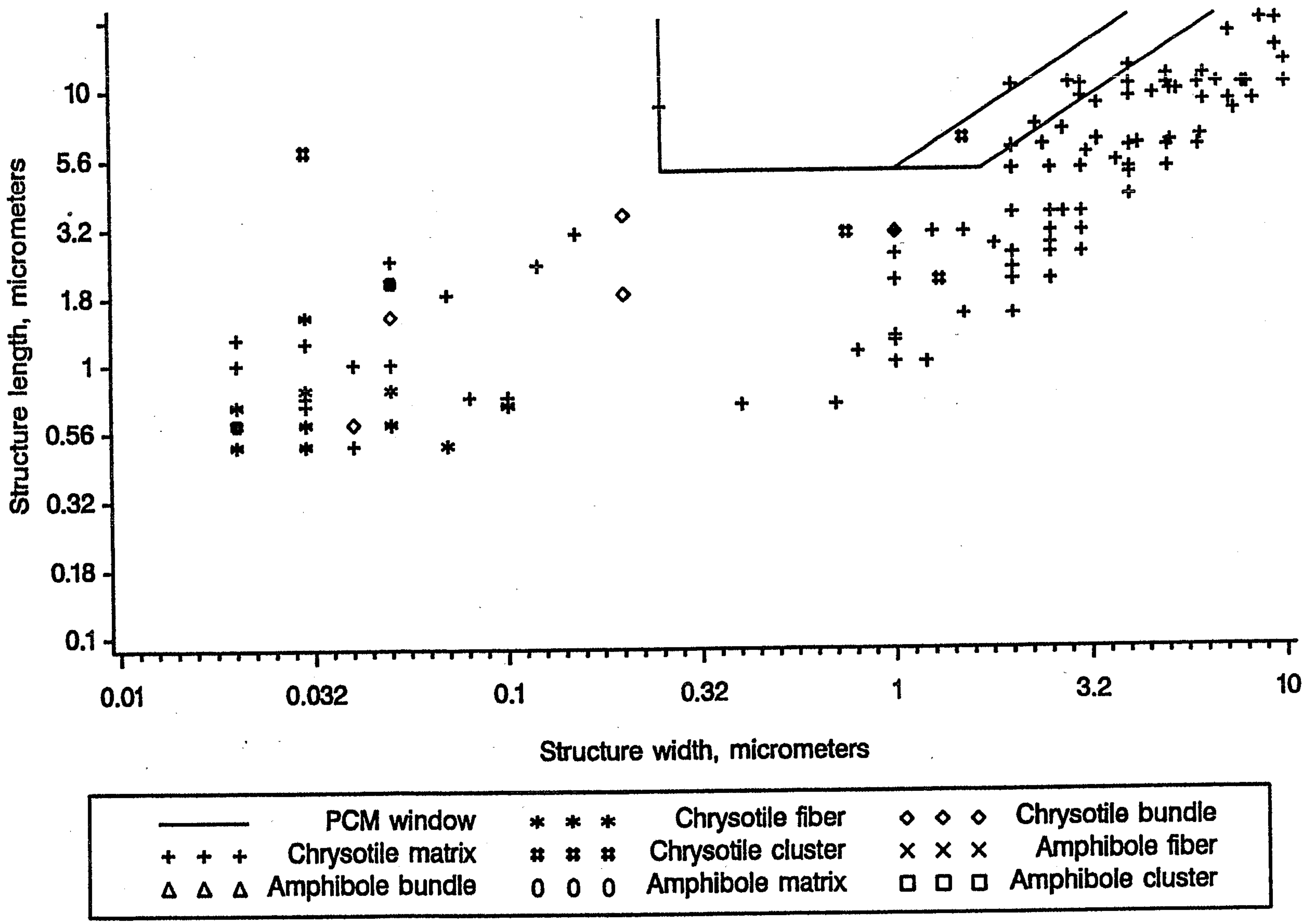


Figure D–19. Size distribution of asbestos structures in air samples collected before and during buffing of asbestos–containing floor tile at Site 12A.

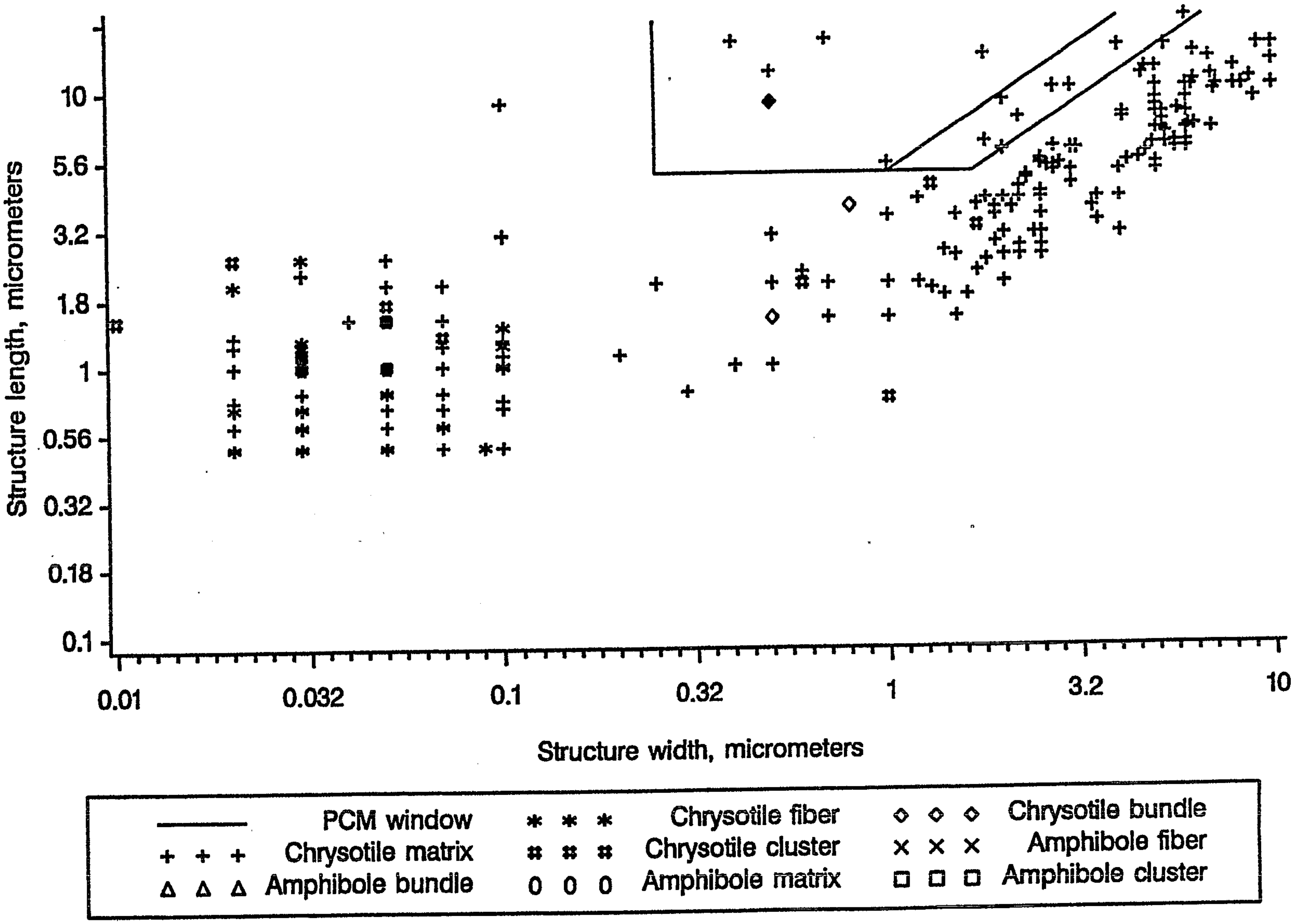


Figure D–20. Size distribution of asbestos structures in air samples collected before and during buffing of asbestos–containing floor tile at Site 12B.

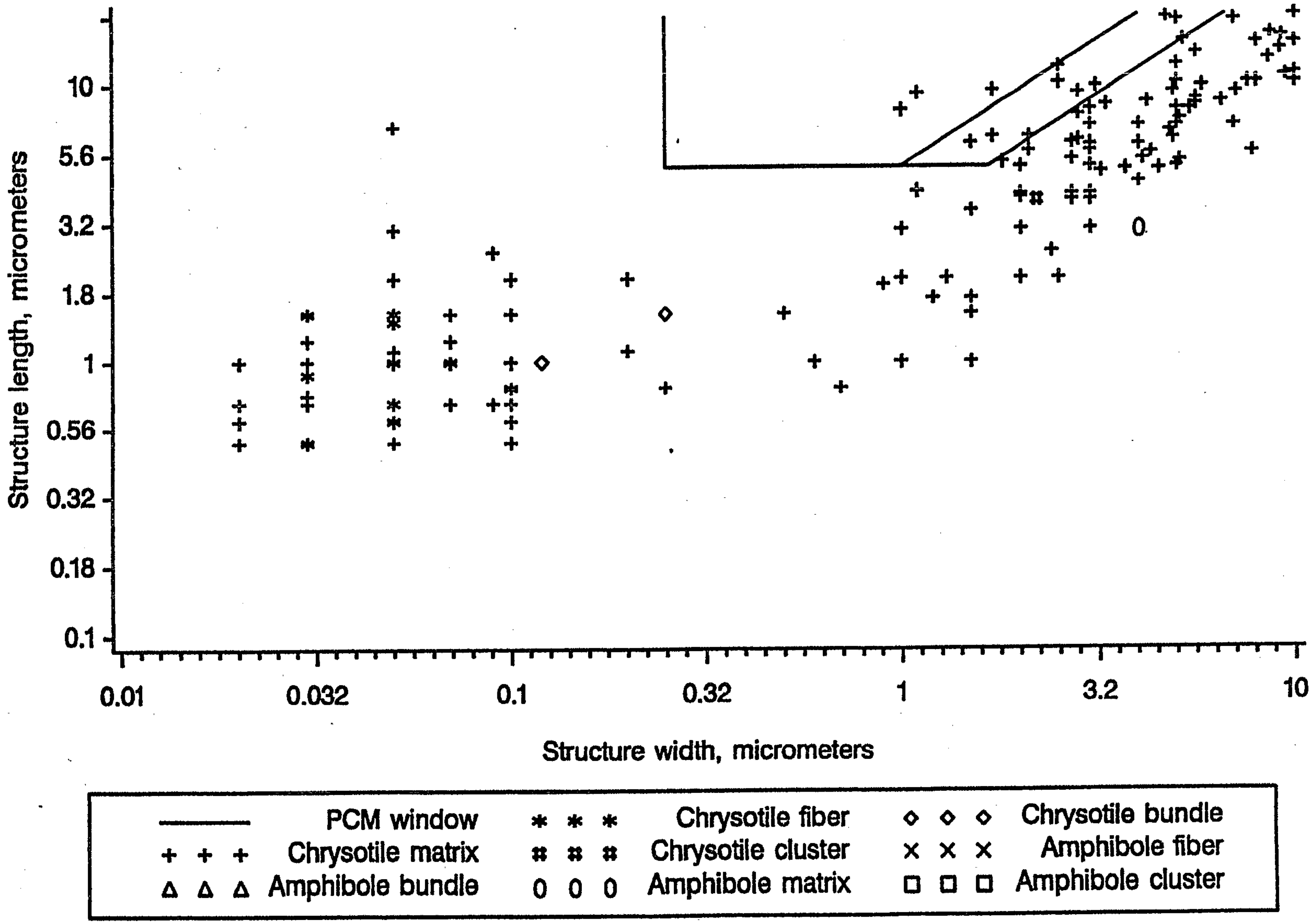


Figure D–21. Size distribution of asbestos structures in air samples collected before and during buffing of asbestos–containing floor tile at Site 13A.

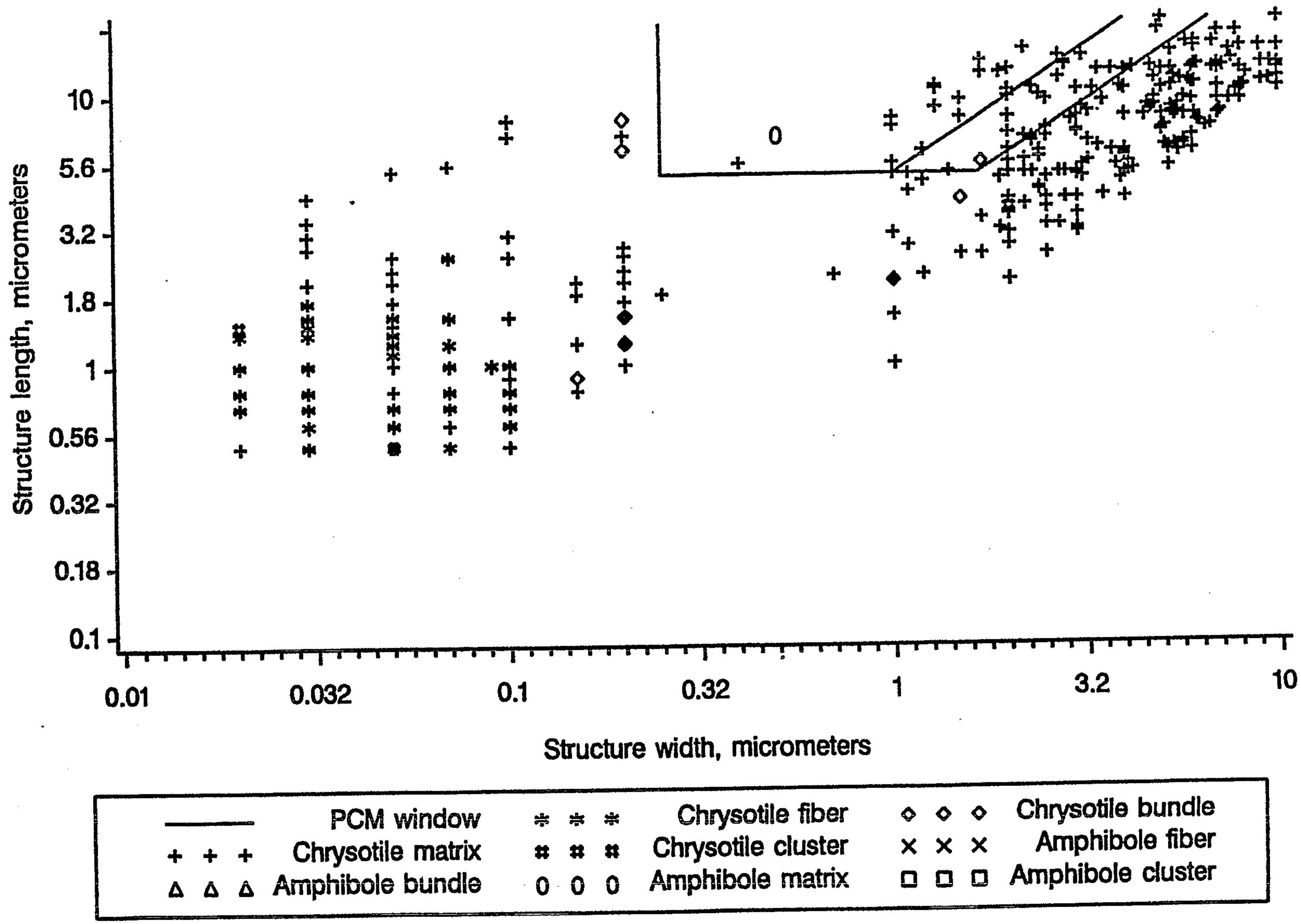


Figure D–22. Size distribution of asbestos structures in air samples collected before and during buffing of asbestos–containing floor tile at Site 13B.

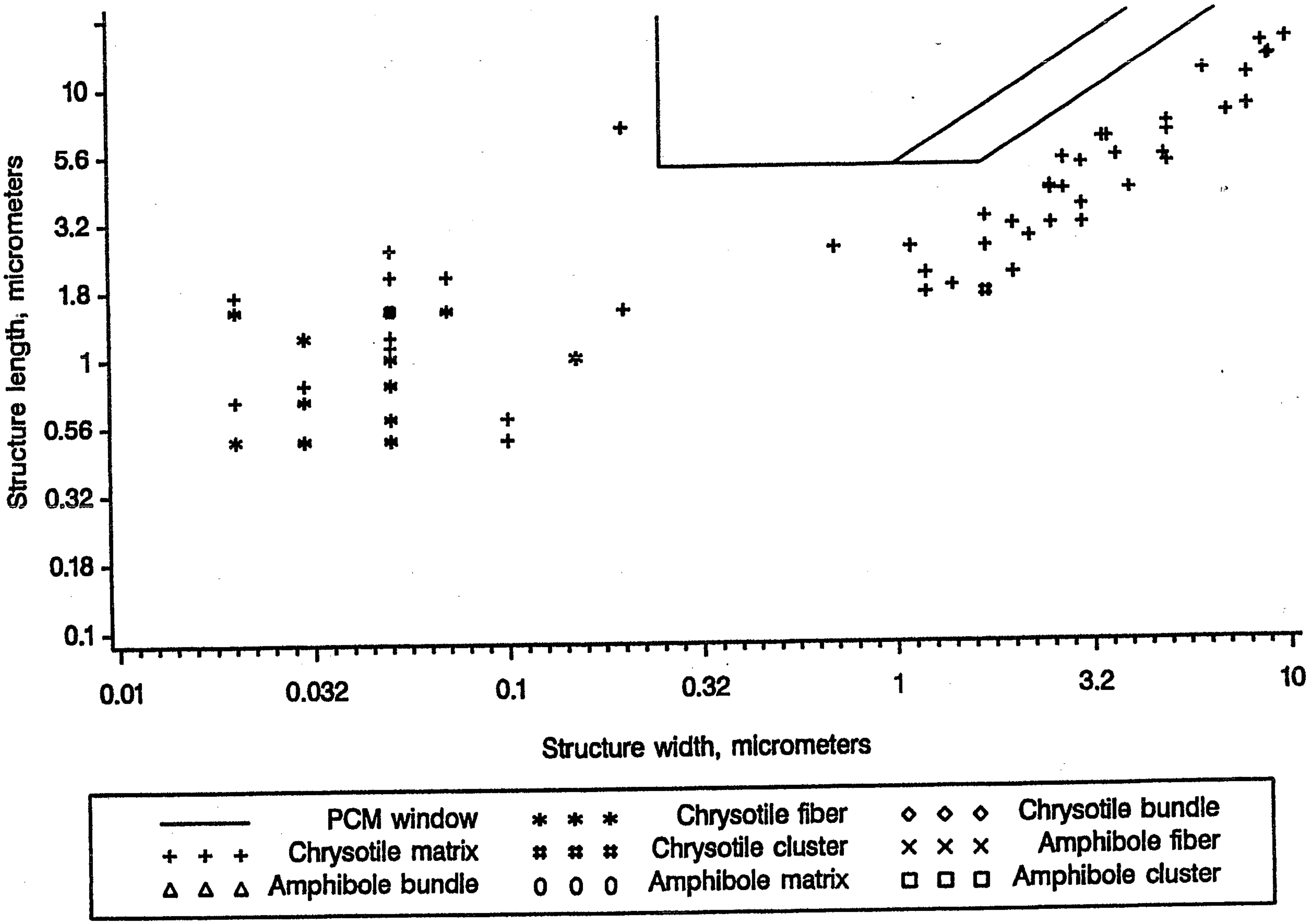


Figure D–23. Size distribution of asbestos structures in air samples collected before and during buffing of asbestos–containing floor tile at Site 14A.

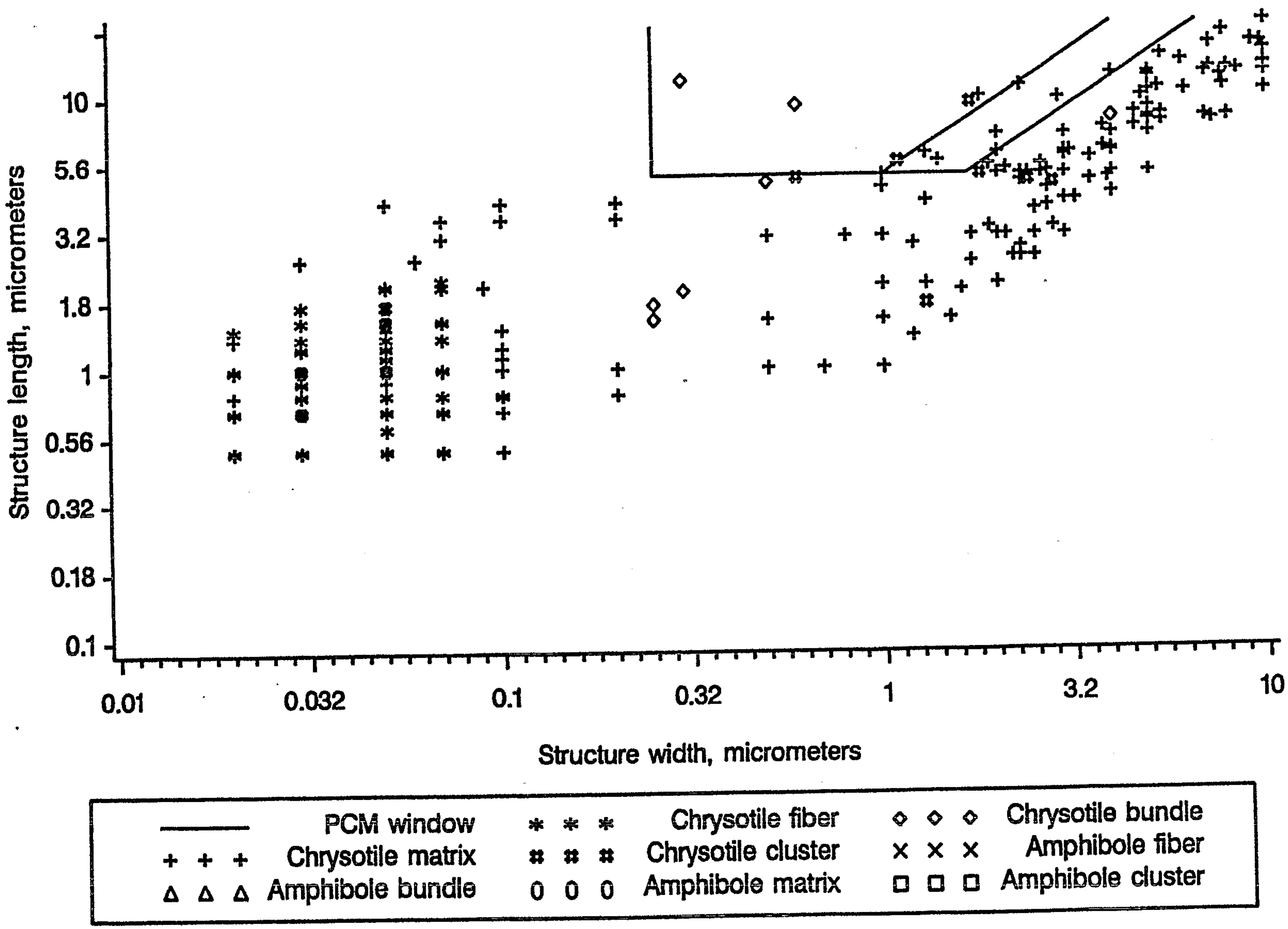


Figure D–24. Size distribution of asbestos structures in air samples collected before and during buffing of asbestos–containing floor tile at Site 15A.

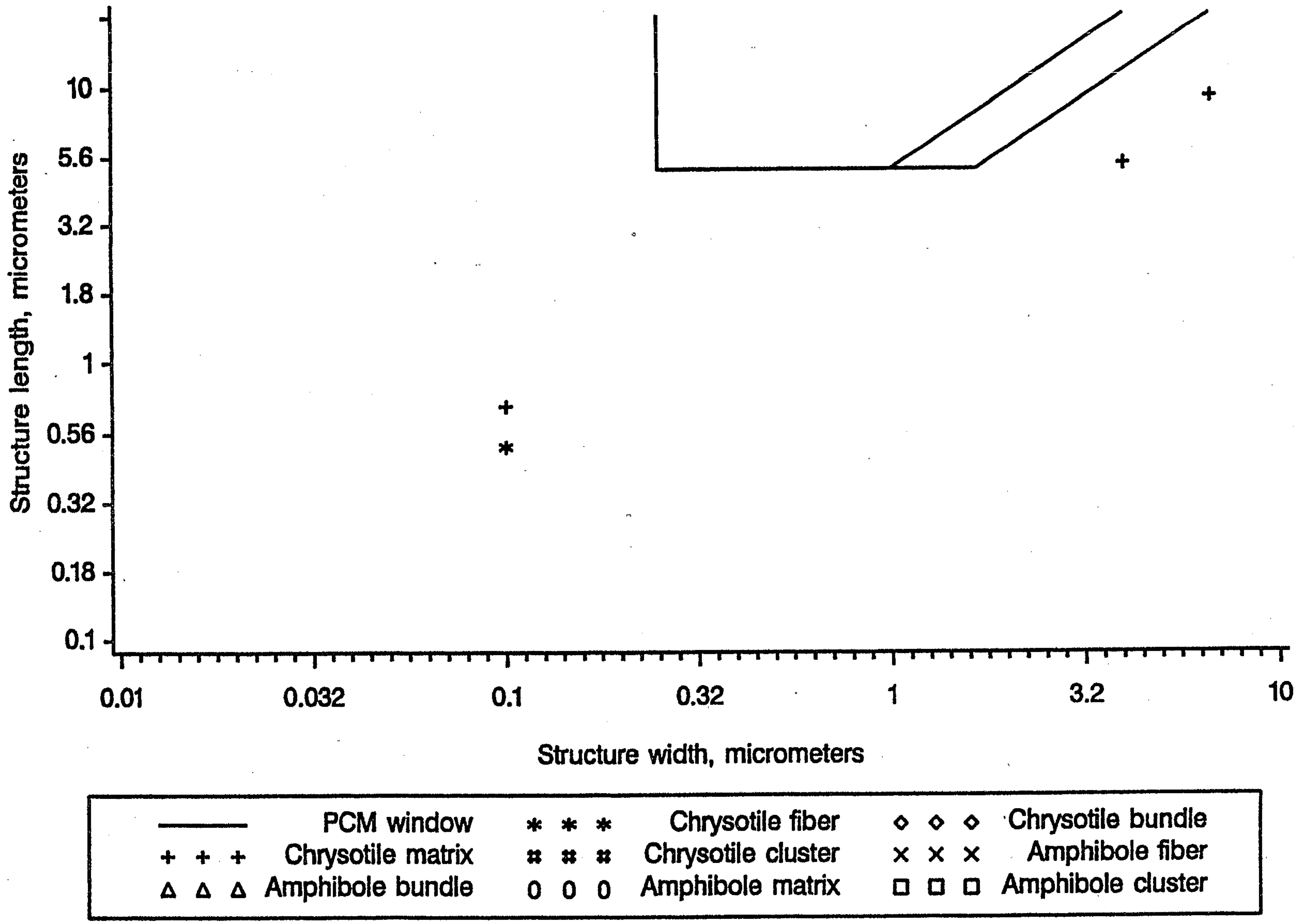


Figure D–25. Size distribution of asbestos structures in air samples collected before and during buffing of asbestos–containing floor tile at Site 16A.

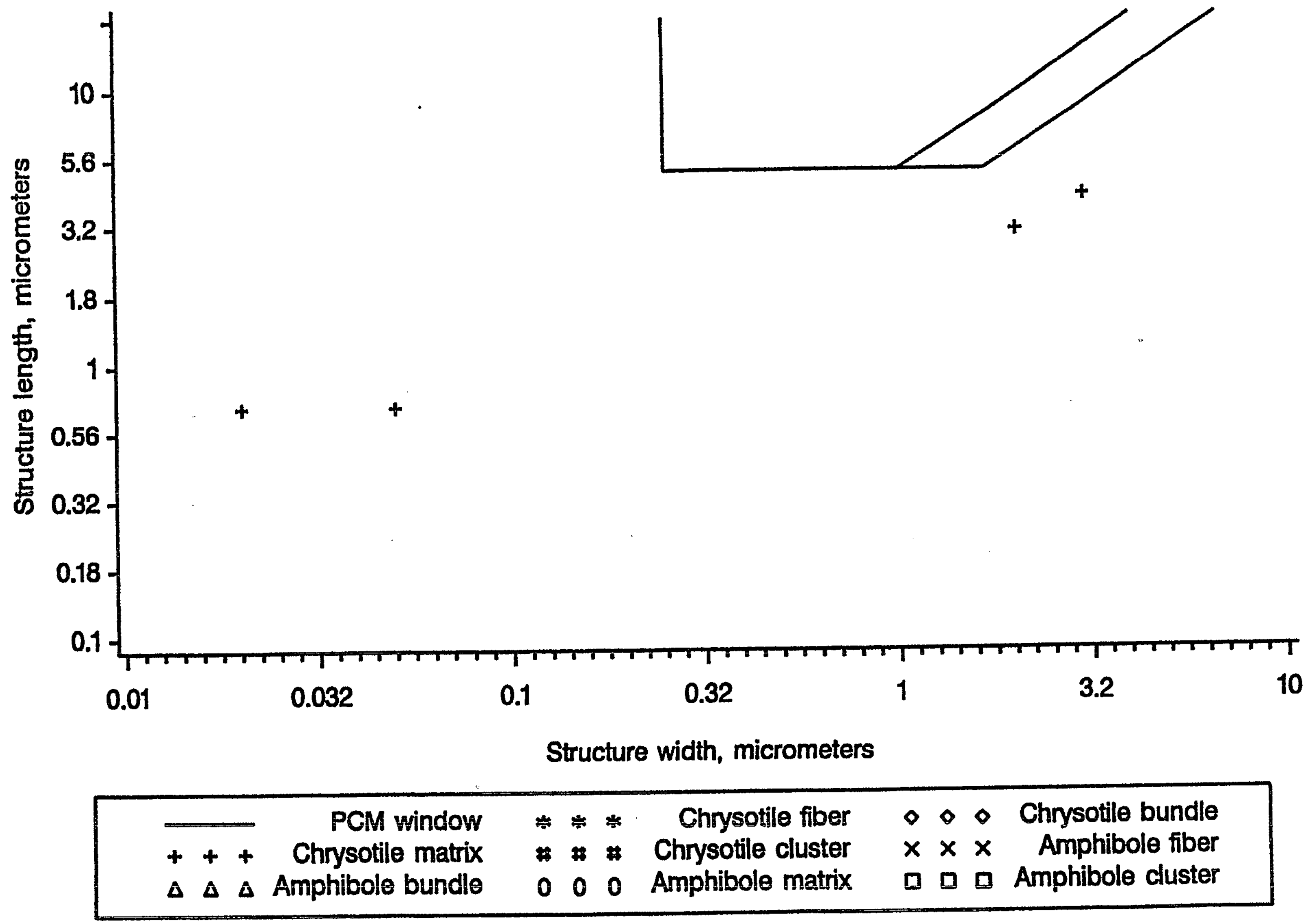


Figure D–26. Size distribution of asbestos structures in air samples collected before and during buffing of asbestos–containing floor tile at Site 16B.

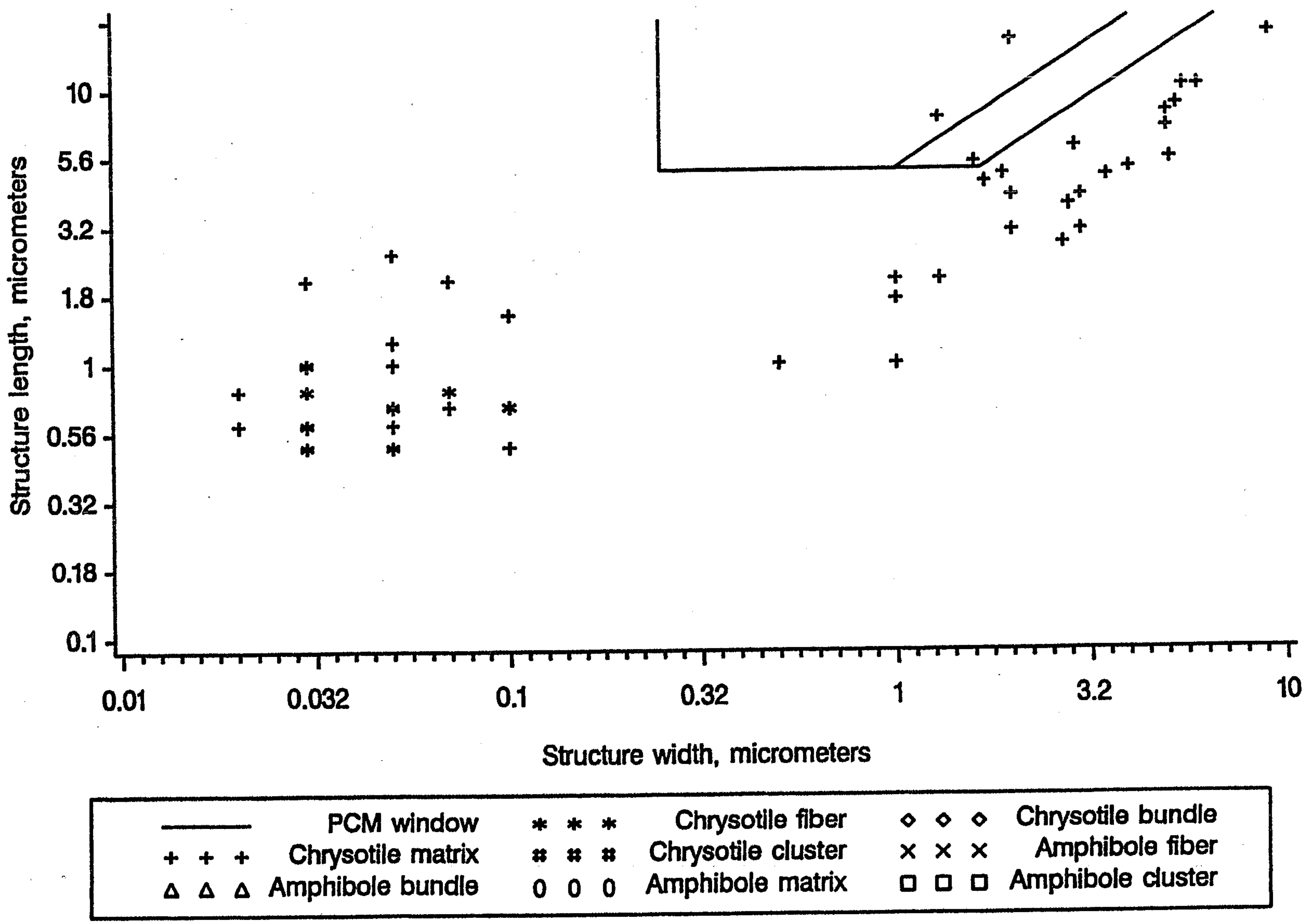


Figure D–27. Size distribution of asbestos structures in air samples collected before and during buffing of asbestos–containing floor tile at Site 17A.

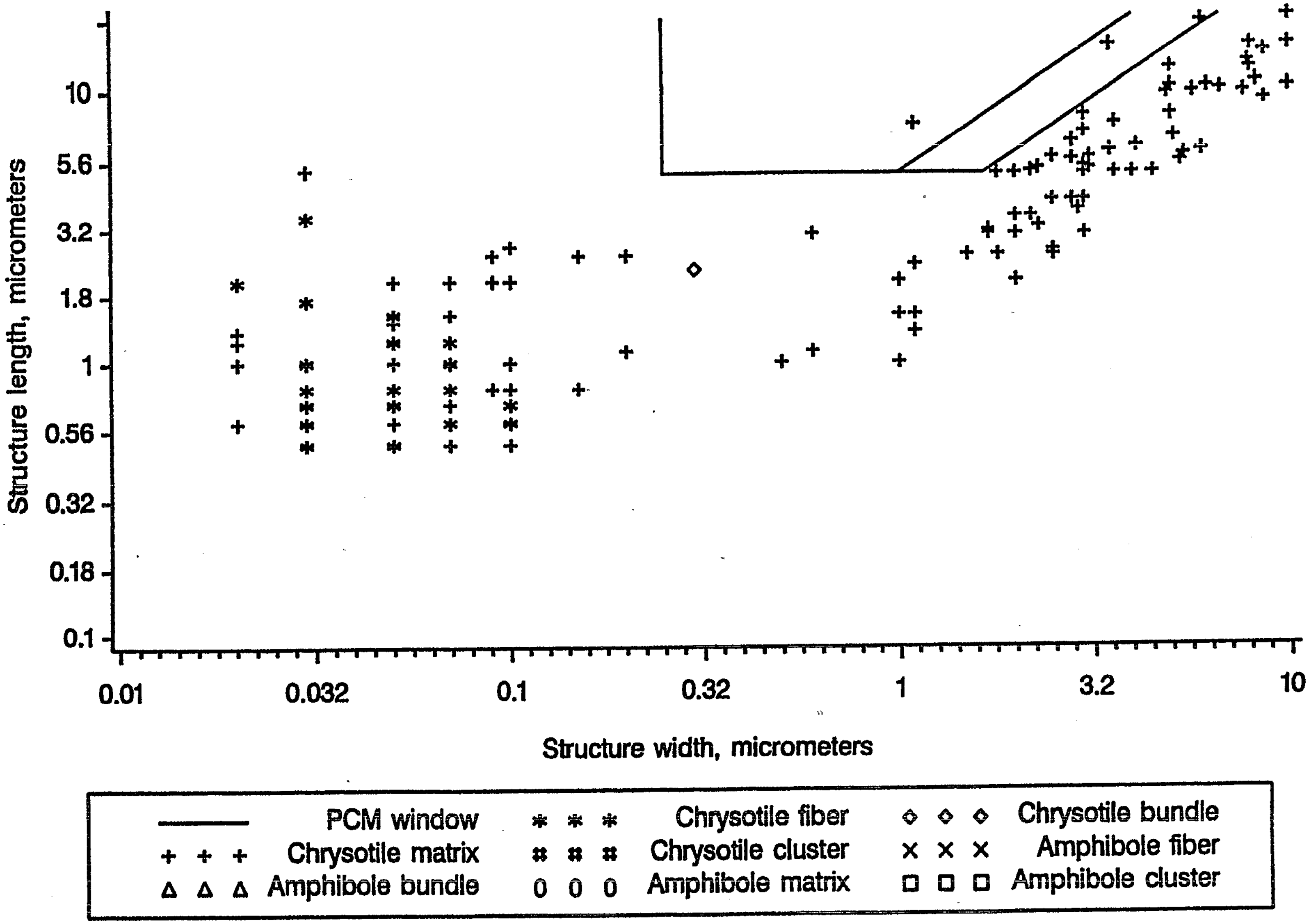


Figure D–28. Size distribution of asbestos structures in air samples collected before and during buffing of asbestos–containing floor tile at Site 17B.

APPENDIX E

PERCENT OCCLUSION OF GRID OPENINGS BY PARTICULATE

TABLE E-1. DEGREE OF OVERLOADING ON SAMPLES ANALYZED BY TEM

Field Sample ID	Lab ID Number	% Particulate/grid
01A-01B	92C-002-01	5-10
01A-02B	92C-002-02	1-5
01A-03B	92C-002-03	<1
01A-01D	92C-002-04	1-5
01A-02D	92C-002-05	1-5
01A-03D	92C-002-06	1-5
01B-01B	92C-002-09	1-5
01B-02B	92C-002-10	1-5
01B-03B	92C-002-11	1-5
01B-01D	92C-002-12	1-5
01B-02D	92C-002-13	5
01B-03D	92C-002-14	5
02A-01B	92C-002-16	1-5
02A-02B	92C-002-17	1-5
02A-03B	92C-002-18	1-5
02A-01D	92C-002-19	5-10
02A-02D	92C-002-20	5-10
02A-03D	92C-002-21	5-10
03A-01B	92C-002-24	<1
03A-02B	92C-002-25	1-5
03A-03B	92C-002-26	<1
03A-01D	92C-002-27	1-5
03A-02D	92C-002-28	1-5
03A-03D	92C-002-29	1-5
03B-01B	92C-002-32	1-5

(continued)

TABLE E-1 (contiuned)

Field Sample ID	Lab ID Number	% Particulate/grid
03B-02B	92C-002-33	1-5
03B-03B	92C-002-34	1
03B-01D	92C-002-35	1-5
03B-02D	92C-002-36	1-5
03B-03D	92C-002-37	1-5
04A-01B	92C-002-39	1
04A-02B	92C-002-40	1
04A-03B	92C-002-41	1-5
04A-01D	92C-002-42	1-5
04A-02D	92C-002-43	1-5
05A-01B	92C-002-47	1-5
05A-02B	92C-002-48	1-5
05A-03B	92C-002-49	1-5
05A-01D	92C-002-50	40-50
05A-02D	92C-002-51	25-35
05A-03D	92C-002-52	15-20
06A-01B	92C-002-55	10-15
06A-02B	92C-002-56	<1
06A-03B	92C-002-57	1-5
06A-01D	92C-002-58	10-15
06A-02D	92C-002-59	10-15
06A-03D	92C-002-60	10-15
06B-01B	92C-002-63	1
06B-02B	92C-002-64	1-5
06B-03B	92C-002-65	5-10

(continued)

TABLE E-1 (contiuned)

Field Sample ID	Lab ID Number	% Particulate/grid
06B-01D	92C-002-66	15-20
06B-02D	92C-002-67	20-40
06B-03D	92C-002-68	15-20
07A-01B	92C-002-70	1
07A-02B	92C-002-71	1
07A-03B	92C-002-72	1
07A-01D	92C-002-73	5
07A-02D	92C-002-74	2-5
07A-03D	92C-002-75	2-5
07B-01B	92C-002-78	1
07B-02B	92C-002-79	1
07B-03B	92C-002-80	1
07B-01D	92C-002-81	15-20
07B-02D	92C-002-82	15-20
07B-03D	92C-002-83	20-25
08A-01B	92D-001-01	1-5
08A-02B	92D-001-02	1-5
08A-03B	92D-001-03	1-5
08A-01D	92D-001-04	30-40
08A-02D	92D-001-05	15-20
08A-03D	92D-001-06	10-20
08B-01B	92D-001-09	5
08B-02B	92D-001-10	2-5
08B-03B	92D-001-11	5
08B-01D	92D-001-12	50-60

(continued)

TABLE E-1 (contiuned)

Field Sample ID	Lab ID Number	% Particulate/grid
08B-02D	92D-001-13	15-20
08B-03D	92D-001-14	50-65
09A-01B	92D-001-16	1-5
09A-02B	92D-001-17	1-5
09A-03B	92D-001-18	1-5
09A-01D	92D-001-19	2-5
09A-02D	92D-001-20	2-5
09A-03D	92D-001-21	5
10A-01B	92D-001-24	1
10A-02B	92D-001-25	2-5
10A-03B	92D-001-26	2-5
10A-01D	92D-001-27	5
10A-02D	92D-001-28	5
10A-03D	92D-001-29	5
10B-01B	92D-001-32	1
10B-02B	92D-002-33	2-5
10B-03B	92D-001-34	2-5
10B-01D	92D-001-35	2-5
10B-02D	92D-001-36	1
10B-03D	92D-001-37	2-5
11A-01B	92D-001-39	1-3
11A-02B	92D-001-40	1
11A-03B	92D-001-41	1
11A-01D	92D-001-42	5
11A-03D	92D-001-44	5-10

(continued)

TABLE E-1 (contiuned)

Field Sample ID	Lab ID Number	% Particulate/grid
11B-01B	92D-001-47	1-3
11B-02B	92D-001-48	1
11B-03B	92D-001-49	1
11B-01D	92D-001-50	5-10
11B-02D	92D-001-51	5-10
11B-03D	92D-001-52	1-3
12A-01B	92D-001-54	1-3
12A-02B	92D-001-55	1
12A-03B	92D-001-56	1
12A-01D	92D-001-57	10-15
12A-02D	92D-001-58	5
12A-03D	92D-001-59	5-10
12B-01B	92D-001-62	1-3
12B-02B	92D-001-63	2-5
12B-03B	92D-001-64	1-3
12B-01D	92D-002-65	5
12B-02D	92D-001-66	10
12B-03D	92D-001-67	5
13A-01B	92D-001-69	1-3
13A-02B	92D-001-70	1
13A-03B	92D-001-71	1
13A-01D	92D-001-72	5-10
13A-02D	92D-001-73	2-5
13A-03D	92D-001-74	2-5
13B-01B	92D-001-77	1-3

(continued)

TABLE E-1 (contiuned)

Field Sample ID	Lab ID Number	% Particulate/grid
13B-02B	92D-001-78	3-5
13B-03B	92D-001-79	3-5
13B-01D	92D-001-80	10-15
13B-02D	92D-001-81	10-15
13B-03D	92D-001-82	25
14A-01B	92D-002-01	1
14A-02B	92D-002-02	1
14A-03B	92D-002-03	1
14A-01D	92D-002-04	5-10
14A-02D	92D-002-05	5-10
14A-03D	92D-002-06	5
15A-01B	92D-002-09	3
15A-02B	92D-002-10	3-5
15A-03B	92D-002-11	1-3
15A-01D	92D-002-12	5-10
15A-02D	92D-002-13	5-10
15A-03D	92D-002-14	5-10
16A-01B	92D-002-17	1
16A-02B	92D-002-18	1-3
16A-03B	92D-002-19	1-3
16A-01D	92D-002-20	1
16A-02D	92D-002-21	1-3
16A-03D	92D-002-22	1-3
16B-01B	92D-002-25	1-3
16B-02B	92D-002-26	3-5

(continued)

TABLE E-1 (contiuned)

Field Sample ID	Lab ID Number	% Particulate/grid
16B-03B	92D-002-27	1
16B-01D	92D-002-28	3-4
16B-02D	92D-002-29	3-4
16B-03D	92D-002-30	3
17A-01B	92D-002-32	1
17A-02B	92D-002-33	1
17A-03B	92D-002-34	1
17A-01D	92D-002-35	1
17A-02D	92D-002-36	1
17A-03D	92D-002-37	1
17B-01B	92D-002-40	3-4
17B-02B	92D-002-41	3
17B-03B	92D-002-42	1
17B-01D	92D-002-43	3-4
17B-02D	92D-002-44	1-3
17B-03D	92D-002-45	3-4

TABLE E-2. DEGREE OF OVERLOADING ON SAMPLES ANALYZED BY PCM

Field Sample ID	Lab ID Number	% Particulate/grid
01A-01D2	92D-001-84	NA
01B-01D2	92D-001-87	10-15
02A-01D2	92D-001-89	10-15
03A-01D2	92D-001-92	5-10
03B-01D2	92D-001-95	10-15
04A-01D2	92D-001-97	5-7
05A-01D2	92D-001-100	25-30
06A-01D2	92D-001-103	10-15
06B-01D2	92D-001-106	30-35
07A-01D2	92D-001-108	15-20
07B-01D2	92D-001-111	20-25
08A-01D2	92D-001-113	50-60
08B-01D2	92D-001-116	70-80
09A-01D2	92D-001-118	2-5
10A-01D2	92D-001-121	15-20
10B-01D2	92D-001-124	10-15
11A-01D2	92D-001-126	8-10
11B-01D2	92D-001-129	10-15
12A-01D2	92D-001-131	10-20
12B-01D2	92D-002-47	20-25
13A-01D2	92D-002-49	10-15
13B-01D2	92D-002-52	5-10
14A-01D2	92D-002-54	3-5
15A-01D2	92D-002-57	3-5
16A-01D2	92D-002-60	3-5

(continued)

TABLE E-2 (continued)

Field Sample ID	Lab ID Number	% Particulate/grid
16B-01D2	92D-002-63	3-5
17A-01D2	92D-002-65	2-4
17B-01D2	92D-002-68	3-5