Quantitative Evaluation of HEPA Filtration Systems At Asbestos Abatement Sites

John R. Kominsky, James M. Boiano and Ronald W. Freyberg[A], Roger C. Wilmoth and Thomas J. Powers, [B]
James A. Brownlee and Donald R. Gerber[C]

[A]Environmental Quality Management, Inc., 1310 Kemper Meadow Drive, Ste. 100, Cincinnati, OH 45240
[B]U.S. EPA Risk Reduction Engineering Laboratory, 26 West M.L.K. Dr., Cincinnati, OH 45268
[C]New Jersey Department of Health, Trenton, NJ 08625

This study was conducted to determine the filtering efficiencies of 31 high-efficiency particulate air (HEPA) filtration units in use at asbestos abatement projects. It demonstrates that substandard performance of HEPA filtration units can result in the release of asbestos fibers into the outdoor air or into adjacent building areas.

Asbestos abatement work practices and procedures recommended by the U.S. Environmental Protection Agency (EPA) include the use of high-efficiency particulate air (HEPA) filtration units as an integral part of the containment system. Although these air filtration units are the principal engineering control for removal of asbestos particulate from airstreams in active abatement areas, little quantitative information is available on their ability to prevent asbestos fiber release from these areas. Limited laboratory and field studies suggest that lack of preventive maintenance, operator misuse, or poor equipment design may result in poorer operating performance than claimed in the manufacturer's specifications.[1,2]

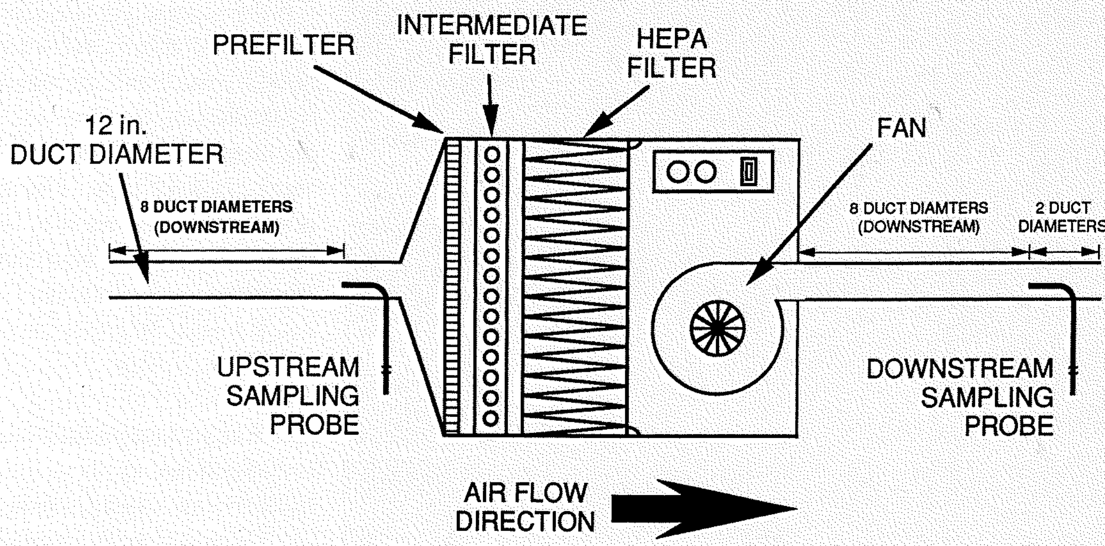
The study detailed herein was conducted to determine the filtering efficiencies of 31 HEPA filtration units at asbestos abatement sites. The study was designed to determine each unit's filtering efficiency for asbestos particles and to compare the asbestos concentration in the discharge air of each unit with outdoor air concentrations.

Study Design and Methods

This study was conducted during the active removal of asbestos-containing material (ACM). Thirty-one HEPA filtration units were tested at 12 abatement sites in New Jersey. Each of the HEPA filtration units were located inside the abatement containment area. All 12 projects involved commercial or industrial buildings, and 10 of the 12 involved occupied buildings. Asbestos-containing surfacing material (fireproofing or decorative plaster) was removed at six of the sites. Asbestos-containing thermal system insulation on mechanical or process equipment (pipes, reactors, furnaces, and ventilation ducts) was removed at the other six sites. At seven project sites, the ACM contained chrysotile asbestos (from five to 65 percent); at two project sites, amosite asbestos (from 25 to 95 percent); and at three project sites, both chrysotile (from 15 to 45 percent) and amosite (from 10 to 95 percent).

Asbestos fiber concentrations were determined in the inlet and discharge air of each HEPA filtration unit tested. Two samples of the inlet air to each unit and two samples of the discharge air

Figure 1. Test Configuration for a HEPA Filtration Unit



from each unit were collected simultaneously. Outdoor air samples were also collected for comparison with the discharge air concentrations of asbestos from each HEPA filtration unit. Four outdoor air samples were collected at each site. If more than one day was spent at a single abatement site, a set of outdoor air samples was collected each day. Figure 1 shows the sampling configuration for a HEPA filtration unit.

Approximately 10 feet of smooth-wall, 12-inch-diameter, 16-gauge aluminum duct was attached to both the upstream and downstream sides of the HEPA filtration unit. A converging transition adapter facilitated the connection with the intake face of each unit and helped balance the airflow through the unit. Two 1/4-inch-diameter holes in the top and side axes of the upstream and downstream ducts served as ports for air-velocity-measurement probes. The holes in the side axes also served as ports for the two air sampling probes. The ports were located eight duct diameters from the inlet (upstream) and eight duct diameters from the fan discharge (downstream).

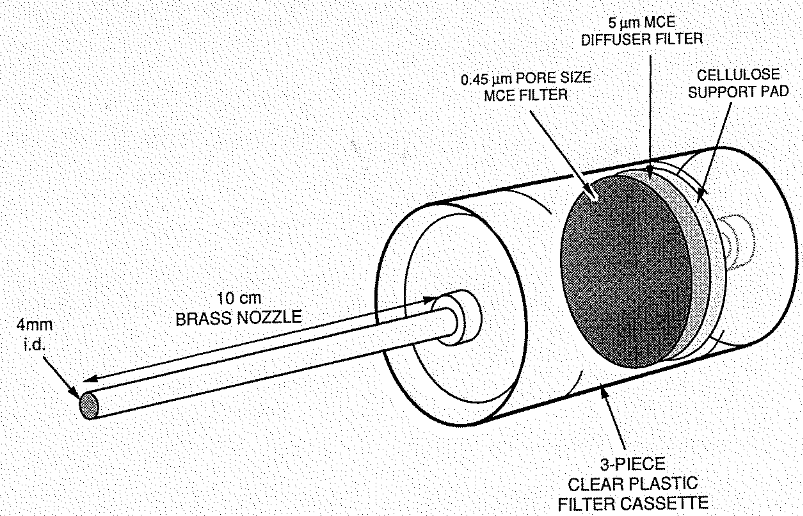
Isokinetic Air Sampling

Isokinetic sampling of the inlet and discharge air of the filtration unit was conducted to determine the respective asbestos fiber concentrations. In isokinetic sampling, the velocity of air entering the sample nozzle (V_n) is the same as the velocity of the airstream (V_s). That is, the area of the sample nozzle tip opening (A_n) and the sample volume flow rate (Q_s) must be adjusted to obtain a velocity ($V_n = Q_s/A_n$) equal to the airstream velocity (V_s) at the sampling point. The sampling constraint ($V_n = V_s$) is termed *isokinetic sampling* or equal-velocity sampling. Figure 2 *(refer to page 8)* is a sketch of the isokinetic sampling nozzle-filter assembly. As part of this study, a portable wind tunnel was used to determine the best configuration of the sampling nozzle-filter assembly to minimize aerodynamic interferences at the nozzle tip during sampling. The configuration selected consisted of a three-piece filter cassette containing a 25-mm, 0.45-µm pore size, mixed cellulose ester (MCE) membrane filter mounted on a 5-µm pore size MCE backup diffusing filter and cellulose support pad. The cassette was preceded by a 10-cm-long brass metal nozzle with a 4-mm inside diameter. The nozzle was mounted directly to the filter cassette to minimize sample loss.

Duplicate samples were collected simultaneously in both the inlet and discharge air ducts. The sampling assemblies were positioned in the duct so that each nozzle was one-third duct diameter from the duct walls. The spatial variability of asbestos concentration across the cross section of the duct was minimized by placing the sampling points eight duct diameters from the last bend or point of flow disturbance.[3]

The sampling flow rate was based on duct velocity (range 450 to 1900 ft/min) at the point where the sampling nozzle was positioned. The sampling period was long enough to achieve a minimum air volume of 1200 liters.

Figure 2. Filter Nozzle-Filter Assembly



The duct volumetric flow rate was determined by 20 measurements taken at multiple points in an equal area traverse of the duct.[4]

Outdoor Air Sampling

Outdoor air samples were collected on 25-mm-diameter, 0.45-µm pore size, mixed cellulose ester (MCE) membrane filters mounted on a 5-µm pore size MCE backup diffusing filter and cellulose support pad. The filter assembly was contained in a three-piece cassette. The samples were collected at a flow rate of approximately 10 L/min to achieve a minimum air sampling volume of 1200 liters.

Laboratory Analysis

The HEPA filtration unit inlet/ discharge samples and the outdoor air samples were analyzed by transmission electron microscopy (TEM). An indirect method of filter preparation was used because the isokinetic sampling nozzle-filter assembly had to be rinsed down to remove any asbestos particles that may have adhered to the walls of the nozzle and because of the potential for a non-uniform deposition of particles on the filter due to the nozzle. The indirect method of filter preparation involved ashing the MCE filter, ultrasonically redispersing the ash in water, and then refiltering it onto a new MCE filter that was prepared by the direct method of filter preparation. Sample grids were analyzed according to the Yamate Method Level II[5] counting rules, except counting was stopped after finishing the grid opening in which the 100th particle was observed. In all other samples, counting was continued until an analytical sensitivity of 0.005 structures per cubic centimeter (s/cm^3) was achieved. The analytical sensitivity is the estimated concentration corresponding to the observation of a single structure.

The indirect method of filter preparation typically leads to concentrations that are higher than those obtained when filters are prepared by the direct method.[6] Therefore, concentrations determined by the indirect method of preparation are not equivalent to concentrations determined by the direct method of filter preparation.

Performance Criteria

The upstream and downstream asbestos concentrations were estimated by the arithmetic mean of the two inlet air and two discharge air concentrations, respectively. The particle-removal efficiency and decontamination factor of each unit were calculated by the following equations:

$$E = [(C_u - C_d)/Cu] \times 100$$

$$DF = C_u/C_d$$

where

E = percent particle-removal efficiency

DF = decontamination factor

C_u = upstream concentration

C_d = downstream concentration

If the filtering efficiency (E) is ≥99.95 percent (i.e., equivalent to a decontamination factor ≥2000), the unit meets the minimum acceptance criterion specified in ANSI N509-1980.[7]

Data Analysis

A one-tailed t-test was used to compare the average of the discharge air measurements from each unit with the outdoor air measurements taken at the site that day. The natural logarithm of the quantity (x + 0.001), where x is the measured airborne asbestos concentration, was calculated for each measurement before performing the t-test. This transformation was used to make variances more equal and to provide data that are better approximated by a normal distribution, thus allowing the application of standard parametric statistical methods. The constant 0.001, a value chosen to be smaller than the majority of analytical sensitivities, was used because some zero values were present and the natural logarithm of zero is undefined. The transformation was used only for these particular t-tests; it was not used in any other part of the data analysis (i.e., graphs or descriptive statistics).

The data were also used to characterize the distribution of discharge air concentrations and to compare this distribution with that of the outdoor air concentrations found at the abatement sites. This approach assumes that discharge air concentrations are independent of outdoor air concentrations at the worksite. This is not an unreasonable assumption because the outdoor air sampling locations were carefully selected to be away from the source of any discharge air. Box plots were used to display the distributions of the measured values. The data were plotted on a logarithmic scale to accommodate measurements ranging over several orders of magnitude. For outdoor air concentrations, measurements were averaged over the number of days at a site to give a distribution based on 12 values. The distributions of the inlet and discharge air concentrations are each based on 31 values. The ratio of the mean discharge air concentration to the mean outdoor air concentration was estimated based on the assumption that the measurements were independent observations from a lognormal distribution. The estimate is given by the ratio of geometric means. A t-test applied to the natural logarithm of the data was used to test whether this ratio was significantly different from 1. If the ratio is statistically different from 1, then the overall mean discharge air concentration is significantly different from the overall mean outdoor air concentration.

Table I. Filtration Performance of 31 HEPA Filtration Units Based on Asbestos Particles

Manufacturer-Model	Unit	Efficiency %[A]	Decontamination Factor[B]
Microtrap MTC	1	99.65	290
Microtrap MTC	2	99.59	250
Microtrap MTC	12	99.69	330
Microtrap Sentinel	11	99.95	2,100
Microtrap Sentinel	13	99.92	1,200
Microtrap Sentinel	14	99.89	920
Microtrap MT3	19	98.16	54
Microtrap MT3	20	99.43	180
Aeroclean 2000	3	>99.99	470,000
Aeroclean 2000	5	90.53	11
Aeroclean 2000	8	99.53	210
Aeroclean 2000	29	>99.99	10,000
Sentry 2000	4	99.35	150
Sentry 2000	24	99.83	580
Sentry 2000	26	99.62	260
Abatement Technology 2000C	6	99.92	1,300
Abatement Technology 2000C	9	99.97	3,600
Abatement Technology 2000C	10	99.93	1,500
Abatement Technology 2000C	23	99.97	3,700
Abatement Technology 2000C	25	99.97	3,100
Critical Systems Mach 2	7	99.96	2,300
Critical Systems Mach 2	21	>99.99	100,000
Critical Systems Mach 2	22	99.91	1,100
Critical Systems Mach 2	27	99.96	2,600
Critical Systems Mach 2	28	99.96	2,300
CRSI 1800	15	99.98	4,200
CRSI 1800	16	99.97	430
CRSI 1800	17	99.87	780
CRSI 1800	18	99.81	520
Red Baron ST2000	30	>99.99	7,700
Red Baron ST2000	31	91.35	12
ANSI Acceptance Criterion		99.95	2,000

[A] Efficiency was rounded to four significant figures.
[B] Decontamination factor was rounded to two significant figures.

Results and Discussion

A summary of each HEPA filtration unit's performance is presented in Table I. Asbestos particle removal efficiencies for the 31 units ranged from 90.53 to >99.99 percent. Nineteen of the 31 units (61 percent) demonstrated filtering efficiencies below the ANSI N509-1980 criterion of 99.95 percent.[4] The decontamination factor (i.e., the unit's ability to remove particles from the airstream) reveals performance differences between various filtration units much more distinctly than does comparing their efficiencies. For example, a unit having a filtering efficiency of 99.99 percent (Unit 29) is 17 times as effective as a unit having a filtering efficiency of 99.83 percent (Unit 24) and 41 times as effective as a unit with a filtering efficiency of 99.59 percent (Unit 2).

Table II. Asbestos Concentrations Measured in the Inlet and Discharge Air of 31 HEPA Filtration Units and Comparative Outdoor Concentrations

		Average asbestos concentration, s/cm^3			
Unit	Site	Inlet Air	Discharge Air	Outdoor Air	t-test[A]
1	1	25.1	0.087	0.046	
2	1	141.4	0.575	0.046	
3	2	2055.3	0.004	5.581	
4	2	60.3	0.393	5.581	
5	2	61.9	5.859	0.177	*
6	3	1070.7	0.823	0.155	*
7	3	2532.3	1.087	0.155	*
8	4	93.1	0.436	0.010	*
9	5	1417.8	0.401	0.011	*
10	5	401.5	0.268	0.011	*
11	6	1313.7	0.615	0.006	*
12	6	248.3	0.766	0.006	*
13	6	728.7	0.622	0.039	
14	6	373.5	0.407	0.039	
15	7	103.3	0.025	0.034	
16	7	60.2	0.141	0.034	*
17	7	46.3	0.060	0.019	
18	7	47.3	0.091	0.019	*
19	7	46.4	0.854	0.031	*
20	7	30.2	0.172	0.031	
21	8	1207.4	0.007	0.008	
22	8	48.1	0.045	0.008	
23	9	272.1	0.073	0.040	
24	9	226.5	0.389	0.040	*
25	9	317.9	0.102	0.084	
26	9	180.9	0.697	0.084	*
27	10	235.4	0.089	0.337	
28	10	229.1	0.101	0.337	
29	11	2888.7	0.298	0.049	
30	12	2328.5	0.297	0.044	*
31	12	354.9	30.711	0.044	*

[A]An asterisk indicates that the average discharge air concentration is significantly greater than the average outdoor air concentration ($p<0.05$).

In a corollary study[8] that measured filtering efficiencies based on dioctyl phthalate (DOP) particles, the same four units (Units 4, 5, 19, and 31) that demonstrated the lowest calculated DOP efficiencies also demonstrated the lowest calculated efficiencies based on asbestos particles. The DOP efficiencies for these four units ranged from 86.91 to 99.60 percent whereas the efficiencies based on asbestos particles for the same four units ranged from 90.53 to 99.35 percent. No obvious pattern was evident for units with DOP efficiencies greater than 99.95 percent.

Table II lists the average inlet air, discharge air, and outdoor air asbestos concentrations for each unit, together with the results of the t-test comparing the discharge air and outdoor air concentrations. Sixteen of the 31 units (52 percent) had an average discharge air concentration significantly higher ($p<0.05$) than the average outdoor air concentration at that site. Unit 31 had the highest discharge air concentration (30.7 s/cm^3) followed by Unit 5 (5.8 s/

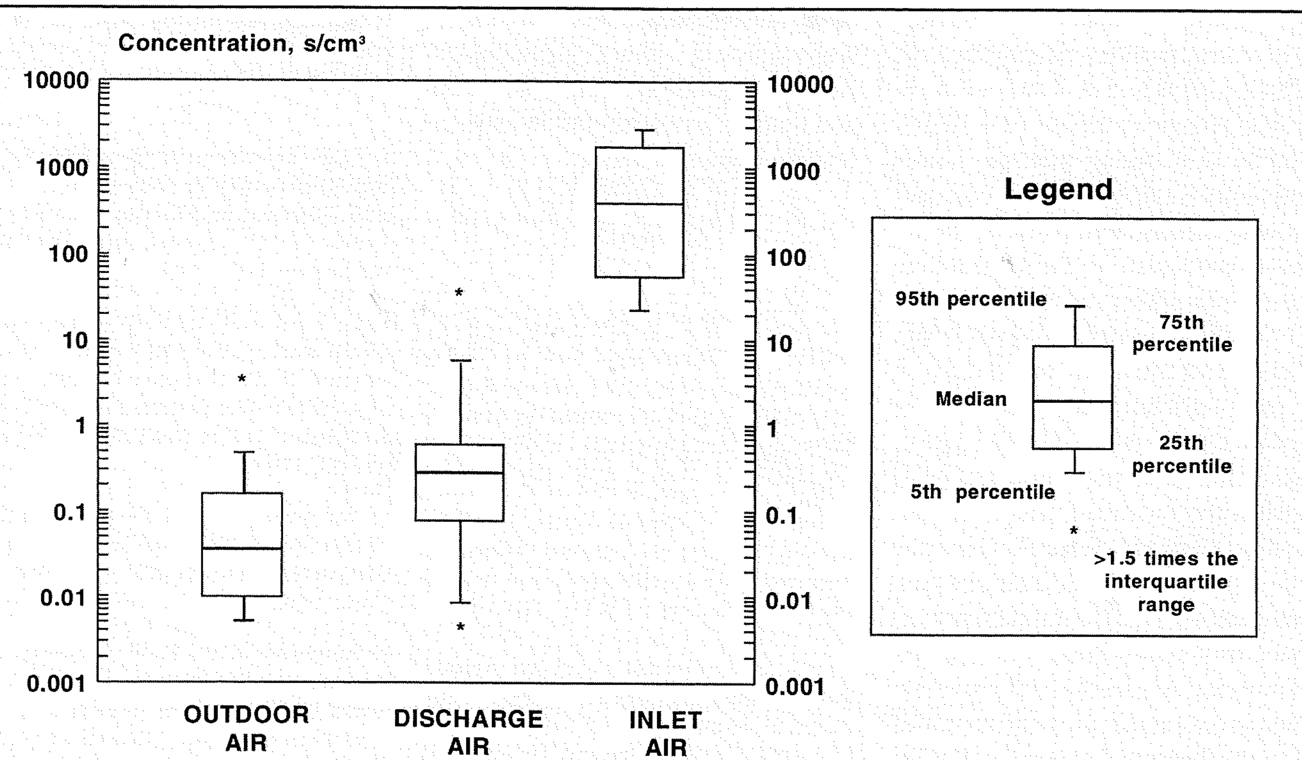


Figure 3. Distribution of airborne asbestos concentrations in the outdoor, discharge, and inlet air. The rectangle stretches from the 25th to the 75th percentile with the median indicated by the horizontal line. Extreme values that lie more than 1.5 times the interquartile range below the 25th percentile or more than 1.5 times the interquartile range above the 75th percentile are marked by an asterisk. The range of the remaining data is shown by the vertical line.

cm^3) and Unit 7 (1.09 s/cm^3). The box plots in Figure 3 show the distribution of inlet air, discharge air, and outdoor air concentrations on a log scale. Although discharge air concentrations are considerably lower than inlet concentrations, they tend to be higher than outdoor air concentrations. The extreme outdoor air value (2.8 s/cm^3) was measured at Site 2. This is an average level over two days of sampling. The first day of sampling showed an average outdoor air concentration of 5.6 s/cm^3, whereas the second day showed an average concentration of 0.18 s/cm^3. The reason for the unusually elevated concentration on the first day at Site 2 is unknown.

The overall t-test shows a significant difference between the mean discharge air concentration and the mean outdoor air concentration ($p<0.01$). The estimated ratio of the mean discharge air concentration to the mean outdoor air concentration is 4.6. If all measurements from Site 2 (the site with unusually high outdoor air concentrations) are excluded, this ratio increases to 6.7.

The TEM analysis of the 62 inlet air, 62 discharge air, and 68 outdoor air samples yielded a total of 9811 asbestos structures. Of these, 64 percent were chrysotile and 36 percent were amphibole. Particle lengths found in the discharge air of the 31 HEPA filtration units ranged from 0.05 to 44 µm, with an average mean length of 2.3 µm. All 31 HEPA filtration units exhausted asbestos structures greater than 0.3 µm in length. Approximately 96 percent of asbestos structures found in the discharge air of the 31 units were longer than 0.3 µm. Approximately 10 percent of all asbestos particles found in the discharge air were longer than 5 µm.

Conclusions

This study has shown that HEPA filtration units in use at asbestos abatement sites can operate below minimum filtering efficiency guidelines. Sixty-one percent of the units tested in this study demonstrated efficiencies below the ANSI N509-1980 criterion of 99.95 percent. Sixteen (52 percent) of the 31 units discharged airborne asbestos concentrations significantly greater than outdoor air levels. Overall, the mean asbestos concentration in the discharge air was approximately five times greater than the mean concentration in the outdoor air .

All 31 HEPA filtration units exhausted asbestos structures longer than 0.3 µm. Approximately 96 percent of the asbestos particles observed in the discharge air of the 31 units were longer than 0.3 µm. Assuming that HEPA filters are 99.97 percent efficient in filtering particles with an aerodynamic equivalent diameter of 0.3 µm, these data suggest that the asbestos particles in the discharge air are probably due to air bypassing the HEPA filter and, to a lesser extent, particles passing through the HEPA filter.

The primary purpose of a HEPA filtration unit during asbestos abatement projects is to prevent (in conjunction with containment barriers) the release of particulate to the surrounding areas. Substandard performance of a HEPA filtration unit can result in significant concentrations of asbestos in the unit's discharge air. Damaged or improperly installed HEPA filters, leaks in the mounting frame, and leaks between the mounting frame and the housing, all of which would cause the air to bypass the HEPA filter, are possible causes for the substandard performance of a HEPA filtration unit. In-place testing standards should be established to ensure that the units are tested at least by the manufacturers or, ideally, by the contractors before they are used on an abatement project. Project designers should consider including in-place performance testing of air-filtration units as a requirement in asbestos abatement specifications.

References

1) Ortega, J. M., J. P. Ortiz, and D. Garcia: Evaluation of Negative-Air Systems Used in Asbestos Removal. 1987 *Annual Report*, Health, Safety, and Environment Division, Los Alamos National Laboratory. LA-11257-PR. 1987, pp. 9-11.

2) Price, J.: Acceptance Testing of HEPA Filtering Systems for Asbestos Abatement. Presented at the American Industrial Hygiene Conference, San Francisco, Ca., May 1988.

3) U.S. Environmental Protection Agency: Stack Sampling Technical Information, A Collection of Monographs and Papers, Vol IV. EPA-450/2-78-042d. Research Triangle Park, N.C., October 1978.

4) Industrial Ventilation: A Manual for Recommended Practice. 17th Ed. Committee on Industrial Ventilation, Lansing, Mi. 1985, p. 9-3.

5) U. S. Environmental Protection Agency: "Methodology for the Measurement of Airborne Asbestos by Electron Microscopy by Yamate", G. S. C. Agarwal and R. D. Gibbons. Washington, D.C., 1984.

6) U. S. Environmental Protection Agency: "Comparison of Airborne Asbestos Levels Determined by Transmission Electron Microscopy (TEM) Using Direct and Indirect Transfer Techniques", EPA 560/5-89-004. Washington, D.C. 1990.

7) American National Standards Institute: Nuclear Power Plant Air-Cleaning Units and Components. ANSI/ASME N509-1980. New York, 1980.

8) Kominsky, J. R., R. W. Freyberg, J. M. Boiano, et al.: "In-Place Performance Evaluation of HEPA Filtration Systems at Asbestos Abatement Sites," *NAC Journal,* 8 (2):21-25 (1990).