# 5. RESULTS AND DISCUSSION

## 5.1. FIELD BLANKS AND LOWER LIMITS OF DETECTION

In Sections 1 and 2, some of the uncertainties of the analytical methods were discussed. In this section, further delineation of these issues and how they affected the interpretation of the analytical results is presented.

### 5.1.1. Phase Contrast Microscopy

Only one of 74 field blanks analyzed by PCM was above the limit of detection (LOD); thus, no correction for fiber contamination of the cellulose ester filters was necessary. The estimated LOD for Method 7400 is 7 fibers/$mm^2$ of filter area.[14-17] This is equivalent to about 1,500 fibers per filter for 25 mm diameter filters and 3,500 fibers per filter for 37 mm diameter filters; thus, for a 1,500 liter sample, the LOD is 1,000 and 2,000 f/$m^3$, respectively. When sample results were reported to be "less than the detection limit," a value of one-half of the LOD was used for statistical computations.

### 5.1.2. Transmission Electron Microscopy

As discussed in Section 2.2, two problems affecting the validity of TEM analyses were identified by the EPA: high interlaboratory variability of analytical results and asbestos contamination of the polycarbonate sampling media during manufacture. Both of these problems were encountered in the present study. First, analysis of samples obtained from two of the buildings surveyed and analyzed in the EPA laboratory were reported to have very low fiber counts and many were reported nondetectable. When reanalyzed in the NIOSH laboratory, substantial numbers of fibers were found. Second, the analyses of the blank polycarbonate filters from this study exhibited the same range of asbestos contamination as did the polycarbonate filters supplied by the EPA to other laboratories (illustrated in Figure 1). To overcome this difficulty and to reduce the cost of analyses, the EPA has assumed that for clearance purposes the contamination level of the filter media is 70 f/$mm^2$. A 37 mm filter has an effective collection area of 855 $mm^2$; therefore, for the contamination level assumed, about 60,000 fibers per filter, the LOD for a 3,000 liter sample is 20,000 f/$m^3$.

## 5.2. CONFIDENCE LIMITS

### 5.2.1. Phase Contrast Microscopy

For PCM fiber analysis, the coefficient of variation, CV (also known as the relative standard deviation, RSD), has two components. One component of the CV for counting randomly (Poisson) distributed fibers on a filter surface is a function of the number of fibers counted. This is related to the sample loading (the number of fibers on the filter) and, hence, the CV may differ for each sample collected. The other component of the CV, termed the subjective component of variability, is a function of differences in the counts of the analyst(s) due to the amount of training and experience of the microscopist, differences in microscope equipment, and quality assurance practices.

The two laboratories used in this study showed a PCM analysis correlation coefficient of 0.91 and an interlaboratory coefficient of variation of 0.41 was demonstrated based on a 25-sample comparison. Additional discussion of interlaboratory comparability is included in NIOSH method 7400.[17] Because of the wide variation of interlaboratory results and in the absence of a known CV between laboratories, a value of 0.45 is used in this method for the subjective component of variability. A graph is included in the method to illustrate the interlaboratory precision of fiber counts, whereby a 90% confidence interval on the mean count can be estimated from a single sample fiber count. Immediately preceding the graph, it is stated that ". . . a further approximation is to simply use +213% and -49% as the upper and lower confidence values of the mean for a 100 fiber count." These percentages can be applied directly to the air concentrations as well.

Table 5-1 was prepared to demonstrate the range of upper and lower 90% confidence limits which would be expected if a group of laboratories having an interlaboratory CV of 0.45 analyzed identical samples. The table shows the confidence limits for a 10 grid or 100 fiber count. (Part A of Table 5-1 is for use with 25 mm filters and Part B is for 37 mm filters.) Because the range varies with the number of fibers counted and the sample volume, computations were also made for several fiber counts using the three sample volumes that are relevant to the present study: 400 liters, the approximate volume collected for personal samples; 1,500 liters, for pre- and post-removal and daily ambient samples; and 2,500 liters, for ambient samples. These tables may be used to approximate the range of values to be applied with 90% confidence when interpreting the results of individual samples analyzed by the same laboratory with respect to an occupational exposure or clearance standard.

### 5.2.2. Transmission Electron Microscopy

An intralaboratory CV of 0.35 was calculated for the fiber analysis by TEM used in this study. In general, there is insufficient experience with TEM to fully establish interlaboratory confidence limits. EPA has reported results of similar studies which indicate an overall CV of about 1.5 with an analytical component of about 1.0.[33] The assumptions used in the preparation of the range of PCM confidence limits presented in Table 5-1 may not hold for the greater variability associated with TEM. To provide some insight as to how a CV of 1.5 affects the 90% confidence limits, it is assumed, for the purpose of illustration, that the (natural) logarithm of the asbestos counts as determined by TEM is normally distributed. If this is the case, then the approximate 90% confidence limit for a true mean count of 1,250,000 f/m$^3$ by TEM on a 37 mm filter would be 378,000 to 13,500,000 f/m$^3$. As seen in Table 5-1, the corresponding interval for a 1,250,000 f/m$^3$ PCM count on a 37 mm filter is 638,000 to 3,913,000 f/m$^3$. These intervals are an indication of the uncertainty that can arise when interpreting the result of a single field sample with respect to an exposure or clearance standard.

TABLE 5-1. 90% CONFIDENCE LIMITS FOR A SINGLE PCM ANALYSIS BY NIOSH METHOD 7400-B (ASSUMING AN INTERLABORATORY SUBJECTIVE COMPONENT OF .45)

| Fibers counted/ 100 grids | Fibers per Filter | Factor for: Lower Limit | Factor for: Upper Limit | Mean and (Range) of Fiber Concentrations ($f/m^3$) within 90% Confidence Limits for Sample Volumes: 400 liters | 1500 liters | 2500 liters |
|---|---|---|---|---|---|---|
| A. LIMITS FOR 25-mm CELLULOSE ESTER FILTERS | | | | | | |
| * | 500,500 | 0.51 | 3.13 | 1,251,000 (638,000 - 3,916,000) | 334,000 (170,000 - 1,045,000) | 200,000 (102,000 - 626,000) |
| 100 | 49,045 | 0.51 | 3.13 | 123,000 (63,000 - 385,000) | 33,000 (17,000 - 103,000) | 20,000 (10,000 - 63,000) |
| 50 | 24,522 | 0.51 | 3.18 | 61,000 (31,000 - 194,000) | 16,000 (8,000 - 51,000) | 10,000 (5,000 - 32,000) |
| 10 | 4,904 | 0.43 | 3.57 | 12,000 (5,000 - 43,000) | 3,000 (1,000 - 11,000) | 2,000 (1,000 - 7,000) |
| 7 (NIOSH LOD) | 3,433 | 0.40 | 3.78 | 9,000 (4,000 - 34,000) | 2,000 (1,000 - 8,000) | 1,000 (0 - 4,000) |
| 3 (UBTL LOD) | 1,471 | 0.31 | 4.66 | 4,000 (1,000 - 19,000) | 1,000 (0 - 5,000) | 1,000 (0 - 5,000) |
| B. LIMITS FOR 37-mm CELLULOSE ESTER FILTERS | | | | | | |
| * | 1,111,500 | 0.51 | 3.13 | 2,779,000 (1,417,000 - 8,698,000) | 741,000 (378,000 - 2,319,000) | 445,000 (227,000 - 1,393,000) |
| 460 | 500,000 | 0.51 | 3.13 | 1,250,000 (638,000 - 3,913,000) | 333,000 (170,000 - 1,042,000) | 200,000 (102,000 - 626,000) |
| 100 | 108,917 | 0.51 | 3.13 | 272,000 (139,000 - 851,000) | 73,000 (37,000 - 228,000) | 44,000 (22,000 - 138,000) |
| 50 | 54,459 | 0.51 | 3.18 | 136,000 (69,000 - 432,000) | 36,000 (18,000 - 114,000) | 22,000 (11,000 - 70,000) |
| 10 | 10,892 | 0.43 | 3.57 | 27,000 (12,000 - 96,000) | 7,000 (3,000 - 25,000) | 4,000 (2,000 - 14,000) |
| 7 (NIOSH LOD) | 7,624 | 0.40 | 3.78 | 19,000 (8,000 - 72,000) | 5,000 (2,000 - 19,000) | 3,000 (1,000 - 11,000) |
| 3 (UBTL LOD) | 3,268 | 0.31 | 4.66 | 8,000 (2,000 - 37,000) | 2,000 (1,000 - 9,000) | 1,000 (0 - 5,000) |

* Maximum Allowed Loading = 1300 fibers/sq mm.

## 5.3. SAMPLING RESULTS

Subsequent tables summarize data from the four survey reports.[1-4] Appendix A consists of the tables included in each of the facility reports. The tables in Appendix A are based on analytical data obtained by PCM and Magiscan II, tabulated in Appendix B, and by TEM, tabulated in Appendix C.

### 5.3.1. Work Activity Samples

Although this study was not undertaken to determine compliance with asbestos standards, the OSHA PEL (200,000 $f/m^3$) and the NIOSH REL (100,000 $f/m^3$) concentrations are used in the following discussion as points of reference.

#### 5.3.1.1. Personal Samples--

Daily time-weighted-average (TWA) asbestos concentrations for each worker at each facility are shown in Table 5-2. The TWA values reported are the sum of two sequential samples (morning and afternoon of the same day) averaged over the total time of the sampling periods (approximately 5 to 6 hours):

$$TWA = (C_{am} \times T_{am} + C_{pm} \times T_{pm}) \;/\; (T_{am} + T_{pm}); \quad C = \text{Concentration}, \; T = \text{Time}.$$

If one or both of the daily samples were overloaded with particulates so that the fibers could not be counted, the TWA exposures were not calculated. The normal workday consisted of one half-shift (morning) of preparation and one half-shift (afternoon) of removal activities. However, on 4 days (6/20, 6/26, 6/28, and 7/2) both shifts were spent in removal activities and on 4 other days (6/21, 7/3, 7/16, and 7/17) the crew only worked a half shift doing removal activities. As would be expected, the TWA concentrations appear to be somewhat higher on these days (except at Facility 1 on 6/21). Figure 5-1 illustrates the range of the TWA exposures, whereas Figure 5-2 illustrates exposures due to preparation and removal activities, separately.

Included in Table 5-2 are daily area sampling results calculated as a TWA in the same manner as the personal samples. The "Prox" samples were taken proximate to the work activity; the "Dist" samples were taken in the middle of the room at a distance from the work activity. The average concentrations of the personal samples and both types of area samples on any given day are not statistically different (at the 5% significance level), although the actual personal sample measurements are usually somewhat higher.

The upper confidence limits for the PBZ samples were below the 2.0 f/cc (2,000,000 $f/m^3$) OSHA PEL in effect at the time of this study. However, only exposures which occurred in Facility 4 were below the current PEL of 0.2 f/cc (200,000 $f/m^3$). The average TWA exposure over the 3 or 4 days worked in each facility are shown in Table 5-3. Of the 45 daily TWA exposures, 3 (7%) were in excess of 626,000 $f/m^3$, 17 (38%) were in excess of 313,000 $f/m^3$, and 27 (60%) were in excess of 200,000 $f/m^3$; only 13 (29%) were less than 100,000 $f/m^3$.

Table 5-4 shows the average fiber concentrations, as analyzed by PCM, for each room during the preparation activities. These concentrations averaged about 20,000 $f/m^3$. As shown in Table 5-5, fiber concentrations during removal

TABLE 5-2. DAILY TWA SAMPLES DURING ASBESTOS ABATEMENT

| Date/ Activity | Worker | Concentration ($f/m^3$) TWA* | Prox+ | Dist# | Date/ Activity | Worker | Concentration ($f/m^3$) TWA* | Prox+ | Dist# |
|---|---|---|---|---|---|---|---|---|---|
| Facility 1 | | | | | Facility 2 | | | | |
| 6/18 | A | 250,000 | | | 6/25 | A | 30,000 | | |
| Half Shift | B | - | | | Half Shift | B | 340,000 | | |
| Preparation | C | - | | | Preparation | C | 220,000 | | |
| Half Shift | D | 210,000 | | | Half Shift | D | - | | |
| Removal | Avg | 230,000 | 190,000 | 220,000 | Removal | Avg | 200,000 | 270,000 | 310,000 |
| 6/19 | A | 300,000 | | | 6/26 | A | - | | |
| Half Shift | B | 100,000 | | | Full Shift | B | 350,000 | | |
| Preparation | C | 250,000 | | | Removal | C | - | | |
| Half Shift | D | 320,000 | | | | D | 290,000 | | |
| Removal | Avg | 240,000 | 240,000 | 240,000 | | Avg | 320,000 | 140,000 | 170,000 |
| 6/20 | A | 470,000 | | | 6/27 | A | - | | |
| Full Shift | B | 330,000 | | | Half Shift | B | - | | |
| Removal | C | 490,000 | | | Preparation | C | 310,000 | | |
| | D | 310,000 | | | Half Shift | D | - | | |
| | Avg | 400,000 | 270,000 | 260,000 | Removal | Avg | 310,000 | 200,000 | - |
| 6/21 | A | 170,000 | | | 6/28 | A | 250,000 | | |
| Half Shift | B | 120,000 | | | Full Shift | B | 200,000 | | |
| Removal | C | 120,000 | | | Removal | C | 350,000 | | |
| | D | 150,000 | | | | D | - | | |
| | Avg | 140,000 | 110,000 | 110,000 | | Avg | 270,000 | 170,000 | 180,000 |
| Facility 3 | | | | | Facility 4 | | | | |
| 7/1 | A | 350,000 | | | 7/15 | A | 11,000 | | |
| Half Shift | B | 300,000 | | | Half Shift | B | 10,000 | | |
| Preparation | C | 340,000 | | | Preparation | C | 3,000 | | |
| Half Shift | D | 160,000 | | | Half Shift | D | 13,000 | | |
| Removal | Avg | 290,000 | 230,000 | 220,000 | Removal | Avg | 9,000 | 7,000 | 8,000 |
| 7/2 | A | 550,000 | | | 7/16 | A | 15,000 | | |
| Full Shift | B | 560,000 | | | Half Shift | B | 13,000 | | |
| Removal | C | 660,000 | | | Removal | C | - | | |
| | D | 640,000 | | | | D | - | | |
| | Avg | 600,000 | 620,000 | 630,000 | | Avg | 14,000 | 13,000 | 32,000 |
| 7/3 | A | 800,000 | | | 7/17 | A | 9,000 | | |
| Half Shift | B | 410,000 | | | Half Shift | B | 5,000 | | |
| Removal | C | 480,000 | | | Removal | C | 8,000 | | |
| | D | 610,000 | | | | D | 10,000 | | |
| | Avg | 570,000 | 620,000 | 550,000 | | Avg | 8,000 | 4,000 | 9,000 |

* Time-Weighted Average over actual working time = 4 to 6 hours.
\+ Average of area samples taken proximate to removal operations.
\# Average of area samples taken in the room but at a distance from operations

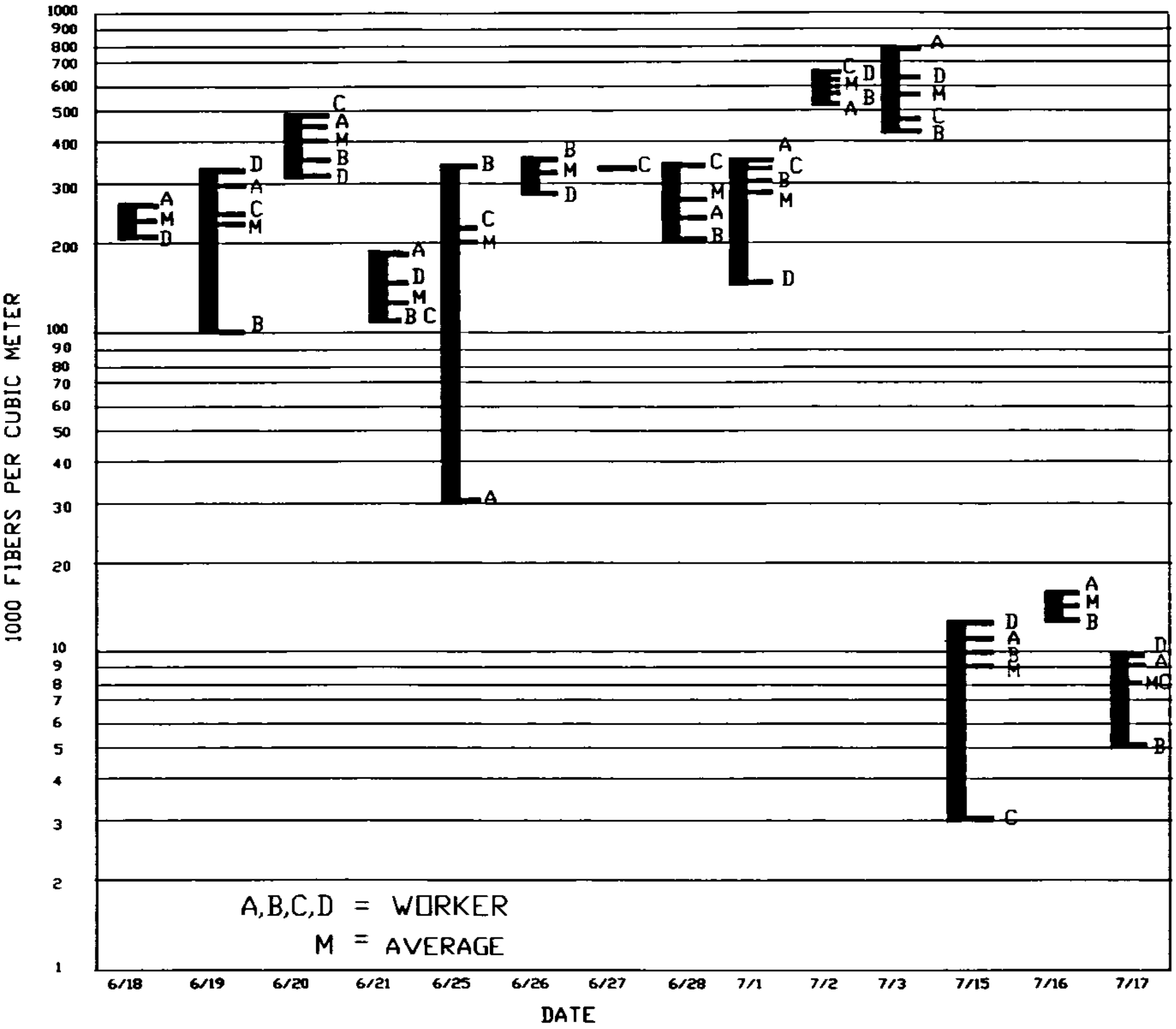



FIGURE 5-1. TWA PERSONAL SAMPLES DURING ASBESTOS ABATEMENT

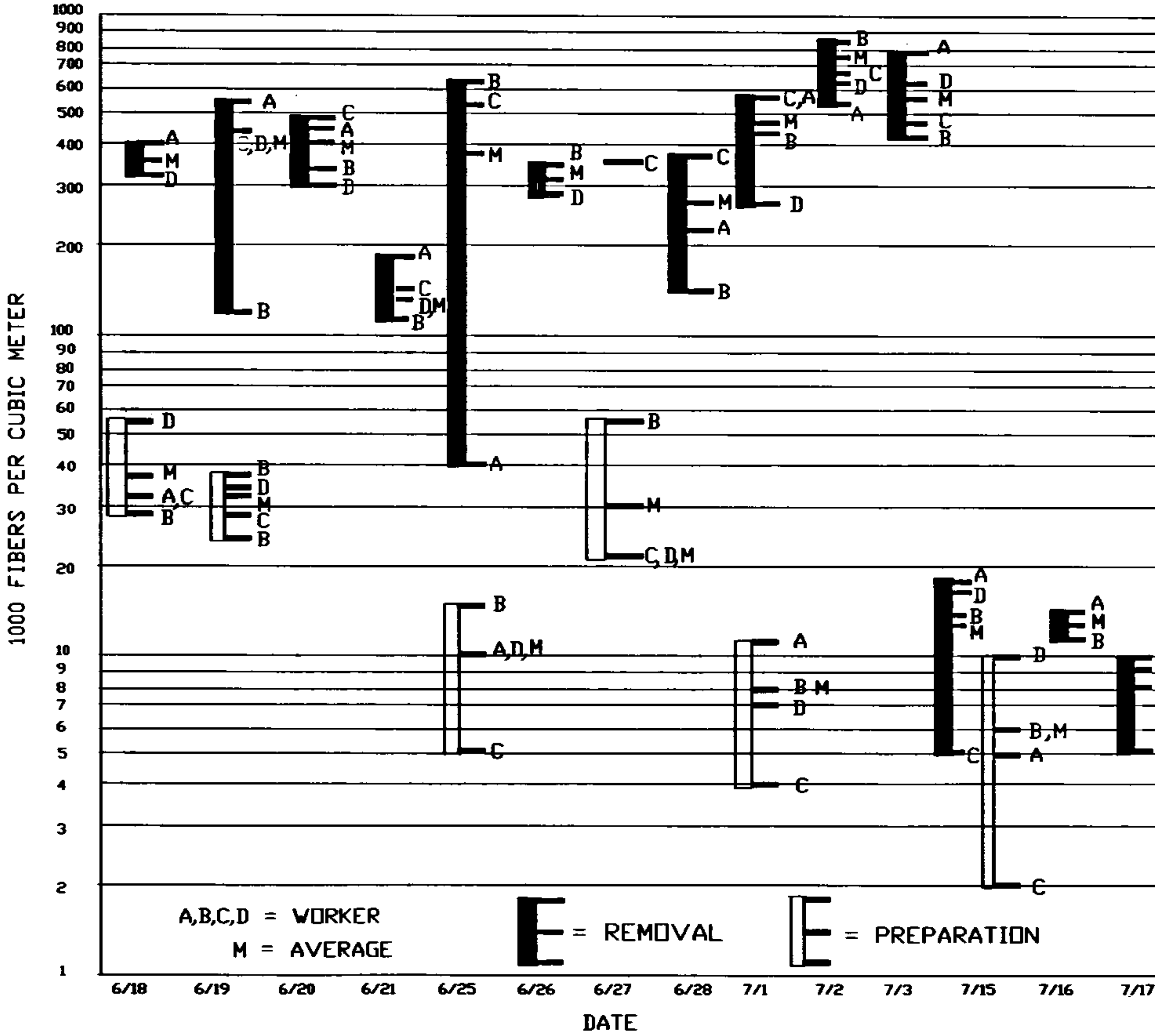



FIGURE 5-2. PERSONAL EXPOSURE DURING PREPARATION AND REMOV
OF ASBESTOS-CONTAINING PIPE LAGGING

TABLE 5-3. AVERAGE TWA* PERSONAL SAMPLES DURING ASBESTOS ABATEMENT

| Worker | Concentration ($f/m^3$) Average | Range | Total Samples | Number of Samples Having Concentration ($f/m^3$) Greater Than 626,000 | 313,000 | 200,000 | 100,000 |
|---|---|---|---|---|---|---|---|
| Facility 1 | | | | | | | |
| A | 300,000 | 170,000 - 470,000 | 4 | 0 | 1 | 3 | 4 |
| B | 180,000 | 100,000 - 330,000 | 3 | 0 | 1 | 1 | 2 |
| C | 290,000 | 120,000 - 490,000 | 3 | 0 | 1 | 2 | 3 |
| D | 250,000 | 150,000 - 320,000 | 4 | 0 | 1 | 3 | 3 |
| Facility | 260,000 | 100,000 - 490,000 | 14 | 0 | 4 | 9 | 12 |
| Facility 2 | | | | | | | |
| A | 140,000 | 20,000 - 250,000 | 2 | 0 | 0 | 1 | 1 |
| B | 290,000 | 200,000 - 350,000 | 3 | 0 | 2 | 2 | 3 |
| C | 300,000 | 220,000 - 350,000 | 3 | 0 | 1 | 3 | 3 |
| D | 290,000 | 290,000 | 1 | 0 | 0 | 1 | 1 |
| Facility | 260,000 | 20,000 - 350,000 | 9 | 0 | 3 | 7 | 8 |
| Facility 3 | | | | | | | |
| A | 560,000 | 350,000 - 800,000 | 3 | 1 | 3 | 3 | 3 |
| B | 420,000 | 300,000 - 560,000 | 3 | 0 | 2 | 3 | 3 |
| C | 490,000 | 340,000 - 660,000 | 3 | 1 | 3 | 3 | 3 |
| D | 470,000 | 160,000 - 640,000 | 3 | 1 | 2 | 2 | 3 |
| Facility | 490,000 | 160,000 - 800,000 | 12 | 3 | 10 | 11 | 12 |
| Facility 4 | | | | | | | |
| A | 12,000 | 9,000 - 15,000 | 3 | 0 | 0 | 0 | 0 |
| B | 9,000 | 5,000 - 15,000 | 3 | 0 | 0 | 0 | 0 |
| C | 6,000 | 3,000 - 8,000 | 2 | 0 | 0 | 0 | 0 |
| D | 12,000 | 10,000 - 13,000 | 2 | 0 | 0 | 0 | 0 |
| Facility | 10,000 | 3,000 - 15,000 | 10 | 0 | 0 | 0 | 0 |
| Overall | | | | | | | |
| Average | 250,000 | | | | | | |
| Range | | 3,000 - 800,000 | | | | | |
| Total | | | 45 | 3 | 17 | 27 | 32 |

* Time-Weighted Average over actual working time = 4 to 6 hours.

TABLE 5-4. SUMMARY OF SAMPLING RESULTS DURING PREPARATION FOR PIPE LAGGING REMOVAL

| Facility/ Location | Samples Type | Number | Concentration ($f/m^3$) Average | Minimum | Maximum |
|---|---|---|---|---|---|
| 1/Room A | Personal | 4 | 33,000 | 26,000 | 37,000 |
| | Personal - Short Term | 1 | 30,000 | | |
| | Area - Proximate | 2 | 19,000 | 9,000 | 29,000 |
| | Area - Distant | 2 | 13,000 | 9,000 | 17,000 |
| 1/Room B | Personal | 4 | 37,000 | 29,000 | 54,000 |
| | Personal - Short Term | 0 | | | |
| | Area - Proximate | 4 | 30,000 | 23,000 | 40,000 |
| | Area - Distant | 2 | 20,000 | | |
| 1/Room C was prepared by a different work crew. | | | | | |
| 2/Room D | Personal | 4 | 10,000 | 5,000 | 16,000 |
| | Personal - Short Term | 3 | 20,000 | 17,000 | 25,000 |
| | Area - Proximate | 2 | 12,000 | 11,000 | 14,000 |
| | Area - Distant | 2 | 14,000 | 13,000 | 16,000 |
| 2/Room E | Personal | 4 | 30,000 | 22,000 | 54,000 |
| | Personal - Short Term | 4 | 39,000 | 33,000 | 45,000 |
| | Area - Proximate | 2 | 23,000 | 23,000 | 23,000 |
| | Area - Distant | 2 | 16,000 | 12,000 | 19,000 |
| 3/Room F | Personal | 4 | 8,000 | 4,000 | 11,000 |
| | Personal - Short Term | 2 | 17,000 | 16,000 | 17,000 |
| | Area - Proximate | 2 | 4,000 | 3,000 | 4,000 |
| | Area - Distant | 2 | 6,000 | 4,000 | 8,000 |
| 3/Room G was prepared by a different work crew. | | | | | |
| 4/Room H+I | Personal | 4 | 6,000 | 2,000 | 10,000 |
| 4/Room I | Personal - Short Term | 4 | 9,000 | 2,000 | 16,000 |
| 4/Room H | Area - Proximate | 2 | 7,000 | 6,000 | 8,000 |
| 4/Room H | Area - Distant | 2 | 8,000 | 3,000 | 13,000 |

TABLE 5-5. SUMMARY OF SAMPLING RESULTS DURING PIPE LAGGING REMOVAL

| Facility/ Location | Samples Type | Number | Concentration ($f/m^3$) Average | Minimum | Maximum | STD |
|---|---|---|---|---|---|---|
| 1/Room A | Personal | 8 | 430,000 | 120,000 | 640,000 | 160,000 |
| | Personal - Short Term | 8 | 900,000 | 520,000 | 1,190,000 | 220,000 |
| | Area - Proximate | 4 | 410,000 | 290,000 | 490,000 | 90,000 |
| | Area - Distant | 4 | 470,000 | 340,000 | 590,000 | 140,000 |
| 1/Room B | Personal | 2 | 360,000 | 320,000 | 400,000 | |
| | Personal - Short Term | 0 | | | | |
| | Area - Proximate | 2 | 360,000 | 310,000 | 410,000 | |
| | Area - Distant | 2 | 410,000 | 380,000 | 440,000 | |
| 1/Room C | Personal | 8 | 200,000 | 120,000 | 530,000 | 150,000 |
| | Personal - Short Term | 7 | 470,000 | 140,000 | 1,120,000 | 330,000 |
| | Area - Proximate | 4 | 150,000 | 100,000 | 200,000 | 50,000 |
| | Area - Distant | 4 | 160,000 | 90,000 | 230,000 | 60,000 |
| 2/Room D | Personal | 10 | 330,000 | 43,000 | 610,000 | 170,000 |
| | Personal - Short Term | 16 | 790,000 | 190,000 | 2,920,000 | 680,000 |
| | Area - Proximate | 8 | 300,000 | 90,000 | 580,000 | 180,000 |
| | Area - Distant | 7 | 280,000 | 30,000 | 770,000 | 250,000 |
| 2/Room E | Personal | 7 | 270,000 | 60,000 | 450,000 | 130,000 |
| | Personal - Short Term | 7 | 540,000 | 70,000 | 1,930,000 | 640,000 |
| | Area - Proximate | 4 | 170,000 | 50,000 | 330,000 | 120,000 |
| | Area - Distant | 4 | 180,000 | 90,000 | 340,000 | 120,000 |
| 3/Room F | Personal | 8 | 470,000 | 170,000 | 1,030,000 | 230,000 |
| | Personal - Short Term | 9 | 960,000 | 160,000 | 2,440,000 | 640,000 |
| | Area - Proximate | 6 | 450,000 | 20,000 | 940,000 | 350,000 |
| | Area - Distant | 6 | 440,000 | 260,000 | 560,000 | 120,000 |
| 3/Room G | Personal | 12 | 670,000 | 260,000 | 1,410,000 | 340,000 |
| | Personal - Short Term | 8 | 2,660,000 | 620,000 | 9,290,000 | 2,830,000 |
| | Area - Proximate | 4 | 710,000 | 570,000 | 960,000 | 170,000 |
| | Area - Distant | 4 | 670,000 | 470,000 | 820,000 | 150,000 |
| 4/Room H | Personal | 4 | 14,000 | 5,000 | 18,000 | 6,000 |
| | Personal - Short Term | 5 | 31,000 | 22,000 | 43,000 | 9,000 |
| | Area - Proximate | 2 | 7,000 | 6,000 | 8,000 | |
| | Area - Distant | 2 | 7,000 | 5,000 | 8,000 | |
| 4/Room I | Personal | 2 | 14,000 | 13,000 | 15,000 | |
| | Personal - Short Term | 4 | 92,000 | 16,000 | 200,000 | 77,000 |
| | Area - Proximate | 1 | 13,000 | | | |
| | Area - Distant | 2 | 32,000 | 13,000 | 51,000 | |
| 4/Room J | Personal | 6 | 10,000 | 1,000 | 23,000 | 8,000 |
| | Personal - Short Term | 6 | 24,000 | 16,000 | 44,000 | 12,000 |
| | Area - Proximate | 4 | 4,000 | 1,000 | 7,000 | 3,000 |
| | Area - Distant | 4 | 6,000 | 2,000 | 11,000 | 4,000 |

operations averaged about 350,000 f/$m^3$ and were an order-of-magnitude greater than exposures observed during preparation, except in Facility 4.

Results from the 15-minute, short-term samples are also shown in Tables 5-4 and 5-5. Of the 70 short-term samples reported in Table 5-5, 15 (21%) exceeded 1,000,000 f/$m^3$. The highest exposure exceeded 9,000,000 f/$m^3$. This occurred during the second day at Facility 3 when a 10-foot section of lagging suddenly separated from the pipe and fell into the poly envelope. A worker cut the envelope to reach in and push large pieces of lagging into the glove bag at the end of the envelope. Although this action was quickly curtailed and the envelope was resealed with tape, the personal exposures were undoubtedly elevated by this episode. Exposures would certainly have been even higher had the lagging fallen to the floor and shattered.

All of the above fiber concentrations were determined by PCM. In order to provide a comparison with TEM analyses, 16 PBZ samples collected on cellulose ester filters in Facility 1 were analyzed by both PCM and by TEM. These were selected to include two sequential daily samples for each worker and also to provide a variety of high to low concentrations as determined by PCM; the results are compared in Table 5-6. The TEM analyses reported for total asbestos structures indicate levels an order-of-magnitude higher than for the fibers reported when the same samples were analyzed by PCM. The sample collected on 6/18 for Worker B, erroneously reported to be <LOD, was later found to be actually obscured by particulate so that the fibers could not be counted by PCM. Particulate did not obscure asbestos structures for the TEM analysis because of the greater power of resolution.

5.3.1.2. Area Samples--

As stated previously, the results of area samples analyzed by PCM indicated fiber concentrations of the same magnitude as the PBZ samples collected during removal; this is shown in Tables 5-2 and 5-5.

The fiber concentration measured by the area samples taken in the corridors adjacent to the poly-baffled door openings varied greatly in relation to the interior area samples (Appendix A, Tables 3A-1 through 4A-4). The frequency of entry and exit through the baffles should affect these sampling locations. In addition, activities including asbestos removal were taking place in other parts of the building. However, with one exception, all were lower (from 5% to 67%) than concentrations measured within the rooms during asbestos removal operations, indicating that the poly baffles were fairly effective in controlling the escape of airborne fibers released in the survey rooms. Twenty four of twenty eight ambient samples taken outside the buildings were below the LOD (1,000 to 2,000 f/$m^3$).

5.3.1.3. Discussion of Work Activity Exposure Results

Data shown in Tables 5-2 through 5-5 indicate that during the preparation (covering) of the pipe lagging workers were exposed to relatively low concentrations of airborne asbestos. In the rooms included in this survey, most of the pipe lagging was in good condition. In other situations, where lagging is deteriorated or damaged, it is quite probable that higher concentrations of airborne asbestos would be encountered during these operations.

TABLE 5-6. TWA* CONCENTRATIONS CALCULATED FROM TEM AND PCM ANALYSES

| Worker | Date | Activity | TEM Analysis | | | | PCM Analysis |
|---|---|---|---|---|---|---|---|
| | | | Structures ($s/m^3$) | | Fibers ($f/m^3$) | | Fibers ($f/m^3$) |
| | | | Total | Asbestos | Total | Asbestos | |
| A | 6/19 | Preparation | 10,000 | 10,000 | 10,000 | 10,000 | 26,000 |
| | 6/19 | Removal | 6,850,000 | 1,830,000 | 4,110,000 | 720,000 | 550,000 |
| | TWA | | 3,570,000 | 960,000 | 2,140,000 | 380,000 | 470,000 |
| | 6/21 | Removal | 3,750,000 | 1,910,000 | 2,100,000 | 560,000 | 170,000 |
| B | 6/18 | Preparation | 370,000 | 250,000 | 290,000 | 180,000 | 29,000 |
| | 6/18 | Removal | 4,920,000 | 3,600,000 | 2,040,000 | 1,020,000 | ---- |
| | TWA | | 3,040,000 | 2,220,000 | 1,320,000 | 670,000 | ---- |
| | 6/19 | Preparation | 0 | 0 | 0 | 0 | 37,000 |
| | 6/19 | Removal | 4,370,000 | 2,170,000 | 2,560,000 | 550,000 | 120,000 |
| | TWA | | 3,130,000 | 1,550,000 | 1,830,000 | 400,000 | 100,000 |
| | 6/20 | Removal | 3,360,000 | 1,840,000 | 2,310,000 | 890,000 | 360,000 |
| | 6/20 | Removal | 4,540,000 | 2,340,000 | 2,480,000 | 570,000 | 300,000 |
| | TWA | | 4,000,000 | 2,110,00 | 2,400,000 | 710,000 | 330,000 |
| C | 6/20 | Removal | 6,550,000 | 2,900,000 | 4,530,000 | 1,320,000 | 550,000 |
| | 6/20 | Removal | 5,670,000 | 4,040,000 | 3,310,000 | 1,890,000 | 430,000 |
| | TWA | | 6,070,000 | 3,520,000 | 3,860,000 | 1,630,000 | 490,000 |
| | 6/21 | Removal | 3,780,000 | 2,270,000 | 2,460,000 | 1,210,000 | 120,000 |
| D | 6/18 | Preparation | 1,270,000 | 50,000 | 1,140,000 | 10,000 | 54,000 |
| | 6/18 | Removal | 5,080,000 | 2,870,000 | 3,340,000 | 1,220,000 | 320,000 |
| | TWA | | 3,510,000 | 1,710,000 | 2,430,000 | 720,000 | 210,000 |
| | 6/20 | Removal | 4,250,000 | 2,590,000 | 2,050,000 | 660,000 | 320,000 |
| | 6/20 | Removal | 4,140,000 | 2,110,000 | 2,660,000 | 930,000 | 290,000 |
| | TWA | | 4,190,000 | 2,330,000 | 2,370,000 | 800,000 | 310,000 |

* Time-Weighted Average over actual working time = 4 to 6 hours.

As described in Section 3.2.2.2., poor work practices were used by the workers at the beginning of the survey. The survey team attempted to instruct the workers in proper techniques the first week. During the second week, the workers were shown a training video, and proper techniques to be used in removing asbestos pipe lagging in glove bags were demonstrated by an instructor from the National Asbestos Council. The workers were observed to adopt many of the demonstrated techniques at the third facility, but the accident described above quite likely increased exposure levels. The high short-time exposure measured (greater than 9,000,000 f/m$^3$) would take some time to dissipate in the sealed room, thereby increasing the TWA exposures. Removal at the last facility was observed to be performed by the application of most of the proper techniques demonstrated by the instructor most of the time.

Sampling results shown in Table 5-5 indicate that fiber concentrations were in the same range for Rooms A through F when lagging was being removed. Average personal exposures in Rooms A and F were about 400,000 f/m$^3$ during these activities; Room G exhibited the highest concentrations (average 850,000 f/m$^3$) which were probably caused by the accidental release. Rooms H, I, and J in Facility 4 were all well below 100,000 f/m$^3$. Fiber concentrations in this facility were significantly lower ($p = 0.05$) than the other facilities.

Although factors such as a different type of lagging (e.g., lower asbestos content, less friable), improved cleanliness of the site before removal, etc., could have influenced the results, it was the opinion of the research team that these conditions were about equivalent in all of the facilities. The low exposure concentrations measured in Facility 4 may have occurred as result of changes in work practice that were observed during the removal of the pipe lagging. The present study did not permit a clear association between work practice and exposure level, however, due to the small number of sites that were studied.

5.3.2. Environmental Sampling

A comparison of pre- and post-removal sampling by both aggressive and nonaggressive procedures was made for two rooms in each of the four facilities. For each comparison, samples were taken using three 25 mm diameter cellulose ester filters, three 37 mm cellulose ester filters, and three 37 mm polycarbonate filters. The cellulose ester filters were analyzed using PCM; approximately 60% at UBTL and 40% in the NIOSH laboratory. About 15% of these samples were split and analyzed by both laboratories. The arithmetic mean of the NIOSH results was about 1.5 times that of the UBTL results, but this difference is not surprising in view of the interlaboratory CV of 0.45.

The post-removal samples were collected after the room had been cleaned, but before the visual inspection and final clearance sampling by the contractor. The results shown in Table 5-7 are the arithmetic means for the PCM samples broken down by location, sampling method, filter type, and pre- or post-removal status. A separate tabulation also groups the samples by facility. Much higher fiber concentrations were obtained by aggressive sampling than by nonaggressive sampling. Of 109 nonaggressive samples, 44 (48.6%) were at levels greater than 1,000 f/m$^3$. Of the 111 aggressive samples, 97 (87.4%) were greater than 1,000 f/m$^3$. The aggressive sampling data indicate that

TABLE 5-7. AVERAGE ASBESTOS CONTAMINATION IN ROOMS AND FACILITIES (PCM ANALYSES)

| ROOM | Sampling Conditions | Non-Aggressive Sampling 25-mm Filter f/m³ | n | 37-mm Filter f/m³ | n | Average f/m³ | n | Aggressive Sampling 25-mm Filter f/m³ | n | 37-mm Filter f/m³ | n | Average f/m³ | n |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | Pre-Removal | 2,000 | 3 | 2,000 | 3 | 2,000 | 6 | 12,000 | 3 | 31,000 | 5 | 23,000 | 8 |
| | Post-Removal | 4,000 | 3 | 3,000 | 3 | 4,000 | 6 | 14,000 | 3 | 20,000 | 3 | 17,000 | 6 |
| B | Pre-Removal | 9,000 | 6 | 6,000 | 3 | 8,000 | 9 | 20,000 | 5 | 29,000 | 5 | 24,000 | 10 |
| | Post-Removal | 3,000 | 3 | 11,000 | 3 | 7,000 | 6 | 42,000 | 3 | 27,000 | 3 | 35,000 | 6 |
| D | Pre-Removal | 1,000 | 3 | 1,000 | 3 | 1,000 | 6 | 2,000 | 3 | 1,000 | 3 | 2,000 | 6 |
| | Post-Removal | 2,000 | 4 | 1,000 | 3 | 2,000 | 7 | 11,000 | 5 | 19,000 | 6 | 15,000 | 11 |
| E | Pre-Removal | 2,000 | 3 | 1,000 | 3 | 2,000 | 6 | 11,000 | 3 | 22,000 | 3 | 17,000 | 6 |
| | Post-Removal | 3,000 | 4 | 4,000 | 5 | 4,000 | 9 | 22,000 | 3 | 53,000 | 6 | 43,000 | 9 |
| F | Pre-Removal | 1,000 | 3 | 2,000 | 3 | 2,000 | 6 | 3,000 | 2 | 12,000 | 3 | 8,000 | 5 |
| | Post-Removal | 1,000 | 3 | 1,000 | 3 | 1,000 | 6 | 15,000 | 3 | 25,000 | 3 | 20,000 | 6 |
| G | Pre-Removal | 1,000 | 3 | 5,000 | 3 | 3,000 | 6 | 51,000 | 3 | 100,000 | 3 | 76,000 | 6 |
| | Post-Removal | 1,000 | 3 | 1,000 | 3 | 1,000 | 6 | 1,000 | 3 | 3,000 | 3 | 2,000 | 6 |
| H | Pre-Removal | 1,000 | 3 | 2,000 | 3 | 1,000 | 6 | 3,000 | 3 | 6,000 | 3 | 4,000 | 6 |
| | Post-Removal | 2,000 | 4 | 3,000 | 5 | 2,000 | 9 | 2,000 | 4 | 2,000 | 3 | 2,000 | 7 |
| I | Pre-Removal | 2,000 | 3 | 1,000 | 3 | 2,000 | 6 | 6,000 | 3 | 17,000 | 2 | 10,000 | 5 |
| | Post-Removal | 2,000 | 4 | 2,000 | 5 | 2,000 | 9 | 4,000 | 4 | 3,000 | 4 | 4,000 | 8 |
| FACILITY | | | | | | | | | | | | | |
| 1 | Pre-Removal | 7,000 | 9 | 4,000 | 6 | 6,000 | 15 | 17,000 | 8 | 30,000 | 10 | 24,000 | 18 |
| | Post-Removal | 3,000 | 7 | 7,000 | 6 | 5,000 | 12 | 28,000 | 6 | 24,000 | 6 | 26,000 | 12 |
| 2 | Pre-Removal | 2,000 | 6 | 1,000 | 6 | 1,000 | 12 | 7,000 | 6 | 12,000 | 6 | 9,000 | 12 |
| | Post-Removal | 3,000 | 8 | 3,000 | 8 | 3,000 | 16 | 15,000 | 8 | 36,000 | 12 | 28,000 | 20 |
| 3 | Pre-Removal | 1,000 | 6 | 4,000 | 6 | 2,000 | 12 | 10,000 | 5 | 56,000 | 6 | 45,000 | 11 |
| | Post-Removal | 1,000 | 6 | 1,000 | 6 | 1,000 | 12 | 8,000 | 6 | 14,000 | 6 | 11,000 | 12 |
| 4 | Pre-Removal | 2,000 | 6 | 2,000 | 6 | 2,000 | 12 | 5,000 | 6 | 10,000 | 5 | 7,000 | 11 |
| | Post-Removal | 2,000 | 8 | 3,000 | 10 | 2,000 | 18 | 3,000 | 8 | 3,000 | 7 | 3,000 | 15 |

* This table shows average asbestos contamination in rooms and facilities by PCM analysis using 25- and 37-mm filters applying both aggressive and nonaggressive sampling methods.

after initial cleaning, fiber contamination increased in Rooms D, E, and F as a result of the removal operations, but that Rooms G and I were less contaminated after cleaning.

Outdoor ambient asbestos concentrations were determined using two 25 mm diameter cellulose filters on each day of testing. Asbestos concentrations of two samples were 1,000 f/m$^3$ and the other 16 were less than the LOD.

TEM results are reported as structures per cubic centimeter (s/cc). Structures include fibers, bundles (compact arrangements of parallel fibers in which separate fibers or fibrils may be visible at the ends or edges of the bundle), clumps (networks of randomly oriented interlocking fibers arranged so that no fiber is isolated from the group), and matrices (one or more fibers attached to or embedded in a nonasbestos particle). The analyses indicate that most of the structures in this study were individual fibers. Total structures determined by TEM should be approximately comparable to fibers as determined by PCM if only fibers visible to PCM were collected on the filter. However, because there are no studies that the authors are aware of to demonstrate the comparability of TEM counts to PCM counts, the use of "structures" for TEM analyses and "fibers" for PCM analyses is used in the present study for clarity. In practice, there are normally many small fibers visible by TEM but not PCM, so that TEM counts are often much higher than the PCM counts.

The polycarbonate filters from the first two facilities were analyzed by TEM in the NIOSH laboratory. Samples collected in Facilities 3 and 4 were originally analyzed in another laboratory using an older electron microscope and, in most cases, the presence of asbestos structures was not identified. A few of these samples were reanalyzed in the NIOSH laboratory and asbestos structure concentrations comparable to those in Facilities 1 and 2 were found. Although it would have been desirable to have all of the samples analyzed in the NIOSH laboratory, only the aggressive sampling filters collected in Facilities 3 and 4 were reanalyzed because of limits on time and resources.

Table 5-8 shows the arithmetic mean of the analytical results for total structures, asbestos structures, total fibers, and asbestos fibers reported for pre- and post-removal, aggressive, and nonaggressive sampling. The average fiber concentrations by PCM (from Table 5-7) are also included in Table 5-8 for ease of comparison. The averages of the asbestos structure analyses are plotted graphically in Figure 5-3.

Figure 5-4 is a graphic comparison of total fibers by PCM and TEM. The TEM counts for nonaggressive sampling are one to two orders of magnitude greater than the PCM counts and about one order of magnitude greater for aggressive sampling. Because the PCM analyses do not discriminate between asbestos and nonasbestos fibers, PCM results are compared to the total fiber concentrations identified by TEM. It is important to note, however, that using Method 7400B[14] only fibers greater than ca. 0.25 in diameter and 5 µm in length with a 5:1 aspect ratio were counted, whereas the TEM total fiber counts include all fibers having a minimum length of 0.5 µm and an aspect ratio of 5:1.[19] The relationship between TEM and PCM analytical results clearly needs better definition; however, it is beyond the scope of the present study.

TABLE 5-8. AVERAGE ASBESTOS CONTAMINATION BY ROOM AND FACILITY (TEM ANALYSES)

| ROOM | Sampling Conditions | Non-Aggressive Sampling: TEM Structures ($s/m^3$) Total | Non-Aggressive Sampling: TEM Structures ($s/m^3$) Asbestos | Non-Aggressive Sampling: PCM ($f/m^3$) Total | Non-Aggressive Sampling: TEM Fibers ($f/m^3$) Total | Non-Aggressive Sampling: TEM Fibers ($f/m^3$) Asbestos | Aggressive Sampling: TEM Structures ($s/m^3$) Total | Aggressive Sampling: TEM Structures ($s/m^3$) Asbestos | Aggressive Sampling: PCM ($f/m^3$) Total | Aggressive Sampling: TEM Fibers ($f/m^3$) Total | Aggressive Sampling: TEM Fibers ($f/m^3$) Asbestos |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A | Pre-Removal | 290,000 | 90,000 | 2,000 | 280,000 | 80,000 | 900,000 | 140,000 | 23,000 | 850,000 | 130,000 |
| | Post-Removal | 240,000 | 70,000 | 4,000 | 180,000 | 60,000 | 610,000 | 250,000 | 17,000 | 530,000 | 210,000 |
| B | Pre-Removal | 70,000 | 70,000 | 8,000 | 60,000 | 50,000 | 350,000 | 190,000 | 24,000 | 310,000 | 150,000 |
| | Post-Removal | 370,000 | 230,000 | 7,000 | 350,000 | 220,000 | 840,000 | 560,000 | 35,000 | 610,000 | 410,000 |
| D | Pre-Removal | 310,000 | 110,000 | 1,000 | 290,000 | 100,000 | 140,000 | 50,000 | 2,000 | 140,000 | 50,000 |
| | Post-Removal | 920,000 | 350,000 | 2,000 | 870,000 | 330,000 | 1,710,000 | 360,000 | 15,000 | 1,540,000 | 300,000 |
| E | Pre-Removal | 90,000 | 60,000 | 2,000 | 80,000 | 50,000 | 1,130,000 | 180,000 | 17,000 | 1,050,000 | 170,000 |
| | Post-Removal | 320,000 | 170,000 | 4,000 | 280,000 | 140,000 | 1,820,000 | 210,000 | 43,000 | 1,450,000 | 130,000 |
| F | Pre-Removal | | | 2,000 | | | 230,000 | 60,000 | 8,000 | 200,000 | 40,000 |
| | Post-Removal | | | 1,000 | | | 260,000 | 100,000 | 20,000 | 230,000 | 80,000 |
| G | Pre-Removal | | | 3,000 | | | 440,000 | 200,000 | 76,000 | 310,000 | 120,000 |
| | Post-Removal | | | 1,000 | | | 230,000 | 150,000 | 2,000 | 200,000 | 130,000 |
| H | Pre-Removal | | | 2,000 | | | 1,140,000 | 240,000 | 4,000 | 1,030,000 | 200,000 |
| | Post-Removal | | | 3,000 | | | 280,000 | 70,000 | 2,000 | 240,000 | 60,000 |
| I | Pre-Removal | | | 2,000 | | | 520,000 | 310,000 | 10,000 | 400,000 | 210,000 |
| | Post-Removal | | | 2,000 | | | 1,130,000 | 90,000 | 4,000 | 910,000 | 70,000 |
| FACILITY | | | | | | | | | | | |
| 1 | Pre-Removal | 180,000 | 80,000 | 6,000 | 170,000 | 70,000 | 630,000 | 170,000 | 24,000 | 580,000 | 140,000 |
| | Post-Removal | 300,000 | 150,000 | 5,000 | 270,000 | 140,000 | 700,000 | 380,000 | 26,000 | 560,000 | 310,000 |
| 2 | Pre-Removal | 200,000 | 90,000 | 1,000 | 190,000 | 70,000 | 640,000 | 120,000 | 9,000 | 590,000 | 110,000 |
| | Post-Removal | 620,000 | 260,000 | 3,000 | 570,000 | 230,000 | 1,760,000 | 280,000 | 28,000 | 1,490,000 | 220,000 |
| 3 | Pre-Removal | | | 2,000 | | | 340,000 | 130,000 | 45,000 | 260,000 | 80,000 |
| | Post-Removal | | | 1,000 | | | 250,000 | 130,000 | 11,000 | 210,000 | 110,000 |
| 4 | Pre-Removal | | | 2,000 | | | 830,000 | 270,000 | 7,000 | 710,000 | 200,000 |
| | Post-Removal | | | 2,000 | | | 700,000 | 80,000 | 3,000 | 570,000 | 60,000 |

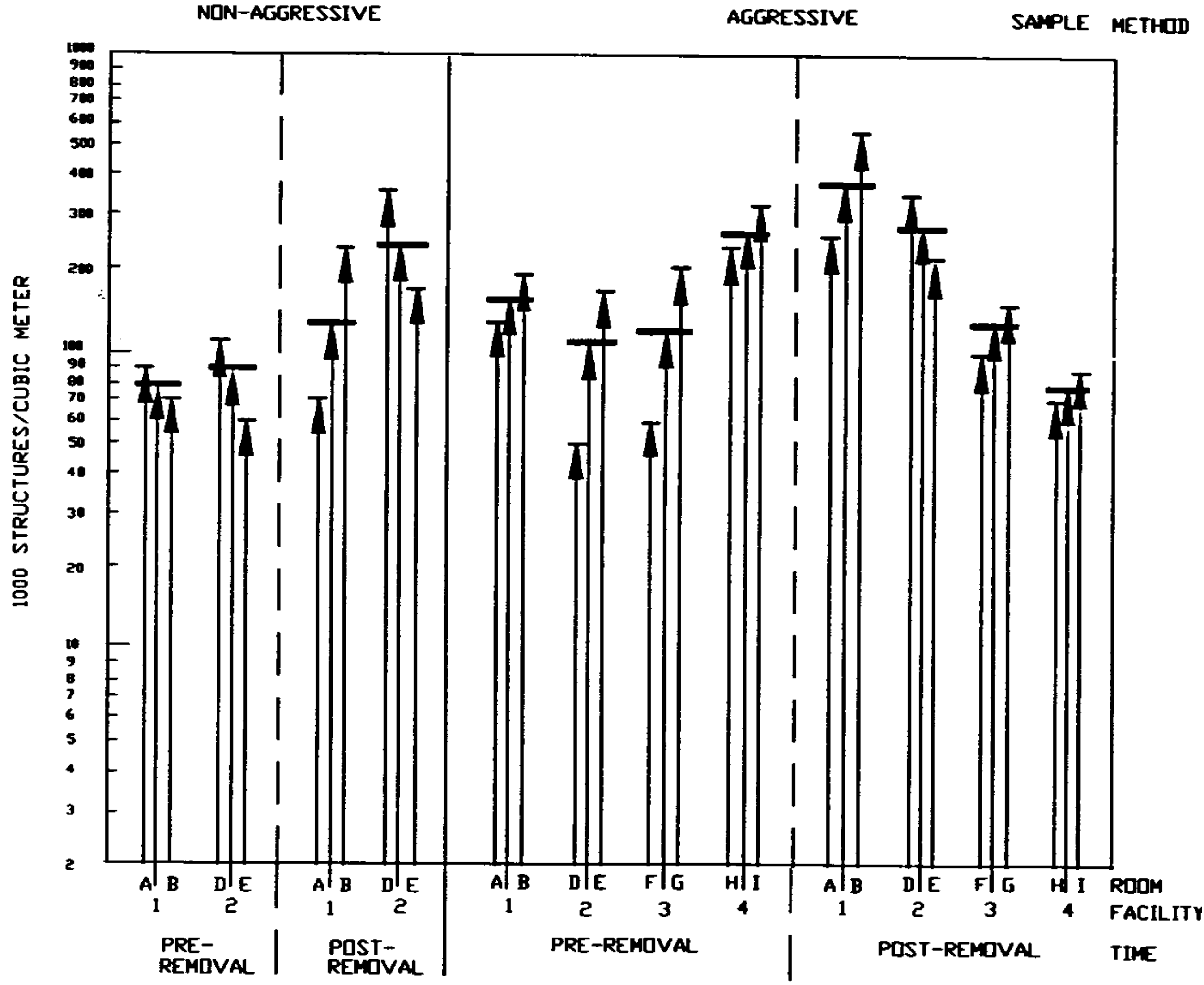



FIG 5-3. AVERAGE ASBESTOS STRUCTURES BY TEM ANALYSIS

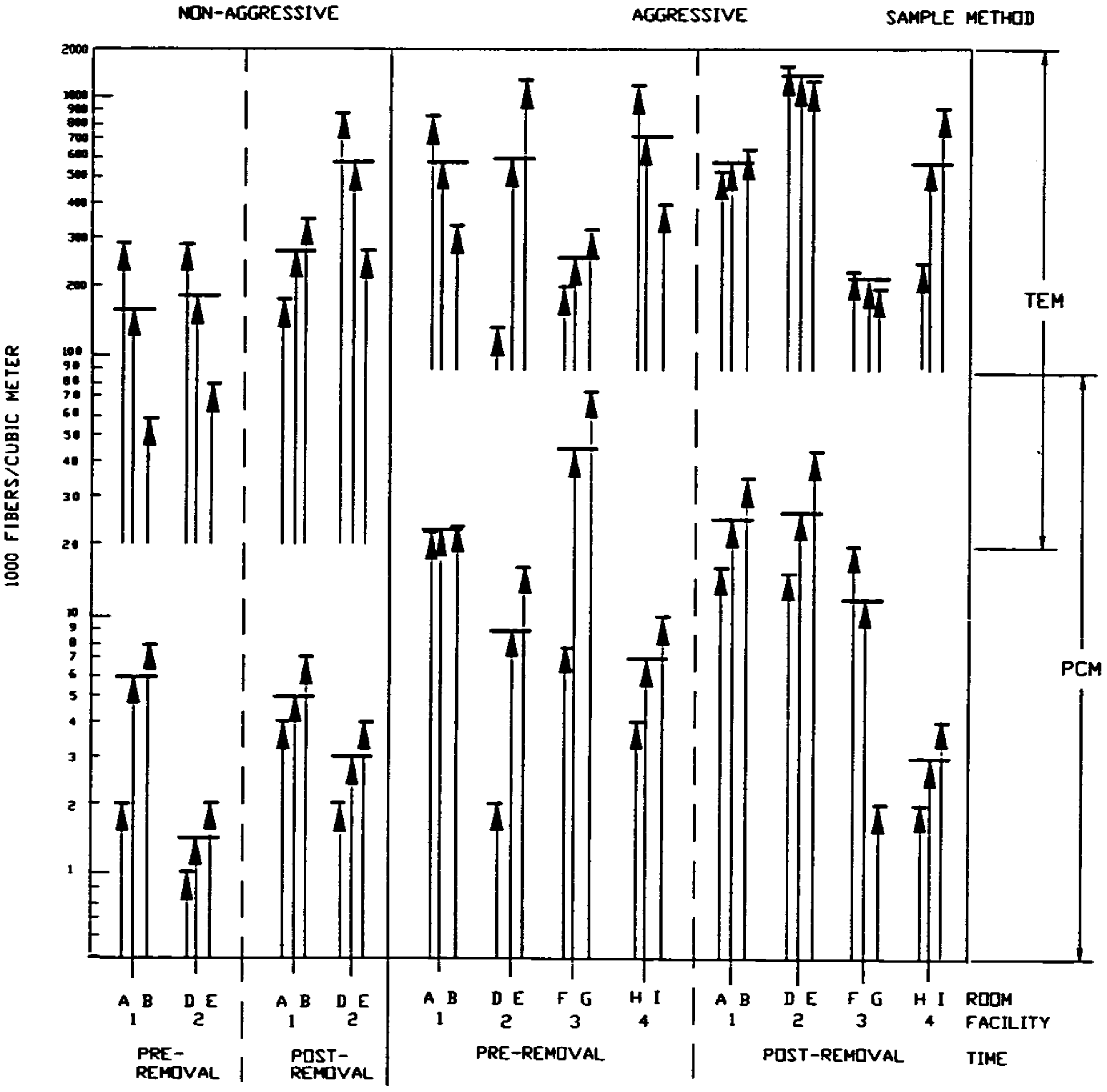



FIG 5-4. COMPARISON OF TOTAL FIBERS BY PCM AND TEM ANALYSIS

**NOTE:** Using Method 7400B[14] only fibers greater than about 0.25 μm in diameter and 5 μm in length with a 5:1 aspect ratio were counted, whereas the TEM total fiber counts include all fibers having a minimum length of 0.5 μm and an aspect ratio of 5:1.[11] The large difference in fiber concentrations are mainly due to the preponderance of small fibers not visible by PCM.

An analysis of the TEM data was made to determine whether the asbestos levels increased as a result of removal operations. The following comparisons were made using analysis of variance (ANOVA) on the log-transformed data:

a.) pre-removal asbestos nonaggressive structure and fiber counts were compared to post-removal counts,

b.) pre-removal asbestos aggressive structure and fiber counts were compared to post-removal counts,

c.) pre-removal aggressive and nonaggressive data were compared, and

d.) post-removal aggressive and nonaggressive data were compared.

In addition, two comparisons were made on untransformed data:

e.) the fraction of fibers that are asbestos in pre-removal samples were compared to that of post-removal samples, and

f.) the fraction of structures that are asbestos in pre-removal samples were compared to that of post-removal samples.

(The fractions (%) of asbestos structures in the total structures and of asbestos fibers in the total fibers are shown in Table 5-9.)

The Summary of this analysis (Appendix D) is as follows:

> In summary, a main question here is the effectiveness of glove bags in containing asbestos material during the removal process, the conclusion that the first two facilities show signs of additional asbestos after removal, whereas the fourth facility shows signs of decrease in such material allows the possibility that the removal crew did improve its removal techniques, so that the glove bag methods used in the fourth facility may have been more effective in containing the asbestos material. (Note that the analysis of PCM data in Table 5-7, comparing pre- and post-removal counts, indicated a similar possibility concerning the decrease in asbestos after removal.)

The present study does not provide enough replicates to specify whether particular work practices will reliably allow effective glove bag containment. The study does show that asbestos emissions can occur when glove bags are used during asbestos abatement and it is prudent to assume that emissions will occur, unless it is proven otherwise.

As noted previously, analysis by TEM methods specify that the dimensions and speciation of all structures be recorded. Using the post-removal aggressive sampling results, EPA researchers analyzed and prepared a graphical representation of the size distribution of the asbestos fibers. This distribution is shown in Figure 5-4. As seen, the large majority of fibers were less than 5 µm in length.

## OTHER OBSERVATIONS

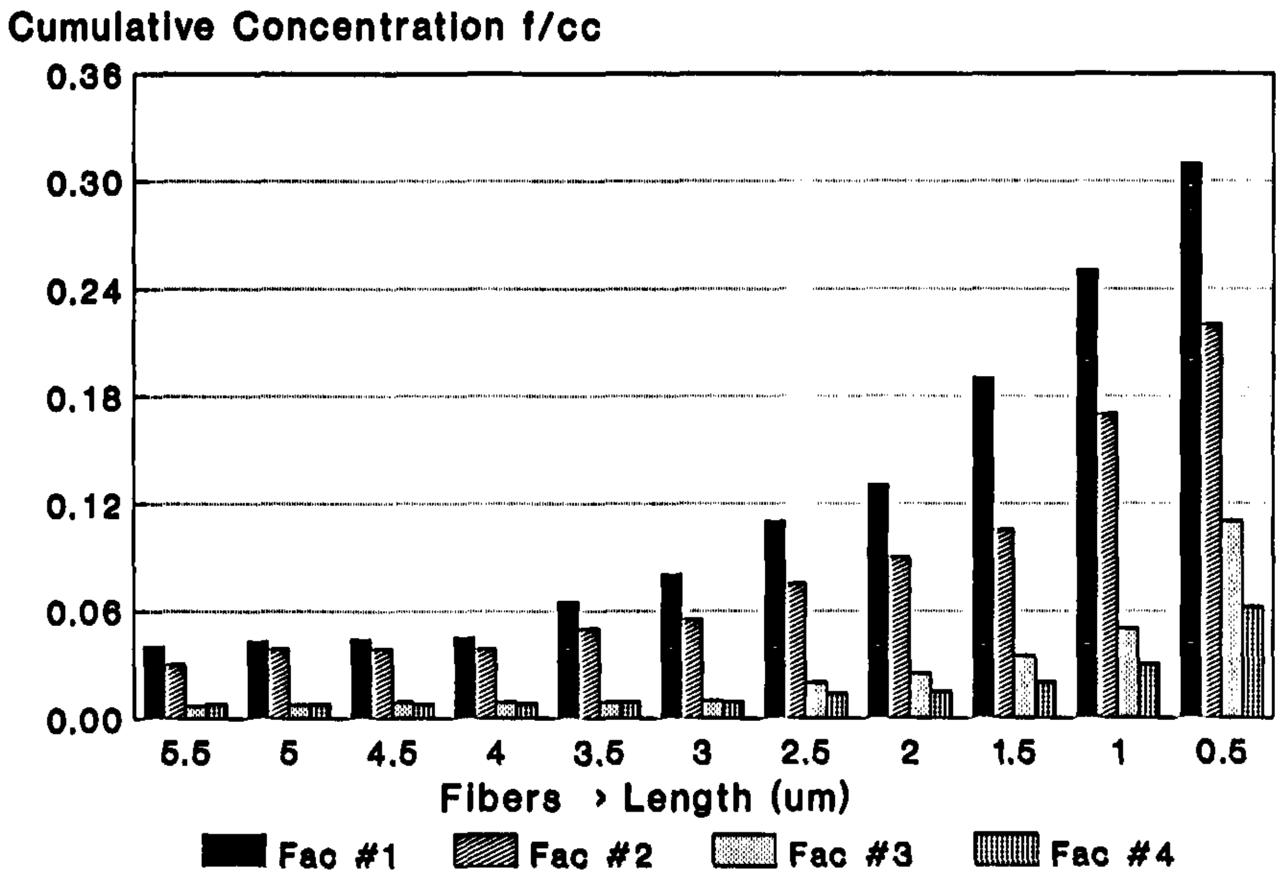
### 5.4.1. Magiscan II

A number of samples collected from the first facility surveyed were analyzed using the Magiscan II® (M-II) system, Version 2.0, and compared with results obtained from the manual use of PCM. For samples obtained during removal operations, the mean concentration was 0.42 f/cc for M-II and 0.46 f/cc for PCM. The correlation coefficient of 43 duplicate samples was 0.91. For fiber concentrations in this range (0.1 to 1.0 f/cc), the M-II could be

TABLE 5-9. AVERAGE PER CENT OF ASBESTOS IN STRUCTURES AND FIBERS

| ROOM | Sampling Conditions | Non-Aggressive Sampling: Asbestos Structures in Total Structures (per cent) | Non-Aggressive Sampling: Asbestos Fibers in Total Fibers (per cent) | Aggressive Sampling: Asbestos Structures in Total Structures (per cent) | Aggressive Sampling: Asbestos Fibers in Total Fibers (per cent) |
|---|---|---|---|---|---|
| A | Pre-Removal | 41.2 | 41.1 | 18.0 | 16.7 |
| | Post-Removal | 27.5 | 31.4 | 41.6 | 40.3 |
| B | Pre-Removal | 87.8 | 88.0 | 50.8 | 46.8 |
| | Post-Removal | 64.5 | 63.3 | 65.8 | 67.0 |
| D | Pre-Removal | 53.6 | 49.7 | 42.7 | 42.7 |
| | Post-Removal | 36.5 | 35.9 | 22.9 | 22.1 |
| E | Pre-Removal | 63.0 | 61.8 | 22.8 | 24.0 |
| | Post-Removal | 53.6 | 50.1 | 15.5 | 12.6 |
| F | Pre-Removal | | | 34.7 | 32.2 |
| | Post-Removal | | | 46.5 | 42.2 |
| G | Pre-Removal | | | 54.4 | 49.1 |
| | Post-Removal | | | 70.7 | 68.6 |
| H | Pre-Removal | | | 37.1 | 36.2 |
| | Post-Removal | | | 27.2 | 25.7 |
| I | Pre-Removal | | | 53.5 | 48.6 |
| | Post-Removal | | | 21.3 | 17.3 |
| FACILITY | | | | | |
| 1 | Pre-Removal | 64.5 | 64.5 | 34.4 | 31.8 |
| | Post-Removal | 46.0 | 47.3 | 52.0 | 51.8 |
| 2 | Pre-Removal | 58.3 | 55.7 | 32.7 | 33.3 |
| | Post-Removal | 45.1 | 43.0 | 19.2 | 17.3 |
| 3 | Pre-Removal | | | 44.5 | 40.6 |
| | Post-Removal | | | 58.6 | 55.4 |
| 4 | Pre-Removal | | | 45.3 | 42.4 |
| | Post-Removal | | | 24.3 | 21.5 |

Figure 5-5. Cumulative Size Distribution of Asbestos Fibers Aggressive Sampling, TEM Analysis



considered as an alternate analytical procedure that would provide results comparable to the manual PCM counting method, but in less time and with less operator fatigue.

However, it was found that when fiber concentrations were in the range of 0.001 to 0.1 f/cc, as with the asbestos abatement preparation operations and clearance procedures, the duplication of results was very poor. The ratio of of M-II to PCM fiber concentrations of duplicate samples were quite variable, ranging from 2:1 to 30:1. The correlation coefficients between the results obtained by the two methods ranged from 0.11 to 0.25. Therefore, the M-II system, as used in this study, was not suitable for measuring these low airborne asbestos fiber concentrations. A subsequent Magiscan software release (Version 4.0) reportedly has improved capability to measure low fiber counts.

### 5.4.2. Engineering Controls

Disposalene®, Profo®, and Safe-T-Strip® glove bags were used during this study. Although the majority of the work was done with Disposalene bags, the study was not designed to measure differences in the fiber concentrations emitted from the glove bags of the various manufacturers. It should be noted that glove bag design and construction has evolved since the time of this study and many conveniences and refinements are incorporated in many glove bags currently available.

### 5.4.3. Work Practices

The survey team observed and intermittently videotaped the work practices of the removal crew. The distributor for Safe-T-Strip® glove bags, who is also a National Asbestos Council instructor, provided on-site training which was very helpful in reinforcing good work practices and techniques. The training was well received by the workers and they were observed to make use of the demonstrated techniques for the duration of the study.

A subjective evaluation of work practices was improvised, and these ratings are summarized in Appendix A, Tables A7-1 through A7-4. Although the work practices appeared to improve as the workers received training and gained experience, it was not possible to identify work practices which would clearly explain the improved containment achieved in the final study site.

Attempts to analyze FAM measurements and compare observed real-time fiber concentrations with specific work conditions and activities were also unsuccessful. The removal work is composed of many short-duration, repetitive tasks; however, the cycle of repetition is inconsistent. In addition, two or more workers performing different tasks simultaneously at different locations in the same room further confounded the situation by the possibility of increasing the background levels from multiple, unrelated sources.

### 5.4.4. Contractor and School Board Monitoring

The removal contractor's program for monitoring airborne exposure to asbestos during the removal operation consisted of supplying the shift foreman with one personal sampling pump. During the present study, no personal sampling was conducted by the foreman because the survey team monitored each of the workers.

The school board also hired an independent consultant to monitor the asbestos abatement activities by observation and by air sampling. However, because abatement work was simultaneously in progress at four diverse sites, the monitoring consultant was unable to provide a level of observation sufficient to ensure full compliance with the work specifications at any one site.

### 5.4.5. Personal Protection

The removal workers wore disposable coveralls in the work area during removal activities. In addition, each worker was fit-tested for a half-face cartridge respirator equipped with high efficiency particulate air filters. These respirators were worn during all removal activities.

### 5.4.6. Safety Considerations

Work was performed over or around obstructions such as sinks, commodes, light fixtures, and other nonremovable structures. Safety hazards were typical of those associated with insecure footing while working on elevated platforms, ledges, and ladders, i.e., slips, falls, awkward working postures, etc. The use of razor knives and stapling guns also presented hazards to workers. Staples driven through the poly into the asbestos lagging presented a special risk of injury to the hands. Care was required when removing the poly from the lagging to avoid skin punctures and lacerations. The poly gloves in the bags provided no protection against this hazard and were not large enough to allow workers to wear additional hand protection.

# 6. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are based on the fiber exposure data collected and on the observation of the work practices used in this study.

## 6.1. Efficacy of Glove Bag Containment

- As used in this study, glove bags did not completely contain airborne asbestos when pipe lagging was being removed.

  Glove bags can be a useful engineering control to reduce worker exposure to asbestos during the removal of ACM. In the present investigation, however, workers' exposures to airborne asbestos were consistently below the OSHA PEL in only one of the four facilities surveyed. The study was not designed to demonstrate the effect of training on glove bag containment efficacy and it did not provide a basis to specify conditions under which adequate containment can be assured.

  Based on these results, it is prudent to assume that glove bags will afford varying degrees of containment, depending on the specific configuration of the structure from which asbestos is to be removed and the manner in which the glove bags are used by the workers.

- Because of the uncertainty in controlling exposures during the use of glove bags, it is essential to provide a backup containment system (e.g., isolation, barriers, negative air) and respiratory protection for workers.

  Worker training and experience are important components of a reliable system of control measures; however, even work performed by well-experienced crews is subject to accidental releases. Emissions of this sort must be prevented from entering other portions of the building.

  As discussed in Section 3, the lack of expertise demonstrated by the workers at the first survey is probably typical of other workers who use glove bags infrequently. Plant maintenance personnel, asbestos operations and maintenance personnel, and many asbestos removal contractors who use glove bags only occasionally could very likely encounter asbestos exposures similar to those observed in these surveys, due to incomplete containment.

  It is also necessary to use personal protective equipment (e.g., disposable coveralls) and respiratory protection during <u>any</u> glove bag operation, because of the potential for undetected leakage of the glove bag and accidental rupture of the bag or seals. OSHA permits the use of high efficiency, air purifying respirators for work with asbestos;[13] however, NIOSH recommends that type C positive pressure, supplied air respiratory protection be used when occupational exposure may occur.[41] Only NIOSH/MSHA-approved respirators should be used. When respirators are used, a written respirator program including a quantitative respirator fit testing program must also be instituted.

- In this study, exposures to asbestos exceeding the NIOSH REL did not occur when the rooms were being prepared for asbestos lagging removal.

  The maximum exposure observed during the preparation of the rooms and covering of the pipes before actual removal was 54,000 $f/m^3$. Preexisting contamination by ACM, i.e., asbestos contamination present in areas to be abated before the abatement operations are started, is an important factor to consider in evaluating the potential for exposure. Both the amount and the state of the preexisting contamination and the magnitude of the disturbance created by the workers activities can influence the contribution of preexisting contamination to airborne asbestos concentrations.

  The rooms evaluated in this study were selected because of the good condition of the pipe lagging and the absence of visible debris. The workers used respirators during removal operations, but did not use them during the preparation stage. It is more usual for abatement work to be performed in areas where damaged lagging and debris are present; under such conditions respiratory protection should always be used in preparing the work site.

6.2. Clearance Methodology

- For clearance testing, the aggressive sampling technique is more sensitive for detecting asbestos contamination than nonaggressive sampling techniques. Asbestos was found in all of the clearance samples that were collected using aggressive sampling techniques and analysis by TEM.

  Where aggressive sampling and TEM analysis techniques were used, preexisting contamination was found in all of the rooms in which this study was conducted, even though these rooms were selected because of the absence of any visual contamination. Using these same sampling and analytical techniques, asbestos concentrations observed following the abatement activities but prior to final inspection were greater than the preexisting contamination levels in five of the eight rooms.

- PCM analysis is not reliable for clearance testing.

  The AHERA regulation permits the use of PCM only until October 7, 1990.[11] The PCM analysis of samples collected using nonaggressive sampling techniques indicated that over 50% of the samples had nondetectable fiber concentrations. Even when aggressive sampling techniques were used, PCM analysis could not always detect the presence of asbestos, even though fibers were observed on all samples analyzed by TEM. Based on these findings, PCM should not be considered as a reliable method for determining the absence of residual asbestos. Furthermore, the results obtained by PCM are very close to the limit of detection for this method, and therefore, the confidence limits are very broad. This makes comparison with a clearance standard difficult.

TEM analysis presents several advantages for the measurement of low concentrations of asbestos fibers. It has the ability to detect short and narrow fibers, identify the type of fiber, and is less affected by overloading of particulates which may obscure fibers when using PCM.

The interlaboratory variability observed for the TEM analysis and the fiber contamination found on the polycarbonate filter media indicate that additional standardization and quality assurance are required. Laboratory accreditation is needed to assure that uniform sample preparation techniques and counting methods are used. Inter and intralaboratory quality control tests are needed to determine coefficients of variability and a measure of the accuracy and ability to replicate results. This need was recognized by both the April 1986 EPA peer review[35] and the Asbestos-Containing Materials in Schools regulation (October 1987).[32] This regulation charged the National Institute of Standards and Technology (NIST) (formerly the National Bureau of Standards) with the responsibility for establishing a laboratory accreditation program. NIST projects that such a program will require 2 to 3 years for implementation to occur. Until such time as TEM laboratory accreditation is accomplished, meaningful quantitative comparisons between laboratories or with EPA standards are possible only with extensive interlaboratory replicate analysis and quality assurance programs. It is recommended that laboratories performing TEM analyses initiate with other laboratories an interim program for quantitative comparisons of samples.

- Magiscan II is suitable for fiber analysis when airborne asbestos concentrations are compared to occupational standards, i.e., concentrations in the 0.2 f/cc (200,000 f/$m^3$) range.

From the limited observations in this study, it appears that the use of PCM with the automatic counting and sizing of particles, e.g., Magiscan II®, Version 2.0, is useful for the analysis of fibers when the concentration is above the present OSHA PEL of 0.2 f/cc (200,000 f/$m^3$). This system can provide results comparable to manual PCM, but in less time and with less operator fatigue. The Magiscan II (Version 2.0) did not correlate well with the PCM analyses for fiber concentrations in the 0.01 f/cc (10,000 f/$m^3$) range. Therefore, it is not appropriate for analysis of low fiber concentrations normally associated with ambient background or abatement clearance fiber concentrations. A modification of this system, Magiscan, Version 4.0, may have utility at these lower concentrations, but it was not evaluated in this study.

## 6.3. Monitoring and Recommended Work Practices for Glove Bag Use

Monitoring of airborne asbestos concentrations by the removal contractor and the building owner is necessary to verify the effective use of glove bags;

frequent observation and supervision by an experienced overseer is necessary to assure that proper work practices are being used. Although conventional workplace sampling for airborne concentrations can provide only after-the-fact exposure information, it may indicate the need for better control on future jobs. A direct-reading instrument (FAM) may be useful to indicate large, accidental releases of fibers and help to minimize contamination by timely corrective actions.

In the absence of other reputed studies that quantify the effectiveness of specific work practices, the following recommendations are given based on good industrial hygiene practice:

- Pre-mist all lagging with amended water.

- Wrap all pipe with poly prior to the start of removal work.

- Use a bag properly designed for the task (i.e., specially designed bags for working around large valves or fittings).

- Start with a clean, empty bag where the pipe interfaces with walls or ceiling. Special care must be used to avoid breaking the tape or adhesive seal; an empty or nearly empty bag is easier to manipulate.

- Cut preformed lagging blocks at the joints to minimize fiber generation.

- Use hoses on the amended water sprayers of sufficient length to facilitate wetting practices; spray frequently during the removal task to assure that freshly exposed materials are wetted.

- Use a HEPA-filtered vacuum device to contain fibers and to assist in collapsing the glove bag and tying it off prior to removal.

- Remove contaminated tools in an inverted glove for transfer to the next glove bag.

- Require documentation of specific training and experience for workers using glove bags.

- Use enclosures with decontamination showers and negative air on large jobs. On smaller jobs, at least seal off vents and wall or ceiling openings with poly and provide double-hung poly curtains at the doors.

- Clean up accumulated debris prior to removal; this will reduce the potential to disturb and resuspend accumulations of loose fibers.

- Stable elevated platforms and scaffolding must be provided where needed. Improvised platforms utilizing existing structures should be discouraged; worker safety should not be jeopardized by expediency.

- If the lagging is not fully wrapped with poly prior to removal, band the lagging with tape at the places where the glove bag is to be attached. This will provide a clean surface for affixing the tape that seals the glove bag, and prevent damage to the lagging when the sealing tape is removed.

- Test the effectiveness of the seals by pressure testing each bag installation (e.g., gently squeeze the bag to assure that the seal is tight).

- Periodically, use a smoke test to assure that correct installation procedures have been followed. Use a smoke tube inside the bag to fill the bag with smoke, then apply gentle pressure to the bag to observe that the seals are secure. The pressure applied should be consistent with the forces exerted on the bag during the removal of the pipe lagging.

- Care should be taken when metal bands, wires, or metal jacketing are encountered to avoid lacerations to the hands or to the glove bag; whenever possible, the sharp edges should be folded in and these items placed gently in the bottom of the bag.

- The accumulation of debris and water in the glove bag should not exceed the ability of the workers to safely manipulate the bag as needed. Bag loading practices should reflect good judgment and experience; heavily loaded bags create awkward and unsafe conditions. Where applicable, the bag may be supported by the use of a platform and/or slings.

- Use a HEPA filter vacuum to contain fibers during all bag opening procedures such as removal or moving.

- Seal the ends of the lagging with "wettable cloth" (plaster-impregnated fiberglass webbing) or equivalent encapsulant, when partial removal creates exposed ends.

- Use a direct-reading aerosol monitor, such as a FAM, to detect failures in control or containment so that on-the-spot corrections can be made.

- Decontaminate the work area thoroughly after the completion of the job. All contamination should be removed, whether it was caused by the removal task or has accumulated over time.

- Place barricades around working areas when outdoor work is performed. Removal of pipe lagging from salvaged or reclaimed pipe should be done in an enclosure or room with suitable controls to prevent the release of asbestos fibers to the environment.

- Crew size should be proper for the task; a minimum of two workers is recommended where heavily loaded bags are anticipated or elevated work is required. Where two or more removal operations are conducted in the same area, an auxiliary worker may be utilized to refill and pressurize the amended water sprayers, to assist in moving or adjusting the glove bags, and to perform other miscellaneous tasks.

## 6.4. Research Needs

There are several research efforts that may help to improve the containment of asbestos while using glove bags: evaluation of work practices for both reduction of emissions and ergonomic considerations; improvements for wetting the lagging before removal, such as using an injection technique to saturate the lagging; and use of glove bags in conjunction with local exhaust applied to the glove bag (negative pressure).

Several removal contractors use high volume HEPA-filtered vacuum systems that are truck-mounted and are connected to the containment area by means of flexible duct work. They are used to produce a negative or reduced pressure and frequent air changes within the sealed area, and/or local exhaust ventilation to the source of asbestos emissions when ACBM are being removed. They are also designed to remove airborne contamination and debris from the removal site or building and provide disposal techniques remote from abatement operation. These systems could offer better containment than conventional removal methods. A study of the efficacy of these systems, as compared to the use of conventional removal techniques, is recommended.

A further recommendation is an evaluation of exposures associated with the effects of age, use, and maintenance procedures on the efficiency of HEPA-filtered vacuum devices, because degradation in these devices could result in significant emissions of asbestos fibers.