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Project Summary

Environmental Release of Asbestos from Commercial Product Shaping

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Abstract

For the first time, the release of respirable asbestos fibers has been quantified in terms of standard mechanical forces using widely accepted methodology and specified QA/QC procedures. Both fabrication of new products from asbestos containing materials and repair or removal of in-use asbestos containing products contribute to the total environmental exposure to asbestos. There is a need to assess these materials and operations with respect to the potential severity of their fiber releases. This research consisted of performing several simulated industrial/commercial shaping operations on several asbestos containing products. The rates of fiber release, expressed as fibers per cubic centimeter of air inside an enclosed test chamber per gram of asbestos milled, were measured. The filter samples were analyzed by the transmission electron microscope (TEM) method. Lengths, widths, and type of asbestos were reported for fibers and other asbestos structures. In addition, samples were taken for phase contrast microscopic (PCM) analysis during most of the experiments. The results of these analyses are compared.

Research on the release of asbestos/substitutes resulting from commercial product manufacture, use, and disposal is of continuing importance. More information about the quantities and dimensions of fibers released during these activities is required in order to develop effective control methods to help protect the public health.

This Project Summary was developed by EPA's Water Engineering Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The scientific community is in general agreement that exposure to asbestos dust increases the risk of: (1) asbestosis, a fibrotic disease of the lung whereby imbedded dust fibers are surrounded by scar tissue; (2) lung cancer; (3) mesothelioma, a cancer of the membrane lining the chest and abdomen; and (4) cancers of the gastrointestinal tract. Prevailing opinion is that there is no minimum dose causing the various cancers. The environmental release of asbestos fibers from the use and disposal of numerous products may present widespread harmful exposure to the general public.

Presently, government agencies such as the National Institute for Occupational Safety and Health (NIOSH) and the Occupational Safety and Health Administration (OSHA) are directing attention to the hazards of asbestos exposure through proposal of more stringent regulations. Current OSHA standards limit asbestos exposure to a time-weighted average of 2 fibers/cm^3 over an 8-hr period, with a 15-min ceiling limit of 10 fibers/cm^3. The existing standard is based on counts of fibers 5 μ or longer in length and having an aspect ratio greater than 3:1 using Phase Contrast Microscopy (PCM) to analyze samples collected from the breathing zone.

The overall objective of this research is to develop and verify testing protocols for quantifying fiber release from commercial asbestos products and proposed substitute materials during common fabricating operations, and secondly, to obtain actual fiber release data with which to rank the release potential of various asbestos product/commercial operation combination. The initial research project was developed by three phases to study environmental release:

- Phase I - Preliminary assessment to define the status and applicability of any existing methods.
- Phase II - Development of a standard test method.
- Phase III - Tests of the potential fiber release of some representative asbestos products/operations.

Phase I was an assessment of previously existing laboratory procedures used to estimate asbestos release rates and/or exposure in the atmosphere. No reproducible methods could be found for generating and measuring the release of asbestos fibers during industrial operations on asbestos-containing materials. Also, no procedure that could be considered controlled and reproducible was identified. Therefore, this research effort proceeded with the design, construction, and testing of the apparatus and identification of the analytical techniques that together would constitute such a method and test the reproducibility of the method. The result of Phase I was a recommendation of test procedure for measuring the asbestos fiber released during commercial product use. Phase II fully developed and tested the laboratory procedure. The objective of Phase II was to evaluate the precision of the laboratory procedure and to determine its sensitivity to variation of fiber generating and sampling factors. Phase III included additional precision tests and a compilation of an asbestos fiber release potential index that ranked various pairs of material operations according to their potential for causing worker and environmental exposure to asbestos fibers. In addition, simultaneous samples were taken and analyzed by the NIOSH PCM method during 32 of the experiments.

The test methodology developed for the project is referred to as the "glove box" method. An apparatus was developed that allows reproducible generation of a cloud of asbestos fibers within a confined volume. The fibers are generated by means that are physically similar to common industrial operations. The equipment was constructed from readily available parts so that it could be reproduced by other investigators. The apparatus consists of a table top glove box, a controlled, variable speed work feeder, a remote power source coupled to the tool by a flexible drive shaft, a fan to provide consistent mixing within the glove box, a filter holder, and means to withdraw up to four samples at constant rates.

Development of an asbestos fiber release potential index required means to generate an aerosol that would allow ranking of industrial or commercial operations on the various products. To this end, the tools and the machining rates and materials to be used mimicked, as closely as possible, those operations commonly employed. The intent was to reproduce the mechanism of the commercial operation, not to reproduce the entire commercial operation. The tools were actuated mechanically rather than by hand to enhance the precision and repeatability of the experiments.

The test materials were obtained directly from manufacturers insofar as was possible. Direct contact was made with the quality control department (or other appropriate division) to be sure of obtaining materials for which manufacturing specifications were known. These data included the percent asbestos, the nature and composition of binders and extenders, and the results of any other physical and chemical analyses that are available. The information attainable from manufacturers was inadequate in some cases so the fiber release potential index computations were based on bulk analyses. These bulk analyses and the PCM analyses were performed at the Mt. Sinai School of Medicine, Environmental Science Laboratory.

A test procedure and quality assurance plan were developed. The analytical procedure of choice was the provisional EPA transmission electron microscopy (TEM) method that was developed for EMSL/RTP by the Illinois Institute of Technology Research (IITRI) under separate contract. The reproducibility of the procedures was tested during this project by replicate performance of the same experiment (sawing of an asbestos cement sheet) and found to be good. Ultimately, the TEM analysis was chosen over the PCM method because of its superior capacity to provide information about the concentration of very small particles.

There is debate among asbestos researchers as to which configurations of small asbestos particles are hazardous. Some adhere to a strict definition of fibers; other include other structures such as bundles of fibers, agglomerations of fibers, and fibers adhered to small pieces of binder or other material. The TEM data of this research include counts of all of these structures and fiber release potential factors calculated only for fibers. All data have been reported to facilitate alternate computations by any reader.

Procedure

To test the potential for release of fibers from commercial use, an asbestos fiber generation system was designed and built to simulate commercial product shaping. The material/operation (M/O) chosen for evaluating the techniques was sawing asbestos cement sheet. The fiber generation system was contained in a controlled atmosphere glove box, as is the sample collection apparatus. Samples were collected on Nuclepore®* polycarbonate filters and sent to the laboratory for analysis of asbestos fibers.

Equipment

The equipment used for generating and measuring airborne asbestos consisted of the following components: 1) controlled atmosphere glove box, 2) fiber generation system, 3) air sampling system, 4) glove box decontamination unit, 5) carbon coating unit, 6) TEM, and 7) PCM.

Glove Box

A Labconco controlled atmosphere glove box (Figure 1) served as the sealed test chamber for the fiber generation and air sampling system. The interior volume of the glove box is about 0.33 m^3. The glove box provides a completely sealed environment in which to conduct the experiments. The glove box has a 0.01 m^3 interchange compartment to prevent contamination of room air during passage of materials into or out of the main chamber. Two 20-cm-diameter glove ports are located on the front of the box, with a pair of neoprene gloves clamped to the ports for use in manipulating components inside the test chamber. The glove box was also equipped with a 70- by 48-cm safety glass viewing panel, two 115-volt electrical outlets, and one 15-watt fluorescent light. The glove box was made of fiber glass reinforced polyester material.

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

Fiber Generation System

The secondary manufacturing operation initially simulated in the glove box was the sawing of asbestos cement sheet. The fiber generation system consisted of a circular saw, saw table, material feed mechanism, and asbestos cement sheet. The design of the system attempted to minimize the number of components inside the box and to use off-the-shelf components to the extent possible.

A small saw table (Figure 2) was fabricated to support the saw and power shaft, as well as the asbestos cement sheet. The table is 30 cm long, 13 cm wide, and 18 cm high, and is bolted to the floor of the glove box. Two spring clips and metal bar hold the materials firmly in place as it is fed to the saw. The material feed apparatus is shown in Figure 3.

Air Sampling System

Air samples were collected by passing a known volume of air through a polycarbonate membrane filter. Real time monitoring of asbestos fibers was conducted using the GCA Fibrous Aerosol Monitor (FAM) (Model FAM-1). The FAM is designed to automatically count airborne fibers for sample times of 1, 10, 100, and 1000 min and display the count and resulting concentration on a digital display.

Glove Box Decontamination Unit

A Dayton vacuum (Model No. 27564) and Dayton asbestos filtering system (Model No. 6X724) were used to decontaminate the glove box. The vacuum line runs from the glove box to the vacuum unit and the filtering system, which was located outside the building. The vacuum is rated at about 90 ft^3/min. The asbestos filter system meet OSHA standards for vacuuming asbestos and consists of a HEPA cartridge filter to back up the primary collection bag. The decontamination unit was designed to remove asbestos in the box without contaminating room air during the cleaning cycle.

Disposal polyvinyl gloves are used to transfer used asbestos cement sheet from the glove box to sealed plastic bags. Whenever the glove box was opened for washing, a personal respirator with a NIOSH-approved filter cartridge was worn in addition to the disposal gloves. Disposable towels were placed in sealed plastic bags after use in washing the glove box interior.

Figure 1. Controlled atmosphere glove box.

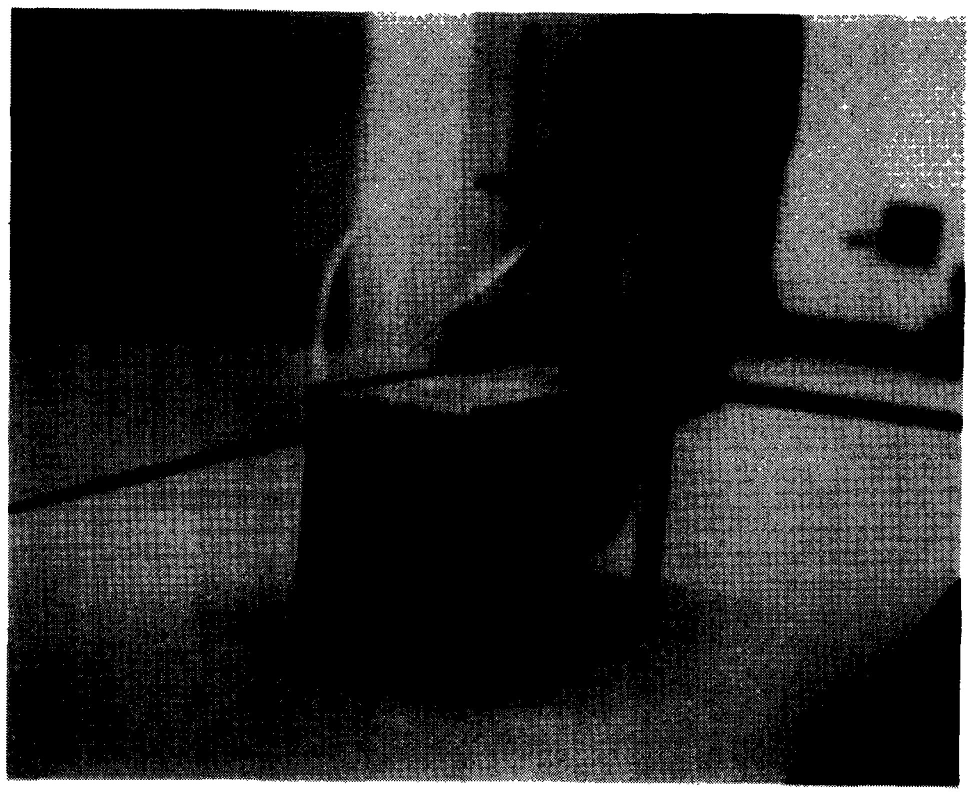

Figure 2. Sawing/grinding table.

Figure 3 *Material feed apparatus*

Carbon Coating Unit

Carbon coating of the polycarbonate filters was performed using a Thermionics (Model TL1 10) Vacuum Evaporator rented from the Department of Anatomy of the George Washington University in Washington, D.C.

Transmission Electron Microscope

Fiber counting and sizing was performed using IITRI's 100 KV TEM. The filters were prepared in a clean room adjacent to the TEM room. The filters were transferred to an electron microscope (EM) grid, and the filter was dissolved in a modified Jaffe Wick Washer. The EM grid was viewed under a fluorescent viewing screen inscribed with graduations to estimate the length and width of fibrous particles.

Laboratory Procedures

The laboratory procedures for generating and measuring airborne asbestos consist of seven steps: 1) sample preparation, 2) fiber generation, 3) sample collection, 4) glove box decontamination, 5) carbon coating, 6) transfer to EM grid, and 7) TEM examination and data collection.

Sample Preparation

Air samples were taken on 37 mm diameter, 0.4 μ pore size polycarbonate fibers. The shiny, smooth side was used as the particle capture surface. The filter was supported by a cellulose pad in a 37 mm plastic filter holder. A piece of tape, which also served as a label, was placed on the filter cartridge so that it formed an air tight seal between the bottom half and middle ring of the plastic filter holder.

Fiber Generation

For the initial set of runs, the sawing of asbestos cement sheet was the method for the generation of fibers. The asbestos cement sheet was fed into the saw wheel at a constant rate by a variable speed motor. The length of material cut and the time required for the cut were recorded on the data sheet. Prior to the cut, the fan in the front left corner of the glove box was switched on to circulate the air inside the box during the cut. The fan operated during the cut, but was switched off at the end of the cut because large cement particles from the bottom of the box were reentrained if the fan were left on.

The theoretical settling rate data are in close agreement with actual settling data obtained under working conditions. Fibers 1 μ to 5 μ in length with an aspect ratio of roughly 5:1 are a common material dispersed from overhead insulation in buildings. The settling velocities for fibers 5 μ, 2 μ, and 1 μ in length, with a 5:1 aspect ratio and with an axis attitude varying between vertical and horizontal, would be approximately 2×10^{-2}, 4×10^{-3}, and 1×10^{-3} cm/sec, respectively. The theoretical times needed for such fibers to settle from a 3 m (9 ft) high ceiling are 4, 20, and 80 hr *in still air*. Turbulence will prolong their suspension.

Sample Collection

During the sawing period, the filters were positioned in the sampling head and covered with the top of the sampling head. After the cut was completed, the filters remained covered for a period of 10 min to allow larger particles to settle out. After the 10 min wait period, the sampling head cover was removed, the sampling pump and FAM switched on, and a 10 min sample drawn through the polycarbonate filters and FAM. The rotameter settings were preset to provide flow rates of about 0, 0.5, 1.0, and 1.75 L/min. No air was drawn through one of the filters so that the effect of particles settling onto the filters or contamination during handling could be determined.

Glove Box Decontamination

Immediately after the filters were removed from the glove box, the glove box was thoroughly vacuumed, including the floor, saw table, side walls, ring stand, fan, and rubber gloves. Makeup air was pulled through the NIOSH approved filter cartridges mounted on the side of the box. The vacuuming took about 10 min. A 10 min sample was then taken with the FAM to determine if the box was sufficiently clean to proceed with another experiment. The criterion of a FAM reading of less than 0.10 f/cc for a 10 min average was selected for the indication of a clean glove box. If the FAM reading exceeded 0.10 f/cc, the glove box was revacuumed and/or washed using water, paper towels, and disposable gloves. A respirator was worn during all these operations.

Carbon Coating

The carbon coating of the polycarbonate filters was performed at the George Washington University, about 10 miles from the ES laboratory. The polycarbonate filters remained in the plastic filter holder at all times, so there was no handling of the filters prior to the application of the carbon film to the filter.

Transfer to EM Grid

The collected particles from the carbon coated polycarbonate filter were transferred to an electron microscope grid. The transfer was accomplished in a modified Jaffe Wick Washer. Briefly, the Jaffe Wick Washer is a petri dish containing a substrate to support the EM grid and carbon coated polycarbonate filter. Solvent is added to cause dissolution of the polycarbonate membrane with a minimum loss or dislocation of the particles. The result is a membrane-free EM grid with particles embedded in the carbon coating.

TEM Examination

The EM grid was examined in the TEM at a magnification of 250X to assess the quality of the EM grid. Since asbestos fibers were found isolated as well as with each other or with other particles in varying configurations, the fibrous particles were characterized as asbestos structures of the following types:

- A fiber was defined as a particle with an aspect ratio of 3:1 or greater with substantially parallel sides.
- A bundle was a particle composed of fibers in a parallel arrangement with each fiber closer than one fiber diameter.
- A cluster was a particle with fibers in a random arrangement such that all fibers were intermixed and no single fiber was isolated from the group.
- A matrix was a fiber or fibers with one end free and the other end embedded or hidden by a particle.

Figure 4 demonstrates the different types of asbestos structures.

The asbestos fiber count was given in terms of the number of asbestos structures that were identified. Thus, a cluster was counted as one asbestos structure, even though there were numerous individual fibers comprising the cluster. Similarly, a bundle was counted as one asbestos structure, even though the bundle was composed of several (though not always distinguishable) fibers.

Width and length measurements were obtained for individual fibers, and a cylindrical shape was assumed for volume calculations. Bundles and clusters were sized by estimating their width and length. A summation of individual diameters was used to obtain total width and an average length for the total length. A laminar sheet shape was assumed with the average diameter of the individual fiber as the thickness. Matrices were sized by summation of the best estimate of individual fiber components. A laminar or sheet structure was assumed for volume calculation.

The selected area electron diffraction (SAED) pattern was obtained for the fiber portion of each structure by use of the field limiting aperture. Electron diffraction patterns from single fibers of asbestos minerals fall into distinct groups. TEM and SAED patterns obtained with standard samples were used as guides to fiber identification. From the visual examination of the electron diffraction pattern, the structure was classified as belonging to one of the following categories:

- Chrysotile
- Amphibole group
- Ambiguous
- No identification

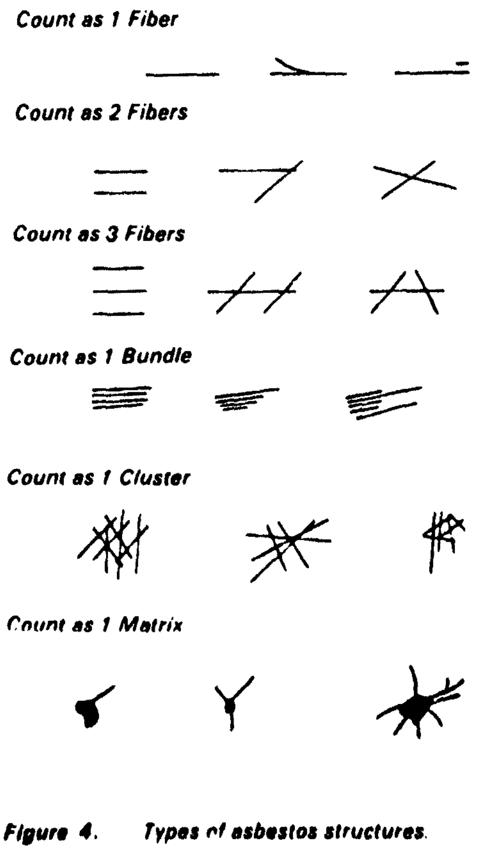

Figure 4. Types of asbestos structures.

Data Reduction

The basic quantities to be calculated are air flow rate, fiber number concentration, and fiber mass concentration.

Some means for assuring comparability among diverse M/O combinations was needed. This was done by weighing the material before and after each experiment to determine the amount of material actually machined. These weights were measured on a laboratory balance having a 160-g capacity and a sensitivity of 0.1 mg. The weight loss, together with the percent asbestos (as per phase contrast microscope and x-ray fluorescence analysis) in the material, provides a factor by which the results were normalized. This factor was merely the mass of asbestos machined from the piece of material. The concentration of asbestos fiber measured was divided by the mass of asbestos machined so that the units of the concentration measured were:

$$\frac{\text{Fibers/cm}^3}{\text{(Gram Milled)(Fraction of Asbestos)}}$$

The mass of asbestos removed from each product by each operation was held constant so that the sawing, drilling, and sanding experiments have a common basis. The fiber concentrations in the aerosol generated during these experiments are then a true release potential index. In addition, a normalization on the volume of material milled will be developed. Other factors affecting worker exposure (such as the length of time of the operation on a material, the mass of asbestos machined away during the operation, and the effectiveness of any control devices) can be tested later so that the index values can be used to project potential exposures.

Personnel Protection

At the conclusion of each experimental run, the operator removed the filters from the main glove box chamber and placed them into the smaller chamber. This smaller chamber (0.01 m³) was sealed off from the contaminated larger chamber during the experiment. During removal of the filters from the smaller compartment, and during the subsequent vacuuming of the larger chamber, the worker wore a mask (MSA-Type S filter or equivalent) for his protection from fugitive particles. The air in the room was tested for fibers periodically with the FAM.

Results and Discussion

The experimental design of this study has been based upon achieving the following objectives:

- Determining the precision of the entire fiber release analytical system (composed of fiber generation system, air sampling system, carbon coating unit, and TEM particle counting methods).
- Comparing TEM results to PCM results.
- Collecting data for asbestos fiber release potential index.

The first of these objectives is of primary concern because determining the precision of the analytical system must precede all subsequent efforts to evaluate asbestos containing products in the laboratory. The second objective is important because broad application of the method for testing will require knowledge of how the methods may be compared. Collecting data for the fiber release potential index was done to determine if the resulting values were significantly different and if the various experimental parameters could be measured accurately.

System Development and Testing

Approximately 20 preliminary tests were conducted in Phase I of the project to establish the values for several of the test variables. After these values were established it was determined that fiber loading test results could be repeated. Phase II consisted of nine reproducibility tests using the cut off wheel on asbestos cement sheet to establish the TEM sampling criteria. Phase III (consisting of five material/operation tests of eight runs each) was designed to determine whether a fiber release potential index could be developed and if so, what was the range of values. During this effort, two additional tests were run to determine the effect of inverting the sample filters. In addition, two tests were run with the filters located at the top and bottom of the glove box to determine if there was stratification of the fibers. A test matrix of the three phases of the project is shown in Table 1.

Table 1. *Test Matrix*

Phase	*Description*	*No. of Tests*	*Operation*	*Material*	*Analysis*
I	*Preliminary experiments*	*20*	*Cut off wheel*	*Asbestos cement sheet*	*Gravimetric & SEM*
II	*Reproducibility tests*	*9*	*Cut off wheel*	*Asbestos cement sheet*	*TEM*
III	*Fiber environmental release index tests*	*8*	*Sawing*	*Asbestos cement sheet*	*TEM*
	• Inverted samples	*2*	*Sawing*	*Asbestos cement sheet*	*TEM*
	• Stratification tests	*2*	*Sawing*	*Asbestos cement sheet*	*TEM*
III	*Fiber environmental release index tests*	*8*	*Sawing*	*Millboard*	*TEM, PCM*
III	*Fiber environmental release index tests*	*8*	*Grinding*	*Brake lining*	*TEM, PCM*
III	*Fiber environmental release index tests*	*8*	*Drilling*	*Asbestos cement sheet*	*TEM, PCM*
III	*Fiber environmental release index tests*	*8*	*Drilling*	*Millboard*	*TEM, PCM*

Comparison of TEM to PCM Results

Millipore filter samples were collected for PCM analysis during all M/O runs except those for sawing of asbestos cement sheet with the cutoff wheel. The results of the PCM analyses were compared to the TEM analyses of the Nuclepore® filter samples that were collected simultaneously for four of the M/O experiments. The samples taken for PCM analysis during the brake shoe/grinding experiments and the inverted Millipore filter samples have been saved but not analyzed because of budgetary restrictions.

It was first attempted to correlate the PCM result to the total asbestos fiber result of the TEM analysis. Even though the TEM is able to discern far smaller and therefore far more fibers than the PCM, it was thought that there might be some multiplier which could be applied to the PCM result to adjust for its lesser sensitivity. The correlation between the two measurements is decent for the millboard/saw experiment. The results for the other experiments are poor: the slopes are negative and the correlation coefficients near zero.

Correlation was tried for all structures (except matrices) found by TEM to the PCM result. The correlations were similar to those obtained for the asbestos fibers. An attempt was made to correlate the total NIOSH fibers (fibers longer than 5 μ with an aspect ratio ≥3.0) actually counted by the TEM analyst to the PCM result. Such fibers were seen on only 2 of the 32 filters analyzed by TEM, and the resulting correlation was uniformly poor. Next, all asbestos structures (again except matrices) not having a length greater than 5 μ and an aspect ratio ≤3.0 reported by the TEM were considered. Again, no correlation was found.

In the comparison of TEM to PCM results, the number and percentages of asbestos fibers, all structures, and asbestos bundles and clusters that project to be longer than 5 μ were examined. The inescapable conclusion is that almost none of the structures generated and measured during these tests are longer than 5 μ and that restricting the analysis to those that exceed 5 μ is tantamount to deciding to ignore 99% of all the asbestos fibers generated during the machining operation.

The difficulty in correlating TEM analysis with PCM results appears to be over the particles with diameters less than 0.4 μ and lengths smaller than 5 μ. The graphic plots of the TEM data for Filter 230 Saw AC Sheet, Filter 362 Drill AC Sheet, Filter 314 Grind Brakes, and Filter 282 Saw Millboard (Figures 5, 6, 7,

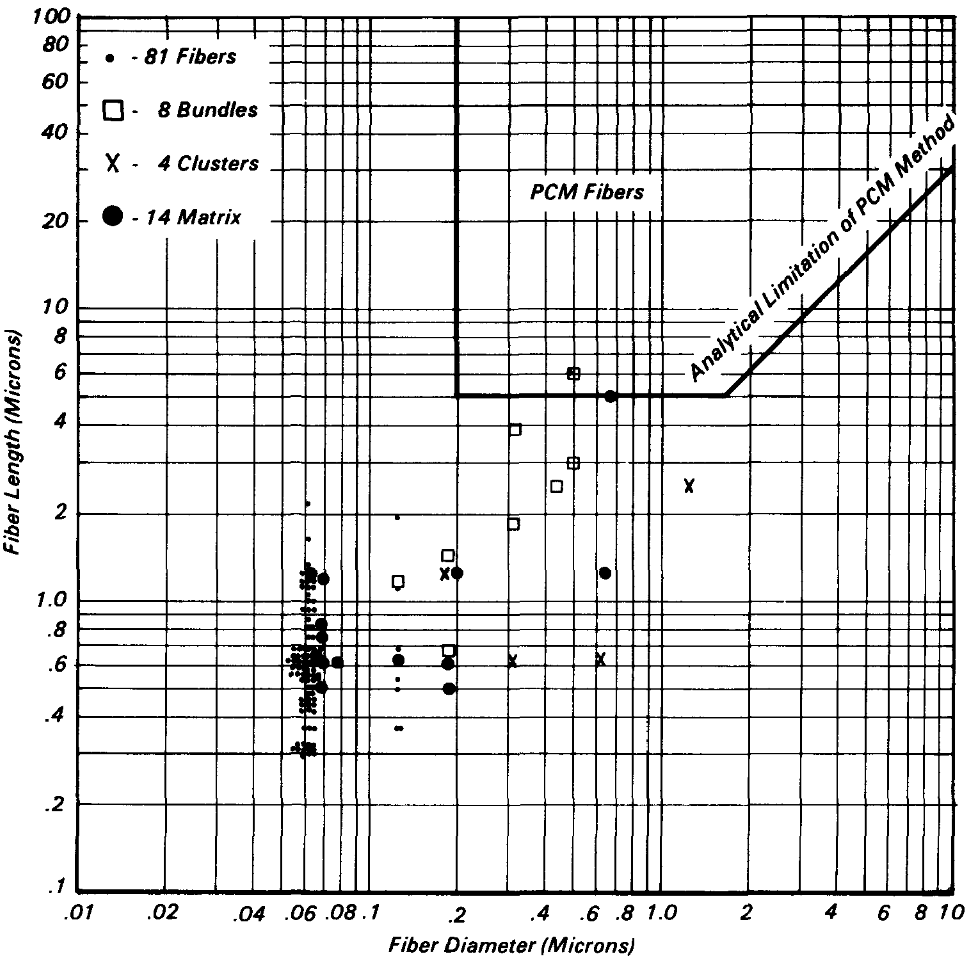

Figure 5. 230 Saw AC Sheet.

and 8) illustrate the particulate sizes as seen by the TEM and the PCM vs TEM comparison difficulties.

Only 14 of the 480 structures reported by TEM for the 8 sawing asbestos cement sheet with the toothed blade were larger than 0.3 μ in diameter. When only asbestos fibers are considered, the situation is even worse. The TEM has sufficient resolution so that any structure larger than 0.125 μ in diameter is classified as a bundle or cluster. There are by definition almost no TEM fibers larger than 0.125 μ. This observation led to the attempt to correlate the PCM result to the concentration of clusters and bundles longer than 5 μ with aspect ratios ≤3.0. There is no correlation between the fraction of particles longer than 5 μ and the fraction having a diameter greater than 0.3 μ. We have arbitrarily chosen 0.3 μ as the smallest size particle visible with the PCM. It may be that 0.2 μ particles are visible with the PCM. It may be that 0.2 μ particles are visible to a skilled microscopist, but that would not change the conclusion that the vast majority of particles reported by TEM are not visible with a light microscope. Figure 9 illustrates the PCM operator's difficulty. This electron photomicrograph reveals several structures that are obviously distinct single fibers and two larger bundles of fibers. The larger of these two would be seen by PCM and labeled a fiber.

It should be noted that 0.0625 μ is an approximation of the fiber diameter that results from the rounding to the nearest 1/16 μ. Precision measurements by other researchers indicate that this smallest diameter, which is regarded as comprising an asbestos fiber, lies between 0.03 μ and 0.07 μ.

The total number of fibers counted during the PCM analyses was somewhat low; only the filters collected during the millboard sawing experiments exceeded the 10 counts/100 fields criteria established by NIOSH. This, in itself, is an interesting result. Ten minutes after cessation of a shaping operation the PCM analysis shows low levels of fibers when in fact the concentration of asbestos fibers is in the hundreds of fibers per cubic centimeter. Projections of the number of concentration of clusters and bundles, which are the structures most likely to be identified as fibers by a light microscopist, indicate the values of their concentrations to be over twice the concentrations measured by PCM. If structures identified as fibers (almost all of which have such small diameters that they are not visible by PCM) are included, the error increases. Further, other researchers have reported that if TEM counts are extended to thousands of particles (from the hundred or so counted in these analyses) more large (>5 μ) structures are found than is expected based upon the log-normal distribution of the shorter fibers. This again implies that the PCM method, in addition to not detecting over 99% of the total asbestos particles in the aerosol, has underestimated the concentrations of structures it ought to have measured by a significant margin.

Asbestos Fiber Release Potential Index

After gaining assurance that the technique was reproducible, the experimental effort turned to development of a fiber release potential index. This index was to be a quantitative measure of the propensity of asbestos containing materials to release fiberous particles during their subjection to various industrial or commercial machining operations. Sawing (with two different types of saw blades), drilling, and grinding were selected as the operations to be tested. Asbestos cement sheet millboard and brake shoes were the material chosen.

The results (Table 2) appear to form the basis for a system for ranking various M/O pairs. There are other differences between the various M/O pairs in terms of the types of structures that they are prone to produce. For example, brake shoe grinding produced significantly more bundles and clusters than any other operation when all structures are considered (Table 3) and when only asbestos structures are considered (Table 4). Sawing asbestos cement sheet with the toothed saw blade produced more matrix particles than any other operation. Interestingly, the percent of all structures that were identified as asbestos is more or less constant and is not well correlated with the percent asbestos in the material being milled. This probably implies that most of the non-asbestos particles generated during the milling operations are larger and settle from the aerosol during the 10-minute waiting period. This means that the test procedure to a large extent segregates the important (asbestos related) portions of the dust created during milling from the less important generation of extraneous dust.

Conclusions

The literature survey carried out in the early stages of this project revealed no procedure, which could be considered controlled and reproducible, existed for generating an asbestos aerosol by operations similar to commercial/industrial machining of non-friable asbestos bearing products. A technique was developed for generating such an aerosol. The technique is simple and relatively inexpensive, and is sufficiently flexible to be adapted to mimic a variety of industrial milling operations on a variety of products.

TEM was selected for analysis of the sampled particles because of its ability to discern extremely small particles and to differentiate asbestos from other fibers. The reproducibility of the technique of the combined generation/analytical system was found to be excellent. Relative standard deviations for repetitive performances of an experiment were typically in the 40% to 80% range.

An index that rates the propensity of six industrial/commercial operations on three asbestos bearing materials was developed. The units of the index are:

$$\frac{\text{Asbestos Fibers}}{\text{(Gram Asbestos Machined) (Air Sampled, cm}^3\text{)}}$$

The experimental procedure maintains the amount of asbestos machined relatively constant so that errors of scale are eliminated and so that the filter samples collected are all loaded properly for TEM analysis. Normalizing the data on the grams of asbestos actually machined during an experiment removes the residual variance within an experimental set and the residual variance among the various experiments. The various material operations tested are listed in decreasing order of their propensity to generate asbestos fibers in Table 5.

Stratification of particles within the aerosol was tested by sampling simultaneously at high and low elevations within the glove box. The aerosol was found to be homogeneous.

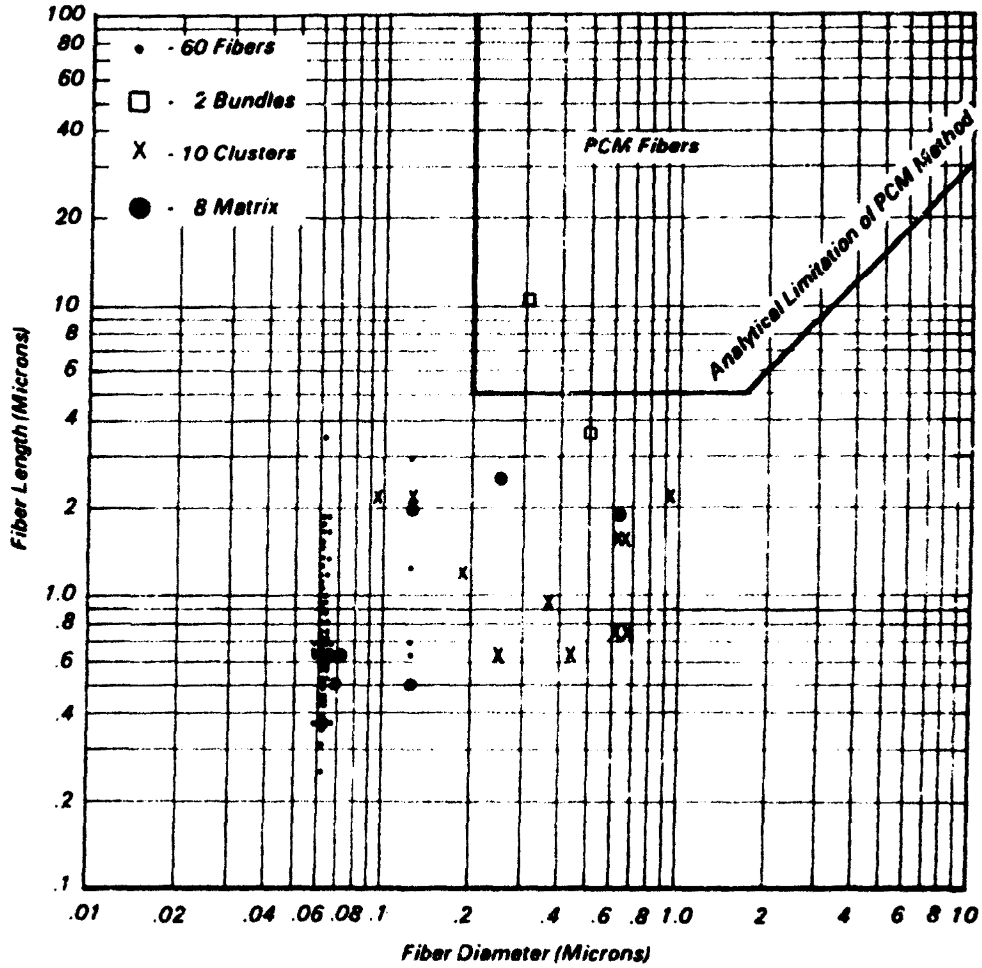

Figure 6. 362 Drill A/C Sheet.

Differences in concentrations measured by upward-facing as opposed to downward-facing filters were tested by sampling simultaneously with upright and inverted filters. No significant difference was found.

Fiber and structure lengths were found to be log-normally distributed. Fiber and structure diameters do not fit the log-normal distribution as well because of the large number of 0.0625 μ (approximately) diameter fibers.

Correlation between TEM results and PCM results was attempted. Samples were taken with Millipore filters during 32 of the experiments, representing four different M/O pairs. No correlation of the PCM analysis of these filters with the TEM analysis of the Nuclepore® filters that were exposed simultaneously could be found. It was determined that only approximately 1% of the structures identified by TEM were longer than 5 μ. None of the structures identified as being fibers by the TEM have diameters sufficiently large to be seen by the PCM. We were unable to identify any subset of the TEM data that would correlate with the PCM data.

Recommendations

The results of this study have suggested several avenues of future research to define and assess the dangers of undetected inhalable asbestiform in atmospheres.

1. Testing should be extended to include additional asbestos products and products containing different types of asbestos (asbestiform) fibers.
2. Future work should include testing of slow speed cutting equipment to evaluate fine particulate envi-

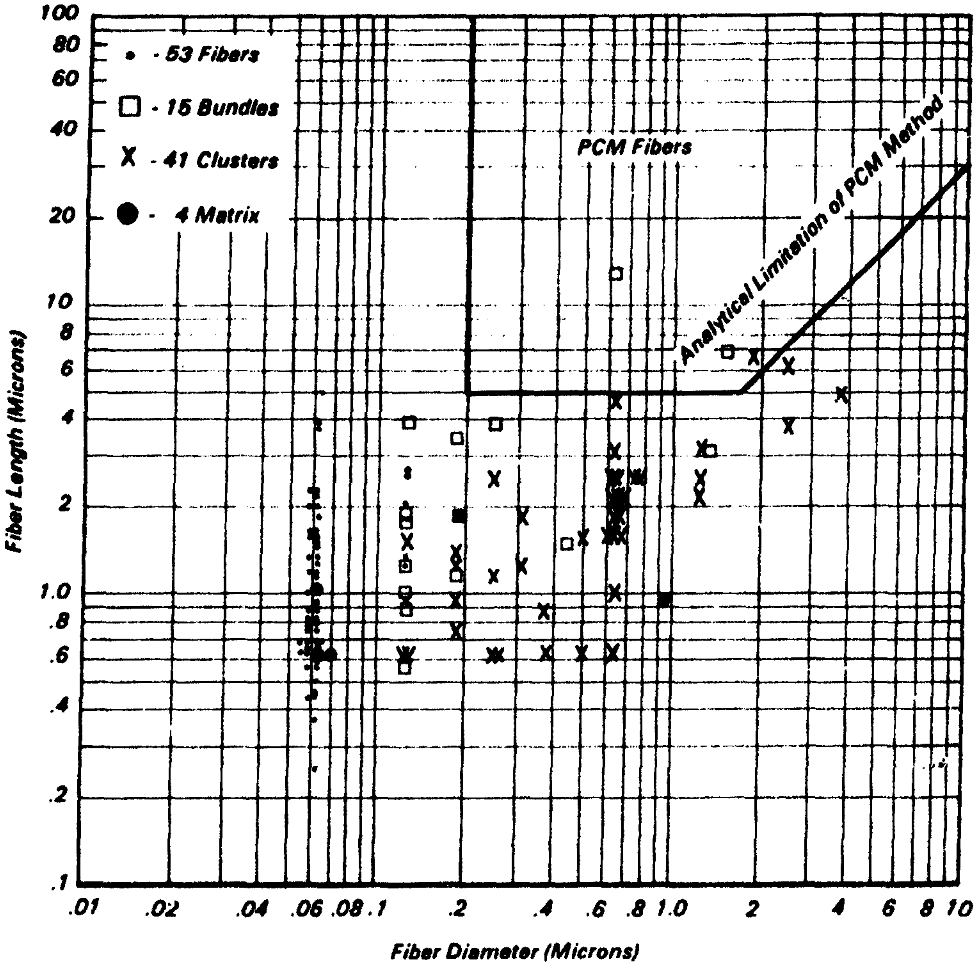

Figure 7. 314 Grind Brakes.

ronment as it has been reported that reducing tool speed significantly reduces fiber release.

3. The efficiency of various vacuum and wetting devices in reducing the amount of asbestos released into the environment should be investigated. This would include the abatement procedures and final disposal evaluation criteria for asbestiform materials.
4. The effects of agglomeration and settling on the fine fiber concentration in the aerosol should be investigated. Agglomeration may significantly affect the concentration and size distribution of suspended fibers and the inhalable particulate fiber fraction thereof.
5. Work on development of a correlation between the TEM and PCM methods should continue in order to determine whether data collected by the latter may be correlated with health effects data. Information on the scanning electron microscope should also be included.
6. Means should be developed for relating the data provided by this technique to worker and general public environmental exposures.

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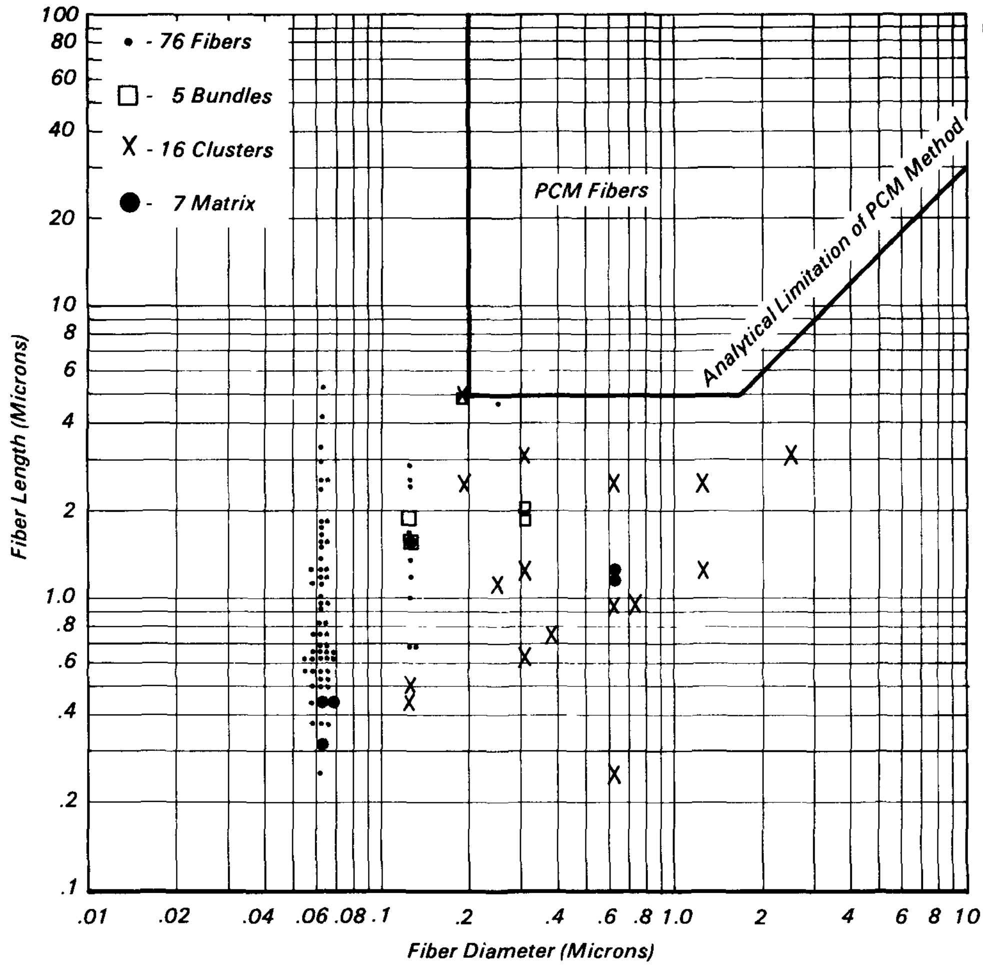

Figure 8. *282 Saw Millboard*

Figure 9. *Electron photomicrograph of fibers, bundles, and matrix particles—asbestos cement sheet/saw.*

Table 2. Asbestos Fiber Release Potential Index

Material/ Operation	Number of Tests	Asbestos Fibers per cc per gm Asbestos Milled: Average (f/cc/gm)	Standard Deviation	Relative Standard Deviation (%)
AC sheet / Cut-off wheel	9	1838.3	338.6	18.4
Millboard / Saw	8	646.6	435.2	67.3
Brakes / Grind	8	465.1	217.3	46.7
AC sheet / Saw	12	305.4	363.7	119.1
AC sheet / Drill	8	282.9	222.6	78.7
Millboard / Drill	8	105.2	32.0	30.5

Table 3. Distribution of Structure Types Generated During Asbestos Release Experiments (TEM Analysis)

Operation	Fibers %	Bundles %	Clusters %	Matrices %
Cut-off AC sheet	76.3	9.5	6.4	7.8
Saw millboard	77.2	5.2	12.3	5.3
Grind brakes	63.2	14.2	18.8	3.8
Saw AC sheet	62.4	12.4	6.5	18.7
Drill AC sheet	82.5	3.8	6.1	7.5
Drill millboard	93.4	0.0	2.5	4.1

Table 4. Distribution of Asbestos Structure Types Generated During Asbestos Release Experiments (TEM Analysis)

Material/ Operation	Asbestos Structure Distribution: Percent Asbestos Fibers	Percent Asbestos Bundles	Percent Asbestos Clusters	Percent Asbestos Matrices	Percent Asbestos
AC sheet / Cut-off wheel	52.8	6.7	4.7	5.4	69.7
Millboard / Saw	64.6	4.7	10.2	3.4	83.0
Brakes / Grind	45.0	10.6	13.9	2.8	72.4
AC sheet / Saw	49.3	7.5	4.8	13.6	75.2
AC sheet / Drill	61.6	3.4	4.3	8.4	77.7
Millboard / Drill	68.5	0.0	1.1	4.5	74.2

Table 5. *Environmental Release*

Material	*Operation*	*Environmental Release Index Value*
Asbestos cement sheet	*Saw (cut-off wheel)*	*1838*
Millboard	*Saw (toothed blade)*	*647*
Brake shoes	*Grind*	*465*
Asbestos cement sheet	*Saw (toothed blade)*	*305*
Asbestos cement sheet	*Drill*	*283*
Millboard	*Drill*	*105*

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The complete report, entitled "Environmental Release of Asbestos from Commercial Product Shaping," (Order No. PB 85-188 878/AS; Cost: $29.50, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
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