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I. SUMMARY

On August 17, 1988, the National Institute for Occupational Safety and Health (NIOSH) received a request for technical assistance from the Pan American Health Organization (PAHO) office in Bridgetown, Barbados. NIOSH was asked to investigate asbestos use and the potential for exposure to to the general public and workers on Barbados. On August 25, 1988, investigators from NIOSH met with officials from PAHO and the Barbados Ministry of Health (BMH) to discuss background events and to present evaluation strategies. Walk-through inspections were conducted. Beginning on August 29, and ending on September 5, 1988, asbestos sampling was conducted at five different sites; a government office building, a hospital, a sugar factory, a public school, and a vehicle maintenance shop. Forty-three air samples, 30 bulk material samples, and 10 settled dust samples were collected during these evaluations.

Asbestos containing materials were identified, by bulk sample analyses, at all sites except the vehicle maintenance shop. Both amosite and chrysotile asbestos were found, in varying percentages. All but one of the settled dust samples (collected from four of the five sites) were negative. A sample of surface dust inside a ventilation system air handling unit at the government office building contained amosite asbestos. These results indicate minimal recent past fiber releases and good housekeeping at the sites sampled. Phase contrast microscopy (PCM) results showed that general area air concentrations of fibers were low at the time. A majority (35 of 43, 81%) of the air sample results were below the analytical limit of detection of 3000 fibers per filter (0.002 fibers per centimeter cubed for a 1200 liter sample). Ambient outdoor air samples were collected at each survey site to serve as controls. At the hospital, four samples were collected which ranged in fiber concentration between 0.004 and 0.006 fibers/cm^3. Three samples collected at the sugar factory were overloaded (i.e. ther was too much dust on the filter) and could not be analyzed by PCM. One other general area air sample from this site contained 0.016 fibers/cm^3. There were no personal breathing-zone exposure samples collected. Seventeen of the filters analyzed by PCM were also chosen to be analyzed by transmission electron microscopy (TEM). Asbestos fibers were identified on nine of these samples. Two were samples from the office building, four were from the hospital, one was from the sugar factory, and two were samples collected from the school. Airborne asbestos fiber concentrations ranged from 0.001 to 0.050 fibers/cm^3. The highest result was from the sugar factory.

The significant findings were that asbestos is widely used and highly accessible to the general public and workers on Barbados, and asbestos fibers were detected in air samples collected at several different, non-industrial, sites, including one school. While airborne fiber concentrations were generally low, except one, they were greater than what was detected in the ambient outdoor air (none was detected). Fibers present in air samples indicates a recent fiber release event, or reentrainment of previously released fibers. Recommendations are made to help health officials minimize potential occupational and public health risks through the establishment of comprehensive asbestos abatement programs and policies.

KEYWORDS: SIC 9999 (not otherwise classified), asbestos, amosite, chrysotile, Barbados, sugar, school, office building, hospital

II. INTRODUCTION

On August 17, 1988, the Pan American Health Organization (PAHO) requested technical assistance from the National Institute for Occupational Safety and Health (NIOSH) to support the Caribbean Epidemiology Center (CAREC), PAHO, in investigating the potential for exposure to asbestos among workers and the general public on Barbados. On August 25, 1988, investigators from NIOSH met with officials from PAHO and the Barbados Ministry of Health (BMH) to discuss background events and to present evaluation strategies. Walk-through inspections were conducted the next day at three sites preselected for evaluation. These were the Treasury Building, Queen Elizabeth Hospital, and the St. Leonard's Secondary School. Beginning on August 29, and ending on September 5, 1988, asbestos sampling was conducted at five different sites. In addition to those preselected, a sugar factory and an vehicle repair shop were evaluated. Forty-three air samples, 30 bulk material samples, and 10 settled dust samples were collected during these evaluations. This report will discuss the evaluations and results from the asbestos sampling.

III. BACKGROUND

The widespread use of asbestos-containing materials (ACM) on Barbados and the relatively recent public awareness there regarding the health hazards related to asbestos exposure, have led to increased requests for Government (Barbados) action. Asbestos issues were brought to the fore during an investigation by a Government ad-hoc committee of the Treasury Building, in Bridgetown, Barbados, in 1987. Asbestos-containing ceiling tiles used throughout this building caused concern among the workers there. Examples of other types of ACM used on Barbados include corrugated- and flat-sheet construction materials, heat-resistant insulation materials, and vehicle brake linings. In view of the carcinogenic potential of inhaled asbestos fibers, it is important to identify the presence (or confirm the absence) and evaluate the potential hazards of environmental exposures to asbestos released from controllable sources. The NIOSH evaluations, admittedly limited, were designed to identify ACM materials, document previous or present fiber releases, and make useful recommendations to the Ministry of Health.

Of primary concern to the BMH staff was the use of ACM in the public schools and the potential exposure to school-aged children. Prior to NIOSH involvement, BMH investigators performed an extensive survey of the asbestos in schools on Barbados. An assessment of the condition of the asbestos containing material was made for each of the schools surveyed. This information will be very useful for future evaluations.

Treasury Building

This large, modern office building was constructed in 1967. There were approximately 300 workers occupying six above ground floors and the ground floor. The ceilings on all floors were covered with 2'x 2' tiles made of an asbestos-cement material. These tiles were in generally good condition, and recently painted, on all floors except the sixth floor. On the sixth floor, the tiles had been coated with a thick, textured paint, which was peeling in a number of locations. It did not appear that the actual tile material was coming off with the paint. Asbestos fiber release resulting in potential exposure episodes, may occur whenever maintenance or repair work requires the removal, drilling, or cutting of the ceiling tiles. The tiles are removed by turning screws in the four corners of the tile. Many tiles were chipped at these corners. Ventilation systems in the building were of the recirculating type, and

were poorly maintained. Released fibers could be distributed by the ventilation systems. On some floors the systems were not operating. System filters were either very old and dirty, or missing. Many of the windows to the outside did not have clear glass, but fibrous glass panels. Most were old, and appeared to be deteriorating due to weathering and the action of the intense sunlight exposure. The wind could free loose fibrous glass fibers and disperse them inside the building causing irritation to the occupants.

Queen Elizabeth Hospital

Queen Elizabeth Hospital is a large (600 bed) health-care facility in Bridgetown. Interest in the hospital was due to recent demolition activities there. Part of the demolition included removal of the roof from a section of the hospital. This roof was made of an asbestos-cement corrugated-sheet material widely used on Barbados. There was concern that asbestos fibers may have been released during the removal, and dispersed into the adjacent hospital areas, since no precautions were taken to prevent this. Other areas of concern that came to our attention during the walk-through were the hospital laundry and boiler rooms. Insulation materials containing asbestos were used on steam and hot water equipment in these areas. An energy conservation program was ongoing to remove the asbestos insulation and replace it with non-asbestos insulation. It was reported that the removal techniques used did not include enclosures, wet methods, or worker protection. The ACM present was generally in bad condition, with much of it exposed and in a friable condition. There were 35 workers in the laundry.

Bulkley Sugar Factory

The Bulkley factory has been producing cane sugar for more than 100 years. During the crop season it employs 120 workers. During the time of this study, the out of crop season, there were 98 workers engaged in maintenance activities. This included much teardown and repair of equipment. Since sugar production is a heat intensive process, much of the equipment is insulated. Not all of the various lagging materials contain asbestos, but many do. We found much of this material to be damaged and in friable condition. Apparent poor housekeeping conditions created an increased potential for exposure to asbestos-containing dusts, in addition to other hazards of sugar production. There was little or no regard for the hazardous nature of asbestos during our survey. Indications were that in the more modern sugar factories, asbestos-containing insulation materials were not being used.

St. Leonard's School

The St. Leonard's School is an educational facility for greater than 2000 students. These students range in age from 11 to 18 years. The boys and girls classroom areas are separate, which is typical on Barbados. The newer additions, which were of interest during this study were constructed circa 1952. The boys school was a single story structure, while the girls school was two stories. The roofs of the school buildings were of asbestos-cement corrugated sheet material. Partitions and stall doors in the lavatories, and the doors to some of the classrooms were constructed using flat-sheet (1/4 inch thick) ACM.

St. Leonard's was a typical school in average to better than average condition. Addressing potential hazards at the public schools was of great concern to officials on Barbados. As in most countries, the youth spend a great deal of time in schools during their formative years. Many public gatherings are held at school facilities as well. Classes were not in session on the day of our survey. There were teachers and some administrative workers present.

Upon inspection, the ACM at St. Leonard's appeared to be in good repair, except for minor damage to some roofing sections. There was more damage at the boys school than at the girls school. The potential asbestos exposure risk from these types of materials is considered to be low if they are undamaged and undisturbed, since these materials are very hard and not friable. Breaking, sawing, drilling or otherwise abraiding the surface would increase the exposure potential. Additional protection would be afforded if the material was sealed by painting. This would be advisable for the door panels, partitions, and the underside of the roof, which are all readily accessible to students.

Department of Transportation Vehicle Shop

This is a large facility for maintenance and repair of the fleet of vehicles and ancillary equipment used by the Department of Transportation. There are several large buildings in the complex. We were interested in observing vehicle brake removal and replacement operations. There was little of this activity on the day of our survey. It was reported that it was most likely to happen in a truck repair area on the north side of the facility. This shop was enclosed on three sides, with the front side open to the environment. There were seven vehicles in this shop for repair.

IV. Methods and Materials

A. Air Samples

Air samples were collected from stationary positions at various locations throughout the identified survey sites. The sampling devices were placed at a height approximating the breathing zone of the occupants. The samples were collected using Nucleopore, 25 millimeter (mm), 0.8 micrometer (um) pore size, mixed cellulose ester filters (open face) and battery-powered sampling pumps calibrated to operate at a nominal flow rate of 3.5 liters per minute (lpm). Sample volumes ranged from 1100 to 1400 liters. Samples were collected outdoors at each site to serve as controls.

1. Phase Contrast Microscopy Analysis (PCM)

All of the air samples were quantitatively analyzed for fibers by PCM according to NIOSH Method 7400 (revision #2, Appendix I).[1] Fibers greater than 5 micrometers (um) in length were counted on each sample at a magnification of 400X. Set A counting rules were utilized. The sample results were reported in total fibers per filter. The limit of detection (LOD) for this method has been determined to be 7 fibers/mm^2 of filter, or 3000 fibers/filter for 25mm diameter filters. This method is designed to count fibers in occupational environments and is most often used to count asbestos fibers. NIOSH Method 7400 does not permit differentiation of fiber types. Electron microscopy is used for fiber identification.

2. Transmission Electron Microscopy (TEM)

Based upon PCM fiber counts and subjective comments by the microscopists, some samples were selected to be analyzed by TEM, using an energy dispersive x-ray system (EDS)

analyzer. The samples were prepared according to NIOSH Method 7402 and analyzed on a Philips 420 TEM[1]. All counting and sizing were conducted at 10,500X magnification. A minimum of 40 grid openings were counted, with each opening having an area of approximately 7.4×10^{-3} mm^2. The LOD for this method is 1 fiber per filter. This method can positively identify fiber type, and is used to determine the fraction of optically visible fibers that are asbestos. This fraction is then applied to the PCM fiber count.

B. Bulk/Surface Samples

Bulk samples of various insulating materials, settled dust, and other pertinent materials were obtained in glass vials. Bulk analysis for asbestos was used to determine the presence of asbestos in suspected materials. The technique used was polarized light microscopy (PLM). PLM allowed determination of the mineral type of individual fibers and estimation of the percent asbestos in a sample. The PLM technique involved placing the sample material (finely powdered) in a liquid of known refractive index on a microscope slide. The material was then observed in a polarizing microscope (Leitz Dialux 20 at 160X) with dispersion staining optics. This caused asbestos materials to exhibit characteristic colors and other optical properties. The percentage of asbestos was determined and reported as a percent area observed in the microscope field.

Surface samples (settled dust on smooth interior surfaces) were collected on filters using the sampling pumps previously described. To obtain these samples, the 25mm filter cassettes were brushed across the surface to be sampled several times in a fashion similar to a vacuum cleaner. These samples were also analyzed by PLM.

V. EVALUATION CRITERIA

As a guide to the evaluation of the hazards posed by workplace exposures in the United States, NIOSH field staff employ occupational exposure evaluation criteria for assessment of a number of chemical and physical agents. These criteria are intended to suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week for a working lifetime without experiencing adverse health effects. The primary sources of environmental evaluation criteria for the workplace are: 1) NIOSH Criteria Documents and recommended exposure limits (RELs), 2) the American Conference of Governmental Industrial Hygienists' (ACGIH) Threshold Limit Values (TLVs), and 3) the U.S. Department of Labor (OSHA) occupational health standards. Often, the NIOSH RELs and ACGIH TLVs are lower than the corresponding OSHA standards. Both NIOSH recommendations and ACGIH TLVs usually are based on more recent information than are the OSHA standards. The OSHA standards also may be required to take into account the feasibility of controlling exposures in various industries where the agents are used; the NIOSH-recommended standards, by contrast, are based primarily on concerns relating to the prevention of occupational disease.

Because, in this study, both occupational and non-occupational environments were evaluated, occupational exposure criteria alone are not adequate. When NIOSH staff are evaluating non-occupational environments in the United States, public exposure estimates, such as those established by the U.S. Environmental Protection Agency (EPA), may be used for comparison.

A. Asbestos Exposure Risks

Epidemiologic studies show that there is a correlation between the intensity and duration of asbestos exposure and an observed excess in lung cancer and mesothelioma (a rare cancer of the chest and abdominal lining). Exposures to asbestos vary in nature, frequency, and duration, and they decrease in approximately the following order of intensity: direct occupational exposure; indirect occupational exposure; family contact exposure ("take-home" from the workplace); and general environmental exposures (from industrial emissions and motor vehicle brake linings, and from consumer products and damaged or deteriorated building materials containing asbestos).[2-13]

Reliable population-based studies on the increased risk of asbestos-associated diseases (pulmonary fibrosis, pleural thickening and asbestosis, lung cancer, and pleural or peritoneal mesothelioma) have been reported for certain groups with well-documented occupational exposures. The risk for both types of asbestos-associated malignancies, lung cancer and pleural or peritoneal mesothelioma, varies in a fashion consistent with a linear (nonthreshold) dose-response relationship. The risk for lung cancer multiplies for cigarette smokers occupationally exposed to asbestos at either high or low levels. Cigarette smoking does not appear to increase the risk for mesothelioma in exposed individuals .[14-20]

No reliable population-based data are available on which to base a direct quantitative assessment of the risk of asbestos-associated cancer due to take-home or other nonindustrial exposures to asbestos. However, indirect risk assessments have indicated that an excess risk does exist.[15,16,20] A persons age at first exposure to asbestos is an important determinant of risk of mesothelioma. Although it has not been proven that there is a linear, nonthreshold dose-response relationship after nonindustrial exposures, it is thought that such a relationship does exist, that exposure to respirable-size asbestos fibers poses a carcinogenic risk for humans, that exposure beginning early in life increases the risk for mesothelioma, and that no safe level of exposure to a carcinogenic agent has been demonstrated; therefore, sources of asbestos that are likely to result in hazardous exposures should be identified and controlled.[14-20]

B. Toxicologic effects of Exposure to Asbestos

Clinical evidence of the adverse effects associated with exposure to asbestos is present in the form of several well-conducted epidemiological studies of occupationally exposed workers, family contacts of workers, and persons living near asbestos mines. These studies have shown a definite association between exposure to asbestos and an increased incidence of lung cancer, pleural and peritoneal mesothelioma, gastrointestinal cancer, and asbestosis.

Asbestosis is a disabling fibrotic lung disease that is caused only by exposure to asbestos. Exposure to asbestos has also been associated with an increased incidence of esophageal, kidney, laryngeal, pharyngeal, and bucal cavity cancers. As with other known chronic occupational diseases, disease associated with asbestos generally appears about 20 years following the first occurrence of exposure. There are no known acute effects associated with exposure to asbestos.

The signs and symptoms of lung cancer or gastrointestinal cancer induced by exposure to asbestos are not unique, except that a chest X-ray of an exposed patient with lung cancer may show pleural plaques, pleural calcification, or pleural fibrosis. Asbestos exposure acts synergistically with cigarette smoking to multiply the risk of developing lung cancer. Symptoms characteristic of mesothelioma include shortness of breath, pain in the walls of the chest, or abdominal pain. Mesothelioma has a much longer latency period compared to lung cancer (40 years versus 15-20 years), and mesothelioma is therefore more likely to be found among workers who were first exposed to asbestos at an early age. Mesothelioma is always fatal.

C. Airborne Exposure Criteria for Asbestos

Since asbestos is a carcinogen, NIOSH urges that the objective or goal is to eliminate asbestos exposures. The evaluation concept of lowest feasible level (LFL) is used by NIOSH investigators. In industrial situations, the minimum reliably quantifiable airborne concentration, as determined by state-of-the-art analytical methodology, is used for the LFL. In other cleaner environments, such as an office building, analytical methods may detect much lower contaminant concentrations. In this case, a more reasonable way to determine the LFL may be to compare measured air concentrations to measured "background concentrations" in similar facilities, or to outdoor air concentrations. If current risk assessments relating exposure to health effects are avaliable, they may also be used in determining the LFL. Which of the above methods is used will depend upon the environment being evaluated.

The current NIOSH REL for occupational exposure in asbestos-laden environments is 0.1 fibers per cubic centimeter of air (f/cm^3), determined as a time-weighted average breathing-zone exposure for up to a 10-hr workday, 40-hr workweek, using NIOSH Method 7400 (phase contrast microscopy). The presence of background dust when collecting high sample volumes may be the limiting factor which may complicate the analysis using this method[21].

The ACGIH, an independent scientific body, recommends that personal exposures to chrysotile asbestos exposures be limited to 2.0 f/cm^3 and amosite asbestos exposure be limited to 0.2 f/cm^3, averaged over an 8-hr workday (with the notation that asbestos is a human carcinogen).[22] In the U.S., the Occupational Safety and Health Administration (OSHA) standard for asbestos, limits exposure to 0.2 f/cm^3 averaged over an 8-hr workday. OSHA also has an asbestos excursion limit. The excursion standard limits employee exposures to 1.0 f/cm^3 averaged over a 30-minute period of exposure.[23]

The United Kingdom and Australia have assigned hygienic standards for occupational exposure to asbestos of 2 f/cm^3 as a time-weighted average. The Federal Republic of Germany considers all forms of asbestos to be carcinogenic to man and believes that no safe exposure concentration can be assigned.[24]

There are no uniformly accepted, standardized, environmental evaluation criteria for non-industrial settings (such as schools and office buildings). Use of the NIOSH PCM method will permit detection and quantitation of about 0.01 f/cm^3 with acceptable statistical reliability ($\pm$ 25% using a 1000 liter air sample). NIOSH recommends using 0.01 f/cm^3 as an action level which should apply to all occupied building space with potentially hazardous asbestos surfaces, and be primarily used to help make risk-management decisions and direct control strategies. It is not an "occupancy" or "safe" asbestos

concentration. NIOSH recommends that at least 5% of air samples below 0.01 f/cm^3 and all air samples above this level should be further analyzed by TEM for specifically determining the identity of fibers detected by the PCM method.

Concentrations of asbestos in urban ambient (outdoor) air were measured in 48 cities in the U.S. between 1969 and 1970. Asbestos was detectable in virtually every metropolitan area. Ambient concentrations were generally below 300 f/m^3 (0.0003 f/cm^3) and never exceeded 3,000 f/m^3 (0.003 f/cm^3), except near sources of asbestos emissions. Mean asbestos concentrations were found to be approximately 120 f/m^3 (0.00012f/cm^3) in 1969, and 60 f/m^3 (0.00006 f/cm^3) in 1970.[25]

VI. Results

The results for samples collected during the five site evaluations are presented in Tables 1-5. Included are analytical results for bulk material and settled dust samples collected to determine asbestos content, surface sweep samples used to determine whether any fiber release episodes had occurred in the recent past, and air samples. With air samples, only the current airborne fiber concentration is measured.

A. Bulk Material Samples

The bulk material sample results are presented in Table 1. Asbestos-containing materials were found at all survey sites except the vehicle maintenance shop.

At the Treasury Building, two samples of asbestos-cement ceiling tile contained primarily amosite at a concentration of 40-50%. One of the samples showed a trace (<1%) of chrysotile asbestos. The tiles throughout the building were in generally good condition. Some of the tiles had damaged edges and/or corners because of removal during maintenance activities requiring access to the space above the tiles (lighting fixtures were recessed). These tiles were very hard (cementitious).

Five of the 11 bulk samples collected at Queen Elizabeth Hospital contained large amounts of asbestos. Three of these samples were of a rope-like pipe wrapping which was commonly found. One sample collected from a steam line to the presses in the laundry contained nearly 100% chrysotile asbestos. Another sample of this type of lagging from a steam line on the laundry boiler contained 70-80% chrysotile asbestos. A third sample of rope lagging, which was wrapped around a tank in a sump area in the hospital boiler room, contained 95-98% amosite asbestos. Two samples of troweled-on lagging were analyzed. A sample of the lagging covering a hot water tank, in the old boiler section of the laundry boiler room, contained 50-55% amosite. The other lagging sample, from the inner layer of the hot water tank in the hospital boiler room, contained 35-40% amosite. A sample of the thin, outer layer of lagging on this hot water tank was <1% amosite, and a sample of lagging at a "T" in a steam line from this boiler room also contained <1% amosite.

Most of the asbestos containing insulating materials found at the hospital were damaged and in otherwise poor condition. Most would also have been considered friable (easily crumbled by hand pressure). All of the materials sampled and found to contain asbestos were easily accessible to workers.

Much of the ACM in the press area of the laundry had been abraded from worker contact. Potential exposures in the two boiler room areas would be limited to the few workers who operate and maintain this equipment. In the laundry and press area there were over thirty workers during the day.

Two bulk samples were collected from St. Leonard's School. A sample of the corrugated-sheet roofing material contained 25-35% chrysotile asbestos. A sample of the flat-sheet material used for partitions and doors contained 50-55% chrysotile asbestos. These materials were generally in good condition. Some of the roofing

material had small holes or broken edges, and one or two partitions had small gouges in them. All of the flat material was painted, while none of the roofing material was. Both of these materials were hard and not easily broken. Fiber release would not be expected if undisturbed. Uncontrolled sawing, sanding, or drillng would not be advisable. Painting the underside of the roof, which is exposed to the interior of the classrooms, should adequately seal the surface. The doors and partitions were already painted. With regard to the broken edges on the roofing, these should also be sealed since loose fibers are exposed. Students should be educated regarding the hazards of asbestos and cautioned about acts of vandalism which would result in expsoure.

B. Surface Sweep Samples

The surface samples collected on filters, whose analytical results are presented in Table 2, were analyzed using PLM. All results were negative, except for one of settled dust from inside the ventilation system air handling unit enclosure, located in the northwest corner of the 1st floor at the Treasury Building. This result showed the presence of amosite asbestos at a concentration of less than 1%. These results indicate that there have been no fibers released recently from the ACM in most locations. A cautionary note should be added since no TEM analysis could be performed on any of these samples. The PLM technique destroys the entire sample disallowing further analysis. TEM is a more sensitive technique. Future samples which are lightly loaded should be analyzed by TEM. Heavily loaded filters cannot be analyzed using fiber-counting, light microscopic techniques.

C. Air Samples Analyzed by Phase Contrast Microscopy

The results of 43 air samples analyzed by PCM are presented in Table 3. This type of sample (air sample) is only useful in determining current exposure potential. Air sampling cannot be used to indicate past or future hazards, and should never be used alone to make such determinations. They are useful, when used with the other methods described in this report, to obtain a clearer exposure profile, or to measure airborne contamination during a time when asbestos is known, or suspected, to be present in the air, such as during demolition or an abatement procedure. These samples were collected in a effort to be as comprehensive as possible during this evaluation. At each of the survey sites, samples were collected in areas of concern and at a control location for comparison purposes. The control locations used were always outdoors.

At the Treasury Building there were 10 air samples collected, including two controls (comparison samples). At least one sample was collected on each floor of the building in areas where work activities

were occuring in a normal fashion. All of the PCM results showed fiber concentrations to be below the analytical limit of detection (LOD) of 0.002 f/cm^3. It must be remembered that PCM analysis only counts fibers and cannot determine the fiber type.

There were 10 air samples collected at the Queen Elizabeth Hospital, including one outdoor sample as a control. Four samples showed fiber concentrations above the LOD. One of these was the control sample, which was collected in a large open area between the hospital laundry and the hospital proper. Two samples from the laundry showed fiber concentations of 0.005 f/cm^3. One was located next to the TULLIS sheet iron and the other next to the AJAX steam irons (northeast side). One sample, collected in the hospital boiler room near the fire pump tank, showed 0.004 f/cm^3. The outdoor air sample fiber concentration was 0.006 f/cm^3. These fiber concentrations are low. The reason that such low levels could be confidently and reliably reported was because of the high sample volumes collected (most between 1200 and 1300 liters). Previously stated quantitation limits were dependent upon a maximum sample volume of 1000 liters. These environments were relatively clean and allowed higher sample volumes without overloading the filters, which is the limiting factor in distinguishing single fibers.

At the Bulkley Sugar Factory, only one of the 10 samples analyzed by PCM showed fiber concentrations above the LOD. This sample was collected in the evaporation area where 0.016 f/cm^3 were found. Three of the samples collected at Bulkley were overloaded. There was a lot of activity in the areas where the samples were collected, and it was much dustier than the other survey sites. Workers were performing maintenance on processing equipment for the next harvest season. This included the removal of lagging (troweled-on insulating covering) from some of the equipment. There appeared to be little regard for whether or not the material contained asbestos, although the plant manager indicated that he was aware that some of the lagging materials did. None of the workers we saw were wearing respiratory protection.

Fiber concentrations from the ten samples collected at St. Leonard's School were all below the LOD of the PCM method. There was little activity at the school since classes were not in session. These sample results may not represent normal classroom conditions. Some of the teachers and administrative workers were in the administration building, preparing for the advent of the new school session. Air samples were collected in five classrooms, outside the classrooms in the walkway, which was also covered by the asbestos roof, and in the meeting room on the second floor of the administration building. The classrooms were closed, so we opened the doors and shutters to allow as much air movement as possible. The samplers were placed on desks near the center of the rooms.

At the vehicle maintenance shop there were only three samples collected. One of these was an outdoor air control sample. There was no brake lining work scheduled for the day, so we placed samplers at each end of the shop where there was general maintenance work going on. The samples did not show fiber concentrations above the analytical LOD. We had a chance to visit several local auto repair businesses later in the day to inquire about the possibility of collecting air samples. They were not interested, but answered questions about their operations. We were told that they had local exhaust control in place for performing brake work. However, we did not see them in use. It was enlightening to know that this type of control was being used on Barbados.

D. Air Samples Analyzed by Transmission Electron Microscopy

All of the air samples analyzed by PCM which showed fiber concentrations above the LOD were then analyzed by TEM. Subjective comments about the fibers observed during PCM analysis were included in the PCM report from the microscopist. The samples whose result included a comment that the fibers present may be a type of asbestos, as well as all outdoor control samples, were also analyzed by TEM. These results are presented in Table 4. Those results followed by an asterisk had fiber concentrations above the LOD using PCM. The microscopist performing the TEM analysis reported that "all fibers detected during the analysis were either amosite or chrysotile asbestos. Therefore, essentially 100% of the fibers counted by PCM can be considered as asbestos fibers."

Asbestos fibers were detected on two of the five air samples collected at the Treasury Building and submitted for TEM analysis. These were the samples from the 3rd and 4th floor sample sites. There were no fibers detected on the outdoor control samples. There were no maintenance activities at the time of the sample collection.

There were six air samples collected at the Queen Elizabeth Hospital which were submitted for TEM analysis. Two were free of asbestos; the outdoor-air control sample, collected between the laundry and the main hospital building, and the air sample collected in the laundry, next to the TULLIS sheet iron. The sample collected next to the AJAX steam presses, a few meters away from the TULLIS machine, had chrysotile asbestos fibers detected on it. Amosite asbestos fibers were detected on two air samples collected in the boiler room for the hospital; one in the vicinity of the hot water tank and the other near the fire pump tank.

The only sample collected outdoors which was not a control sample, and on which asbestos was detected by TEM, was collected on the balcony of Obstetrics Ward B-1, located directly adjacent to a construction site. An old wing of the hospital, which had a roof of asbestos-containing sheeting, was demolished to make room for the new construction. It is not known what precautions, if any, were taken during removal of the old roof to contain the asbestos. It is believed that the fibers detected on this sample were linked to the demolition/construction activity. One sample collected at the Bulkley Sugar Factory, in the evaporation area, contained amosite asbestos. Process equipment maintenance, which included the removal of insulation material, was being performed in this area. This was also a heavy worker traffic area. There was no asbestos detected on the outdoor air sample.

Four air samples collected at the St. Leonard's School were submitted for TEM analysis. One collected from the boys school area, form 2^2, room 10, contained amosite asbestos. Another, collected on a window sill outside the administrative office, and under cover of the asbestos roof, contained both amosite and chrysotile asbestos. Asbestos was not detected on the outdoor-air control sample.

Caution should be used when interpreting these results. While asbestos was detected, in most cases the number of fibers actually counted were very low. The range of fiber concentrations calculated from the TEM analytical results was from 0.001 to 0.05 f/cm^3. The important information here is that airborne asbestos fibers were detected in areas where workers and the general public, including school-aged children, were potentially exposed at concentrations greater than the measured background. This indicates that there was a recent release of fibers which was not controlled.

E. Microscopic Analysis of Overloaded Air Samples

The use of air flow rates which were too great for the dusty conditions encountered led to the collection of three overloaded air samples at the Bulkley Sugar Factory. Because of overloading, particles on the filters were uncountable by PCM. Therefore, they were analyzed by polarized-light microscopy. The results of these analyses are in Table 5.

Asbestos was detected on two of the three samples. Chrysotile alone was detected on the sample collected in the alternator room, and both chrysotile and amosite were detected on the sample collected in the milling area. Since these results were not fiber counts, but merely indicated the presence of asbestos, fiber concentrations could not be determined. The results bolster the evidence that the environment in areas of this factory is potentially hazardous.

VII. Discussion

The NIOSH evaluations of government and public buildings, and industrial environments on Barbados found that potentially hazardous asbestos-containing materials are widely used. Some were found to be damaged and in bad condition. Sampling and analysis showed that, in the survey sites which were chosen for this evaluation, there have not been extensive fiber releases in the recent past, but there were asbestos fibers detected in the air. The concentrations found were low, most within the range of fiber concentrations reported in ambient air in U.S. cities (0.0003 to 0.003 fibers/cm^3), and there were not asbestos fibers found on all samples (9 of 43). However, airborne asbestos was found at all but one survey site, with none being found on outdoor air control samples.

Because the onset of asbestos-associated cancers generally follows initial exposures only after long latency periods of 20 or 30 years or more, the early recognition, evaluation, and control of potentially hazardous exposures to asbestos are essential. This is especially true for environments in which infants, children, and young adults may be exposed to airborne asbestos fibers. Such environments on Barbados may include homes, day-care facilities, hospitals, and schools where asbestos-containing construction materials may be deteriorated. Most private homes, small commercial buildings, and many larger commercial buildings have asbestos roofing material. All of the public schools, hospitals, and many Government buildings which we saw, also have asbestos roofs. This roofing material is the single most prevalent ACM observed. Many of the structures have no barrier on the interior to limit accessibility to the ACM, or to contain released fibers. Any maintenance, repair, or removal of this material without adhering to strict control measures will likely result in a hazardous exposure. Vandalism is also a potential problem. Roofing professionals in the U.S. are expressing concerns over the protection of worker health and the environment during renovation and demolition of roofs which have asbestos-containing materials.[26]

In addition to the roofing materials there are any number of other materials containing asbestos on Barbados. Some have been discussed in this report, such as, ceiling tiles and thermal insulation materials. Changeover to non-asbestos materials, such as in energy conservation programs, where ACM is removed in large quantities, will also likely result in hazardous exposures if 1) proper removal techniques, 2) exposure controls, and 3) proper disposal methods are not used. Considerable attention has been paid to these three subject areas in asbestos abatement over the last decade in the United States. The use of this technology on Barbados should not be difficult. A fourth area, which may require more effort is education and training. The ability to identify potential asbestos-containing material, to know the health hazards associated with exposure to asbestos, and to give asbestos proper respect are equally important.

Because of the relative freshness surrounding the importance of asbestos issues on Barbados, agencies mandated to administer public and occupational health programs lack sufficient staff with expertise and guidance as to 1) the training, technical consultation, and standardized methods necessary to conduct valid and reliable environmental sampling and analysis of asbestos, 2) the limitations (sensitivity, specificity, limits of detection and quantification) of available bulk- and air-sampling methods, 3) the assessment of risk identified by sampling and analytical programs, 4) what to tell non-occupationally exposed groups (students, parents, and community members) about their level of risk of asbestos-associated diseases, 5) what to tell the occupationally exposed groups about their risks, especially if their job involves contact with asbestos, 6) how to decide whether to implement a control program, and 7) how to choose between alternative control measures.

VIII. Recommendations

The following recommendations are made to assist PAHO and the Barbados Ministry of Health in implementing programs necessary to effectively address problems related to public and occupational asbestos issues:

1. A group within the Barbados Ministry of Health should be designated to coordinate and administer the policies made regarding asbestos on Barbados. Those in this group should receive comprehensive training in the recognition, evaluation, and control of asbestos exposure situations. This training should include course work in the health hazards associated with asbestos, hazard evaluation and control techniques, and the recognition of potential asbestos containing materials. In addition, course work and practical experience will be necessary in the subject areas of visual assessment, inspection of asbestos abatement job sites, modern abatement techniques, and the monitoring of abatement sites during and following abatement activities.

2. The Ministry of Health should develop guidelines and procedures to be followed by contractors, or others planning asbestos abatement activities, regarding notification that such abatement work is planned and when it will commence. In the United States, the U.S. Environmental Protection Agency (USEPA) requires notification if 260 square feet or more of asbestos containing material (materials containing >1% asbestos) are to be removed and disposed of. The USEPA also requires notification if 160 linear feet of ACM, such as pipe lagging, is to be removed and disposed of. This notification is required 20 days in advance of the project. The USEPA can then approve or disapprove the notification. Additionally, guidelines and procedures regarding a final inspection, for clearance purposes, by the Ministry of Health following an abatement activity should be developed. An accepted rule followed in the U.S. as a clearance criteria is an airborne fiber concentration, under aggressive conditions, of 0.01 fibers/cm^3 using phase contrast microscopy both inside and outside of the abatement area.

3. The Barbados Ministry of Health should have staff members trained to perform air sampling and analysis for asbestos. They should purchase the necessary equipment to perform this function. This should include sampling pumps, filter media, tubing, etc. for sample collection, and a phase contrast microscope with necessary accompanying equipment for PCM analysis (see Appendix I for NIOSH method 7400 description).

4. Worker guidelines should be established pertaining to safe asbestos abatement activities. These should include worker training and education, personal protection, and modern abatement procedures.

5. A guidance document, which would be available to the general public and workers alike would be beneficial as an educational, as well as an instructional tool. This document should include general and specific information regarding 1) background information on exposure to asbestos, 2) how to determine if an asbestos-containing material is present, 3) establishing maintenance programs, 4) asbestos exposure control procedures, 5) modern abatement methods and, 6) how to conduct abatement projects.

6. Efforts should be made to educate the general public with respect to the hazardous nature of asbestos, and how to recognize the common asbestos-containing materials on Barbados. The Ministry of Health should dissemminate information as widely as possible to let the public know that asbetos-containing materials in good condition are not hazardous if left undisturbed, and maintenance activities which involve ACM require special work practices. This could include a telephone number for people to call when urgent information is needed, or to report a hazardous situation. A central clearinghouse for asbestos information accessible to the public should be established.

The final three recommendations are made to address situations observed during the site surveys.

7. All maintenance and repair activities at the Treasury Building which involve the ceiling tiles should be performed after daily workshift and public access hours, or during the weekend. Precautions should be taken to prevent worker exposure to asbestos whenever the tiles are removed or modified (by sawing, drilling, etc.). At the minimum, these precautions should include respiratory protection and wet work methods. The use of disposable gloves and coveralls for larger jobs would be good. Wet cleanup methods should be used in the areas surrounding the jobsite, such as mopping floors and wiping desk tops and other elevated horizontal surfaces with a damp cloth. Mops and cloths should be rinsed frequently. Building ventilation systems should all be in working order. Regular and preventive maintenance schedules should be instituted and monitored.

8. All damaged, friable asbestos-containing materials which are accessible in the laundry areas, such as on steam lines at the presses, in the laundry boiler rooms, and the hospital boiler room at the Queen Elizabeth Hospital should be replaced or repaired. Personal protection (respiratory protection, disposable TYVEK coveralls, etc.), modern abatement techniques (enclosures and wet methods), and proper disposal of asbestos-containing wastes should be used. Wet cleanup methods should follow abatement activities.

9. The underside of the asbestos-cement roofing material at the St. Leonard's School should be sealed. A coating of good quality paint would be sufficient for this purpose. It would be prudent to institute a policy of cleaning the classrooms using wet methods on a regular schedule. A minimum of once a week is suggested. It would be good to impress upon the students the hazards of damaging the roofing and flat-sheet asbestos-cement materials.

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XI. DISTRIBUTION AND AVAILABILITY OF REPORT

Copies of this report are temporarily available upon request from NIOSH, Hazard Evaluations and Technical Assistance Branch, 4676 Columbia Parkway, Cincinnati, Ohio 45226. After 90 days, the report will be available through the National Technical Information Service (NTIS), 5285 Port Royal, Springfield, Virginia 22161. Information regarding its availability through NTIS can be obtained from NIOSH Publications Office at the Cincinnati address. Copies of this report have been sent to:

1. Pan American Health Organization
2. Barbados Ministry Of Health
3. Caribbean Epidemiologic Center

Table 1
Results of Asbestos Analyses of Bulk Material Samples
Five-Site Study / Barbados / August 29 - September 5, 1988
HETA 88-372

Sample Description	Percent Asbestos Amosite	Chrysotile
Treasury Building Samples		
Ceiling tile, 2nd floor archive	45-50	<1
Ceiling tile, 1st floor, NW corner	40	ND*
Ventilation system filter material, 1st floor, NW	ND	ND
Queen Elizabeth Hospital		
Rope-like pipe lagging, steam press line, laundry	ND	95-98
Settled dust from west wall, sheet folding, laundry	ND	ND
Settled dust from washing machine area, laundry	ND	ND
Pipe lagging, overhead pipe, newer boiler, laundry	ND	ND
Rope-like pipe lagging, steamline, boiler to laundry	ND	70-80
Lagging, hot water tank next to older boiler, laundry	50-55	<1
Settled dust, top of older boiler, laundry	ND	ND
Lagging, inner layer, hot water tank, hospital boiler	35-40	ND
Lagging, outer layer, hot water tank, hospital boiler	<1	ND
Pipe lagging, steamline "T", east wall, hospital boiler	<1	ND
Rope-like lagging on tank in sump area, hospital boiler	95-98	ND
Bulkley Sugar Factory		
Lagging from pipe on floor, evaporator area	<1	ND
Lagging Material on floor from overhead pipe, evap. area	ND	ND
Lagging from tank in evaporator area, near milling area	ND	ND
Block-like lagging on pipes in milling area	60	ND
Rope-like lagging on pipes in milling area	ND	50-60
Lagging from small surge/condensate tank, milling area	ND	ND
Lagging from large diameter elbow between evap & mill	30-35	<1
Lagging from storage tank, mezzanine level	20-25	<1
Settled dust from stairs leading to furnace	<1	ND
Settled dust next to furnace	<1	ND
Lagging from ash arrestor	25	<1
St. Leonard's School		
Corrugated roofing material	ND	25-35
Flat sheeting material used for doors and partitions	<1	50-55
MTW Vehicle Maintenance Shop		
Suspected brake-lining dust	ND	ND

* ND - none detected

Table 2

Results of Asbestos Analyses of Surface Sweep Samples
Five-Site Study
Barbados
August 29 - September 5, 1988

HETA 88-372

Sample Description	Percent Asbestos Amosite	Chrysotile
Treasury Building Samples		
Settled dust from shelves in 2nd floor archive area	ND*	ND
Settled dust inside ventilation system air handling unit enclosure, NW corner of 1st floor	<1	ND
Settled dust from window sill, NW corner, 1st floor	ND	ND
Queen Elizabeth Hospital		
Settled dust from window sill outside Obstetrics Ward B1	ND	ND
Settled dust from balcony ledge near construction	ND	ND
St. Leonard's School		
Settled dust from window sill, Form 1^5, Room 5	ND	ND
Settled dust from window sill, Form 2^n, Room 10	ND	ND
Settled dust from mahogany lectern in assembly hall	ND	ND
MTW Vehicle Maintenance Shop		
Settled dust collected on outside of truck cab	ND	ND
Settled dust from floor near left rear wheel of brake job	ND	ND

* ND - none detected

Table 3

Results of Phase Contrast Microscopy Fiber Analysis of Air Samples
Five-Site Study
Barbados
August 29 - September 5, 1988

HETA 88-372

Sample Location	Sample Volume (liters)	Concentration (fibers/cc)
Treasury Building Samples		
Control Section, 1st floor, SE work area	1336	<0.002*
Returns and Possessions, Inland Revenue, 2nd floor, N work area	1370	<0.002
Office Audit, Inland Revenue, 3rd floor, central area	1390	<0.002
Personnel and Administration, Inland Revenue, 4th floor, S work area	1422	<0.002
Audit Department, Inland Revenue, 5th floor, central work area	1316	<0.002
Office of Supervisor of Insurance, 6th floor, N work area	1354	<0.002
Audit Department, Supervisor of Insurance, 6th floor, S work area	1261	<0.002
Outdoor balcony, 6th floor, N end	1292	<0.002
Outdoor, first floor roof, E face	1251	<0.002
Data Processing, Inland Revenue, ground floor, S work area	1326	<0.002
Queen Elizabeth Hospital		
Next to AJAX steam irons, SE side, laundry	1306	<0.002
Next to TULLIS sheet iron, W side, laundry	1231	0.005
Next to AJAX steam irons, NE side, laundry	1298	0.005
Laundry boiler room, between newer boilers	1325	<0.002
Laundry boiler room, on out-of-service boiler	1321	<0.002
Hospital boiler room, on hot water tank	1281	<0.002
Hospital boiler room, on fire pump tank	1238	0.004
Outdoor sample, Obstetrics Ward B-1 balconey, next to construction site	1224	<0.002
Pipe chase/laundry chute area, ground floor	1109	<0.002
Outdoor sample, between laundry and hospital	1200	0.006

* <0.002 - This value in the table indicates that the sample result was less than the analytical limit of detection (LOD).

Table 3, continued

Sample Location	Sample Volume (liters)	Concentration (fibers/cc)
Bulkley Sugar Factory		
Alternator room	1274	overloaded**
Milling area, south	1158	<0.002
Milling area, north	1225	overloaded
Evaporation area	1158	0.016
Between furnaces and ash arrestor	1159	<0.002
#3 Furnace area	1183	overloaded
Machine shop	1186	<0.002
Under evaporator #3	1186	<0.002
Mezzanine above milling	1153	<0.002
Outdoor sample	1231	<0.002
St. Leonard's School		
Form 2^2, room 10	1255	<0.002
Form 1^5, room 5	1270	<0.002
Upper 5B	1361	<0.002
Outdoors, under walkway roof, near Form 1^5, room 5	1187	<0.002
Outdoor air, in parking area	1218	<0.002
Outdoors, under walkway roof, administrative office	1332	<0.002
$3B^2$, room 6	1109	<0.002
Outdooors, on walkway roof, near form 2^n, room 10	1148	<0.002
Form 2^n, room 10	1079	<0.002
Meeting room above admininsrative office	1158	<0.002
MTW Vehicle Maintenance Shop		
North repair shop, east end on bench	1261	<0.002
North repair shop, west end on truck cab	1326	<0.002
Outdoor air sample	1264	<0.002

* <0.002 - This value in the table indicates that the sample result was less than the analytical limit of detection (LOD).

** Overloaded indicates that the filter was obscured so that fibers could not be counted by PCM.

Table 4
Results of Transmission Electron Microscopy Analysis of Air Samples
Five-Site Study
Barbados
August 29 - September 5, 1988

HETA 88-372

Sample Location	Type of Asbestos Identified
Treasury Building	
Office Audit, Inland Revenue, 3rd floor, central area	Amosite and chrysotile
Personnel and Administration, Inland Revenue, 4th floor, S work area	Amosite
Audit Department, Inland Revenue, 5th floor, central work area	None detected
Outdoor balcony, 6th floor, N end	None detected
Outdoor, first floor roof, E face	None detected
Queen Elizabeth Hospital	
Next to TULLIS sheet iron, W side, laundry	None detected*
Next to AJAX steam irons, NE side, laundry	Chrysotile*
Hospital boiler room, on hot water tank	Amosite
Hospital boiler room, on fire pump tank	Amosite*
Outdoor sample, Obstetrics Ward B-1 balcony, next to construction site	Amosite and chrysotile
Outdoor sample, between laundry and hospital	None detected*
Bulkley Sugar Factory	
Evaporation area	Amosite*
Outdoor sample	None detected
St. Leonard's School	
Form 2^2, room 10	Amosite
Outdoors, under walkway roof, near Form 1^5, room 5	None detected
Outdoor air, in parking area	None detected
Outdoors, under walkway roof, administrative office	Amosite and chrysotile

* indicates a sample whose PCM result was greater than the analytical LOD

Table 5

Qualitative Results of Microscopic Analysis of Overloaded Air Samples
Five-Site Study
Barbados
August 29 - September 5, 1988

HETA 88-372

Sample Location	Type of Fiber Identified
Bulkley Sugar Factory	
Alternator room	Chrysotile, cellulose
Milling area, north	Chrysotile, amosite, glass, cellulose
#3 Furnace area	Cellulose

FORMULA: various

M.W.: various

FIBERS

METHOD: 7400
ISSUED: 2/15/84
REVISION #2: 3/1/87

OSHA: 0.2 asbestos fibers (> 5 µm long)/mL
NIOSH: 0.1 asbestos f/mL [1]; 3 glass fibers (>10 µm x <3.5 µm)/mL [2]
ACGIH: 0.2 crocidolite; 0.5 amosite; 2 chrysotile and other asbestos, f/mL

PROPERTIES: solid, fibrous

SYNONYMS: actinolite asbestos [CAS #13768-00-8], grunerite asbestos (amosite) [CAS #12172-73-5], anthophyllite asbestos [CAS #17068-78-9], chrysotile asbestos [CAS #12001-29-5], crocidolite asbestos [CAS #12001-28-4], tremolite asbestos [CAS #14567-73-8]; fibrous glass.

SAMPLING

SAMPLER: FILTER
(0.8- to 1.2- µm cellulose ester membrane, 25-mm diameter; conductive cowl on cassette)

FLOW RATE*: 0.5 to 16 L/min (see step 4)

VOL-MIN*: 400 L @ 0.1 fiber/mL (see step 4)
-MAX*: (see step 4)
*Adjust for 100 to 1300 fibers/mm² (step 4)

SHIPMENT: routine (securely packed to reduce shock)

SAMPLE STABILITY: stable

FIELD BLANKS: 10% (≥2) of samples

ACCURACY

RANGE STUDIED: 80 to 100 fibers counted

BIAS: see EVALUATION OF METHOD

OVERALL PRECISION (s_r): 0.115 to 0.13 (A Rules) [3] (see Appendix C)

MEASUREMENT

TECHNIQUE: LIGHT MICROSCOPY, PHASE CONTRAST

ANALYTE: fibers (manual count)

SAMPLE PREPARATION: acetone/triacetin "hot block" method [4]

COUNTING RULES: Set A (P&CAM 239 [3,4]) or Set B (modified CRS [5])

EQUIPMENT: 1. positive phase-contrast microscope
2. Walton-Beckett graticule (100-µm field of view):A Rules use Type G-22; B Rules use Type G-24
3. phase-shift test slide (HSE/NPL)

CALIBRATION: HSE/NPL test slide

RANGE: 100 to 1300 fibers/mm² filter area

ESTIMATED LOD: 7 fibers/mm² filter area

PRECISION: 0.10 to 0.12 (A Rules) [3] (see Appendix C)

APPLICABILITY: The method gives an index of airborne fibers in workplace atmospheres. Phase contrast microscopy will not differentiate between asbestos and other fibers; use this method in conjunction with electron microscopy (e.g., Method 7402) for positive identification. Fibers < ca. 0.25 µm diameter will not be detected by this method [6].

INTERFERENCES: Any other airborne fiber may interfere since all particles meeting the counting criteria are counted. Chain-like particles may appear fibrous. High levels of non-fibrous dust particles may obscure fibers in the field of view and increase the detection limit.

OTHER METHODS: This method introduces changes for improved sensitivity and reproducibility. It replaces P&CAM 239 [3,7] and Method 7400 (dated 5/15/85).

REAGENTS:

1. Acetone.*
2. Triacetin (glycerol triacetate), reagent grade.

*See SPECIAL PRECAUTIONS.

EQUIPMENT:

1. Sampler: field monitor, 25-mm, three-piece cassette with 50-mm electrically-conductive extension cowl and cellulose ester filter, 0.8- to 1.2-µm pore size, and backup pad.
   NOTE 1: Analyze representative filters for fiber background before use. Discard the filter lot if mean is ≥ 5 fibers per 100 graticule fields. These are defined as laboratory blanks.
   NOTE 2: Use an electrically-conductive extension cowl to reduce electrostatic effects. Ground the cowl when possible during sampling.
2. Personal sampling pump, 0.5 to 16 L/min (see step 4 for flow rate), with flexible connecting tubing.
3. Microscope, positive phase contrast, with green or blue filter, 8 to 10X eyepiece, and 40 to 45X phase objective (total magnification ca. 400X); numerical aperture = 0.65 to 0.75.
4. Slides, glass, frosted-end, pre-cleaned, 25 x 75 mm.
5. Cover slips, 22 x 22 mm, No. 1-1/2, unless otherwise specified by microscope manufacturer.
6. Lacquer or nail polish.
7. Knife, #10 surgical steel, curved blade.
8. Tweezers.
9. Heated aluminum block for clearing filters on glass slides (see ref. [4] for instructions on manufacture).
10. Micropipets, 5-µL and 100- to 500-µL.
11. Graticule, Walton-Beckett type with 100-µm diameter circular field (area = 0.00785 mm^2)at the specimen plane (Type G-22 for A Rules; Type G-24 for B Rules). Available from PTR Optics Ltd., 145 Newton Street, Waltham, MA 02154 [phone (617) 891-6000] and McCrone Accessories and Components, 2506 S. Michigan Ave., Chicago, IL 60616 [phone (312) 842-7100].
    NOTE: The graticule is custom-made for each microscope. Specify disc diameter needed to fit exactly the ocular of the microscope and the diameter (mm) of the circular counting area (see APPENDIX A).
12. HSE/NPL phase contrast test slide, Mark II. Available from PTR Optics Ltd.
13. Telescope, ocular phase-ring centering.
14. Stage micrometer (0.01-mm divisions).
15. Wire, multi-stranded, 22-gauge.

SPECIAL PRECAUTIONS: Acetone is extremely flammable. Take precautions not to ignite it. Heating of acetone in volumes greater than 1 mL must be done in a ventilated laboratory fume hood using a flameless, spark-free heat source.

SAMPLING:

1. Calibrate each personal sampling pump with a representative sampler in line [3].

2. For personal sampling, fasten sampler to the worker's lapel near the worker's mouth. Remove top cover from cowl extension (open face) and orient face down. Wrap joint between cowl and monitor body with shrink tape to prevent air leaks.
   NOTE: If possible, ground the cassette to remove any surface charge, using a wire held in contact (e.g., with a hose clamp) with the conductive cowl and a non-electrical metal fixture, or a cold-water pipe.
3. Submit at least two field blanks (or 10% of the total samples, whichever is greater) for each set of samples. Remove top covers from the field blank cassettes and store top covers and cassettes in a clean area (bag or box) with the top covers from the sampling cassettes during the sampling period. Replace the top covers in the cassettes when sampling is completed.
4. Sample at 0.5 L/min or greater [8]. Adjust sampling flow rate, Q (L/min), and time, t (min), to produce a fiber density, E, of 100 to 1300 fibers/mm^2 ($3.85 \cdot 10^4$ to $5 \cdot 10^5$ fibers per 25-mm filter with effective collection area A_c= 385 mm^2) for optimum accuracy. These variables are related to the action level (one-half the current standard), L (fibers/mL), of the fibrous aerosol being sampled by:

$$t = \frac{(A_c)(E)}{(Q)(L)10^3}.$$

   NOTE: The purpose of adjusting sampling times is to obtain optimum fiber loading on the filter. A sampling rate of 1 to 4 L/min for 8 hrs is appropriate in non-dusty atmospheres containing ca. 0.1 fiber/mL. Dusty atmospheres require smaller sample volumes ($\leq$400 L) to obtain countable samples. In such cases take short, consecutive samples and average the results over the total collection time. For documenting episodic exposures, use high flow rates (7 to 16 L/min) over shorter sampling times. In relatively clean atmospheres, where targeted fiber concentrations are much less than 0.1 fiber/mL, use larger sample volumes (3000 to 10000 L) to achieve quantifiable loadings. Take care, however, not to overload the filter with background dust. If $\geq$ 50% of the filter surface is covered wth particles, the filter may be too overloaded to count.
5. At the end of sampling, replace top cover and small end caps.
6. Ship samples with conductive cowl attached in a rigid container with packing material to prevent jostling or damage.
   NOTE: Do not use untreated polystyrene foam in shipping container because electrostatic forces may cause fiber loss from sample filter.

SAMPLE PREPARATION:

NOTE: The object is to produce samples with a smooth (non-grainy) background in a medium with refractive index $\leq$ 1.46. This method collapses the filter for easier focusing and produces permanent mounts which are useful for quality control and interlaboratory comparison. The aluminum "hot block" technique may be used outside the laboratory[4]. Other mounting techniques meeting the above criteria may also be used (e.g., the laboratory fume hood procedure for generating acetone vapor as described in Method 7400 - revision of 5/15/85, or the non-permanent field mounting technique used in P&CAM 239 [1,3,7,21]). A videotape of the mounting procedure is available from the NIOSH Publication Office [19].

7. Ensure that the glass slides and cover slips are free of dust and fibers.
8. Adjust the rheostat to heat the "hot block" to ca. 70 °C[4].
   NOTE: If the "hot block" is not used in a fume hood, it must rest on a ceramic plate and be isolated from any surface susceptible to heat damage.

9. Mount a wedge cut from the sample filter on a clean glass slide.
   a. Cut wedges of ca. 25% of the filter area with a curved-blade steel surgical knife using a rocking motion to prevent tearing. Place wedge, dust side up, on slide.
      NOTE: Static electricity will usually keep the wedge on the slide.
   b. Insert slide with wedge into the receiving slot at base of "hot block". Place tip of a micropipet containing ca. 250 µL acetone into the inlet port of the PTFE cap on top of the "hot block". Inject the acetone into the vaporization chamber with a slow, steady pressure on the plunger button while holding pipet firmly in place. After waiting 3 to 5 sec for the filter to clear, remove pipet and slide from their ports.
      CAUTION: Although the volume of acetone used is small, safety precautions are necessary. Work in a well-ventilated area such as a laboratory fume hood. Take precautions not to ignite the acetone. Continuous, frequent use of this device in an unventilated space may produce explosive acetone vapor concentrations.
   c. Using the 5-µL micropipet, immediately place 3.0 to 3.5 µL triacetin on the wedge. Gently lower a clean cover slip onto the wedge at a slight angle to reduce bubble formation.
      NOTE: If too many bubbles form or the amount of triacetin is insufficient, the cover slip may become detached within a few hours. If excessive triacetin remains at the edge of the filter under the cover slip, fiber migration may occur.
   d. Glue the edges of the cover slip to the slide using lacquer or nail polish [9] Counting may proceed immediately after clearing and mounting are completed.
      NOTE: If clearing is slow, warm the slide on a hotplate (surface temperature 50 °C) for up to 15 min to hasten clearing. Heat carefully to prevent gas bubble formation.

CALIBRATION AND QUALITY CONTROL:

10. Microscope adjustments. Follow the manufacturers instructions. At least once daily use the telescope ocular supplied by the manufacturer to ensure that the phase rings (annular diaphragm and phase-shifting elements) are concentric. With each microscope, keep a logbook in which to record the dates of microscope cleanings, adjustments, and calibrations.
    a. Each time a sample is examined, do the following:
       (1) Adjust the light source for even illumination across the field of view at the condenser iris.
           NOTE: Use Köhler illumination if available.
       (2) Focus on the particulate material to be examined.
       (3) Make sure that the field iris is in focus, centered on the sample, and open only enough to fully illuminate the field of view.
    b. Check the phase-shift detection limit of the microscope periodically for each analyst/microscope combination:
       (1) Center the HSE/NPL phase-contrast test slide under the phase objective.
       (2) Bring the blocks of grooved lines into focus.
           NOTE: The slide contains seven blocks of grooves (ca. 20 grooves per block) in descending order of visibility. For asbestos counting the microscope optics must completely resolve the grooved lines in block 3 although they may appear somewhat faint, and the grooved lines in blocks 6 and 7 must be invisible. Blocks 4 and 5 must be at least partially visible but may vary slightly in visibility between microscopes. A microscope which fails to meet these requirements has resolution either too low or too high for fiber counting.

(3). If image quality deteriorates, clean the microscope optics. If the problem persists, consult the microscope manufacturer.

11. Document the laboratory's precision for each counter for replicate fiber counts.
    a. Maintain as part of the laboratory quality assurance program a set of reference slides to be used on a daily basis. These slides should consist of filter preparations including a range of loadings and background dust levels from a variety of sources including both field and PAT samples. The Quality Assurance Officer should maintain custody of the reference slides and should supply each counter with a minimum of one reference slide per workday. Change the labels on the reference slides periodically so that the counter does not become familiar with the samples.
    b. From blind repeat counts on reference slides, estimate the laboratory intra- and intercounter s_r (see step 21). Obtain separate values of relative standard deviation for each sample matrix analyzed in each of the following ranges: 5 to 20 fibers in 100 graticule fields, 21 to 50 fibers in 100 graticule fields, 51 to 100 fibers in 100 graticule fields, and 100 fibers in less than 100 graticule fields. Maintain control charts for each of these data files.
    NOTE: Certain sample matrices (e.g., asbestos cement) have been shown to give poor precision [5]
12. Prepare and count field blanks along with the field samples. Report counts on each field blank.
    NOTE 1: The identity of blank filters should be unknown to the counter until all counts have been completed.
    NOTE 2: If a field blank yields greater than 7 fibers per 100 graticule fields, report possible contamination of the samples.
13. Perform blind recounts by the same counter on 10% of filters counted (slides relabeled by a person other than the counter). Use the following test to determine whether a pair of counts by the same counter on the same filter should be rejected because of possible bias: Discard the sample if the difference between the two counts exceeds $2.77\ (F)s_r$, where F = average of the two fiber counts and s_r = intracounter relative standard deviation from step 11.
    NOTE: If a pair of counts is rejected by of this test, recount the remaining samples in the set and test the new counts against the first counts. Discard all rejected paired counts. It is not necessary to use this statistic on blank counts.
14. Enroll each new counter in a training course which compares performance of counters on a variety of samples using this procedure.
    NOTE: All laboratories engaged in asbestos counting should participate in a proficiency testing program such as the NIOSH Proficiency Analytical Testing (PAT) Program and routinely exchange field samples with other laboratories to compare performance of counters.

MEASUREMENT:

15. Center the slide on the stage of the calibrated microscope under the objective lens. Focus the microscope on the plane of the filter.
16. Adjust the microscope (Step 10) [6].
17. Select one of the following sets of counting rules:
    NOTE: The two sets of rules produce equivalent mean counts on a variety of asbestos sample types [5] and must be strictly followed to obtain valid results. No hybridizing of the two sets of rules is permitted. Calibration with the HSE/NPL test slide determines the minimum detectable fiber diameter (ca. 0.25 µm).
    a. A Rules (same as P&CAM 239 rules [1,3,7]; see APPENDIX B).
        1. Count only <u>fibers</u> longer than 5 µm. Measure length of curved fibers along the curve.

2. Count only fibers with a length-to-width ratio equal to or greater than 3:1.
3. For fibers which cross the boundary of the graticule field:
   a. Count any fiber longer than 5 µm which lies entirely within the graticule area.
   b. Count as 1/2 fiber any fiber with only one end lying within the graticule area, provided that the fiber meets the criteria of rules a.1. and a.2.
   c. Do not count any fiber which crosses the graticule boundary more than once.
   d. Reject and do not count all other fibers.
4. Count bundles of fibers as one fiber unless individual fibers can be identified by observing both ends of a fiber.
5. Count enough graticule fields to yield 100 fibers. Count a minimum of 20 fields. Stop at 100 graticule fields regardless of count.

b. B Rules (see APPENDIX B)

NOTE: The B Rules are preferred analytically because of their demonstrated ability to improve the reproducibility of fiber counts [5].

1. Count only ends of fibers. Each fiber must be longer than 5 µm and less than 3 µm diameter.
2. Count only ends of fibers with a length-to-width ratio equal to or greater than 5:1.
3. Count each fiber end which falls within the graticule area as one end, provided that the fiber meets rules b.1 and b.2. Add split ends to the count as appropriate if the split fiber segment also meets the criteria of rules b.1 and b.2.
4. Count visibly free ends which meet rules b.1 and b.2 when the fiber appears to be attached to another particle, regardless of the size of the other particle. Count the end of a fiber obscured by another particle if the particle covering the fiber end is less than 3 µm in diameter.
5. Count free ends of fibers emanating from large clumps and bundles up to a maximum of 10 ends (5 fibers), provided that each segment meets rules b.1 and b.2.
6. Count enough graticule fields to yield 200 ends. Count a minimum of 20 graticule fields. Stop at 100 graticule fields, regardless of count.
7. Divide total end count by 2 to yield fiber count.

18. Start counting from the tip of the filter and progress along a radial line to the outer edge. Shift up or down on the filter, and continue in the reverse direction. Select graticule fields randomly by looking away from the eyepiece briefly while advancing the mechanical stage. Ensure that, as a minimum, each analysis covers one radial line from the filter center to the outer edge of the filter. When an agglomerate covers ca. 1/6 or more of the graticule field, reject the graticule field and select another. Do not report rejected graticule fields in the total number counted.

NOTE 1: When counting a graticule field, continuously scan a range of focal planes by moving the fine focus knob to detect very fine fibers which have become embedded in the filter. The small-diameter fibers will be very faint but are an important contribution to the total count. A minimum counting time of 15 seconds per field is appropriate for accurate counting.

NOTE 2: This method does not allow for differentiation of fibers based on morphology. Although some experienced counters are capable of selectively counting only fibers which appear to be asbestiform, there is presently no accepted method for ensuring uniformity of judgement between laboratories. It is, therefore, incumbent upon all laboratories using this method to report total fiber counts. If serious contamination from non-asbestos fibers occurs in samples, other techniques such as transmission electron microscopy must be used to identify the asbestos fiber fraction present in the sample (see NIOSH Method 7402).

CALCULATIONS AND REPORTING OF RESULTS:

19. Calculate and report fiber density on the filter, E (fibers/mm^2), by dividing the total fiber count per graticule field, F/n_f, minus the mean field blank count per graticule field, B/n_b, by the graticule field area, A_f (0.00785 mm^2 for a properly calibrated Walton-Beckett graticule):

$$E = \frac{(\frac{F}{n_f} - \frac{B}{n_b})}{A_f}, \text{ fibers/mm}^2.$$

20. Calculate and report the concentration, C (fibers/mL), of fibers in the air volume sampled, V (L), using the effective collection area of the filter, A_c (385 mm^2 for a 25-mm filter):

$$C = \frac{(E)(A_c)}{V \cdot 10^3}.$$

NOTE: Periodically check and adjust the value of A_c, if necessary.

21. Report intralaboratory and interlaboratory relative standard deviations (from Step 11) with each set of results.

NOTE: Precision depends on the total number of fibers counted [3,10]. Relative standard deviation (also called coefficient of variation) is documented in references [3,10,11,12] for fiber counts up to 100 fibers in 100 graticule fields. Comparability of interlaboratory results is discussed below. As a first approximation, use 213% above and 49% below the count as the upper and lower confidence limits for fiber counts greater than 20 (Fig. 1).

EVALUATION OF METHOD:

A. This method is a revision of P&CAM 239 [1,3,7]. A summary of the revisions is as follows:

1. Sampling:
   The change from a 37-mm to a 25-mm filter improves sensitivity for similar air volumes. The change in flow rates allows for 2-m^3 full-shift samples to be taken, providing that the filter is not overloaded with non-fibrous particulates. The collection efficiency of the sampler is not a function of flow rate in the range 0.5 to 16 L/min [8].
2. Sample Preparation Technique:
   The acetone vapor-triacetin preparation technique is a faster, more permanent mounting technique than the dimethyl phthalate/diethyl oxalate method of P&CAM 239 [1,3,4,7,13]. The aluminum "hot block" technique minimizes the amount of acetone needed to prepare each sample.
3. Measurement:
   a. The Walton-Beckett graticule standardizes the area observed [13,14].
   b. The HSE/NPL test slide standardizes microscope optics for sensitivity to fiber diameter [6,13].

c. An international collaborative study involved 16 laboratories using prepared slides from the asbestos, cement, milling, mining, textile, and friction material industries [5]. The modified CRS (NIOSH B) Rules were found to yield equivalent counts but were more precise than the AIA (NIOSH A)* Rules. The relative standard deviations (s_r) varied with sample type and laboratory. The ranges were:

	s_r		
	Intralaboratory	Interlaboratory	Overall
AIA (NIOSH A Rules)*	0.12 to 0.40	0.27 to 0.85	0.46
Modified CRS (NIOSH B Rules)	0.11 to 0.29	0.20 to 0.35	0.25

*Under AIA rules, only fibers having a diameter less than 3 μm are counted and fibers attached to particles larger than 3 μm are not counted. NIOSH A Rules are otherwise similar to the AIA rules.

d. The B Rules have also been favorably received by analysts as less ambiguous and simpler to use; these rules also showed the least bias relative to AIA rules in the collaborative study. An independent NIOSH laboratory study using amosite fibers reported a relative standard deviation, including within- and between-sample variability, of 0.16 for the B Rules [15]. Another NIOSH study was conducted using field samples of asbestos [18]. This study indicated intralaboratory s_r in the range 0.17 to 0.25 and an interlaboratory s_r of 0.45. This agrees well with other recent studies [5,10,12].

e. Because of past inaccuracies associated with low fiber counts, the minimum recommended loading has been increased to 100 fibers/mm² filter area (80 fibers total count). This level should yield intracounter s_r in the range of 0.13 to 0.17 [3,7,15,18].

B. Interlaboratory Comparability:

At this time, there is no independent method for assessing the overall accuracy of this method. One measure of reliability is to estimate how well the count for a single sample agrees with the mean count from a large number of laboratories. The following discussion indicates how this estimation can be carried out based on measurements of the interlaboratory variability, as well as showing how the results of this method relate to the theoretically attainable counting precision and to measured intra- and interlaboratory s_r.

Theoretically, the process of counting randomly (Poisson) distributed fibers on a filter surface will give an s_r that depends on the number, N, of fibers counted:

$$s_r = 1/(N)^{1/2} \qquad (1)$$

Thus s_r is 0.1 for 100 fibers and 0.32 for 10 fibers counted. The actual s_r found in a number of studies is greater than these theoretical numbers [5,10,11,12].

An additional component of variability comes primarily from subjective laboratory-to-laboratory differences. In a study of ten counters in a continuing sample exchange program, Ogden [10] found this subjective component of intralaboratory s_r to be approximately 0.2 and estimated the overall s_r by the term

$$\frac{(N + (0.2 \cdot N)^2)^{1/2}}{N} \qquad (2)$$

Ogden found that the 90% confidence interval of the individual intralaboratory counts in relation to the means were +2 s_r and - 1.5 s_r. In this program, one sample out of ten was a quality control sample. For laboratories not engaged in an intensive quality assurance program, the subjective component of variability can be higher.

In a study of field sample results in 46 laboratories, the Asbestos Information Association [12] also found that the variability had both a constant component and one that depended on the fiber count. These results gave a subjective interlaboratory component of s_r (on the same basis as Ogden's) for field samples of ca. 0.45. A similar value was obtained for 12 laboratories analyzing a set of 24 field samples [18]. This value falls slightly above the range of s_r (0.25 to 0.42 for 1984-85) found for 80 reference laboratories in the NIOSH Proficiency Analytical Testing (PAT) program for laboratory-generated samples [11].

A number of factors influence s_r for a given laboratory, such as that laboratory's actual counting performance and the type of samples being analyzed. In the absence of other information, such as from an interlaboratory quality assurance program using field samples, the value for the subjective component of variability is chosen as 0.45. Note that, though based on at least two studies, this is a somewhat arbitrary choice. It is hoped that by the use of this number in the absence of other information, laboratories will carry out the recommended interlaboratory quality assurance programs to improve their performance and thus reduce the s_r.

The above relative standard deviations apply when the population mean has been determined. It is more useful, however, for laboratories to estimate the 90% confidence interval on the mean count from a single sample fiber count (Figure 1). These curves assume similar shapes of the count distribution for interlaboratory and intralaboratory results [10].

For example, if a sample yields a count of 24 fibers, Figure 1 indicates that the mean interlaboratory count will fall within the range of 227% above and 52% below that value 90% of the time. We can apply these percentages directly to the air concentrations as well. If, for instance, this sample (24 fibers counted) represented a 500-L volume, then the measured concentration is 0.02 fibers/mL (assuming 100 fields counted, 25-mm filter, 0.00785 mm^2 counting field area). If this same sample were counted by a group of laboratories, there is a 90% probability that the mean would fall between 0.01 and 0.05 fiber/mL. These limits should be reported in any comparison of results between laboratories .

Note that the s_r of 0.45 used to derive Figure 1 is used as an estimate for a random group of laboratories. If several laboratories belonging to a quality assurance group can show that their interlaboratory s_r is smaller, then it is more correct to use that smaller s_r. However, the estimated s_r of 0.45 is to be used in the absence of such information. Note also that it has been found that s_r can be higher for certain types of samples, such as asbestos cement.

Quite often the estimated airborne concentration from an asbestos analysis is used to compare to a regulatory standard. For instance, if one is trying to show compliance with an 0.5 fiber/mL standard using a single sample on which 100 fibers have been counted, then Figure 1 indicates that the 0.5 fiber /mL standard must be 213% higher than the measured air concentration. This indicates that if one measures a fiber concentration of 0.16 fiber /mL (100 fibers counted), then the mean fiber count by a group of laboratories (of which the compliance laboratory might be one) has a 95% chance of being less than 0.5 fibers/mL; i.e., $0.16 + 2.13 \times 0.16 = 0.5$.

It can be seen from Figure 1 that the Poisson component of the variability is not very important unless the number of fibers counted is small. Therefore, 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.

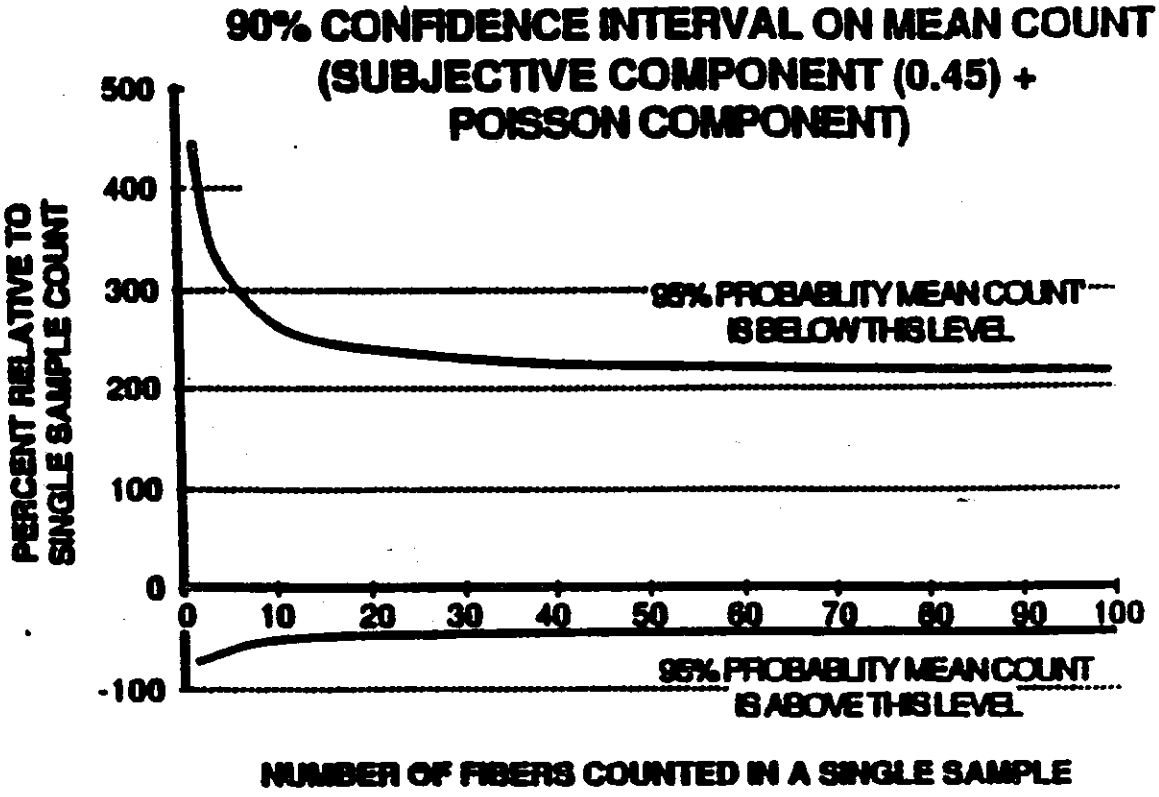

Figure 1. Interlaboratory Precision of Fiber Counts

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METHOD REVISED BY: James W. Carter, David G. Taylor, Ph.D., CIH, and Paul A. Baron, Ph.D., NIOSH/DPSE; based on the revised Method P&CAM 239 [1,3,4].

APPENDIX A: CALIBRATION OF THE WALTON-BECKETT GRATICULE:

Before ordering the Walton-Beckett graticule, the following calibration must be done to obtain a counting area (D) 100 µm in diameter at the image plane. The diameter, d_c (mm), of the circular counting area and the disc diameter must be specified when ordering the graticule.

1. Insert any available graticule into the eyepiece and focus so that the graticule lines are sharp and clear.
2. Set the appropriate interpupillary distance and, if applicable, reset the binocular head adjustment so that the magnification remains constant.
3. Install the 40 to 45X phase objective.
4. Place a stage micrometer on the microscope object stage and focus the microscope on the graduated lines.
5. Measure the magnified grid length of the graticule, L_o (µm), using the stage micrometer.

6. Remove the graticule from the microscope and measure its actual grid length, L_a (mm). This can best be accomplished by using a stage fitted with verniers.
7. Calculate the circle diameter, d_c (mm), for the Walton-Beckett graticule:

$$d_c = \frac{L_a}{L_0} \times D.$$

Example: If L_0 = 108 µm, L_a = 2.93 mm and D = 100 µm, then d_c = 2.71 mm.

8. Check the field diameter, D (acceptable range 100 µm ± 2 µm) with a stage micrometer upon receipt of the graticule from the manufacturer. Determine field area (acceptable range 0.00785mm² ± 0.00032 mm²).

APPENDIX B: COMPARISON OF COUNTING RULES:

Figure 2 shows a Walton-Beckett graticule as seen through the microscope. Although the graticule incorporates the 3:1 aspect ratio, both the "A" and "B" rules will be discussed as they apply to the labeled fibers in the figure.

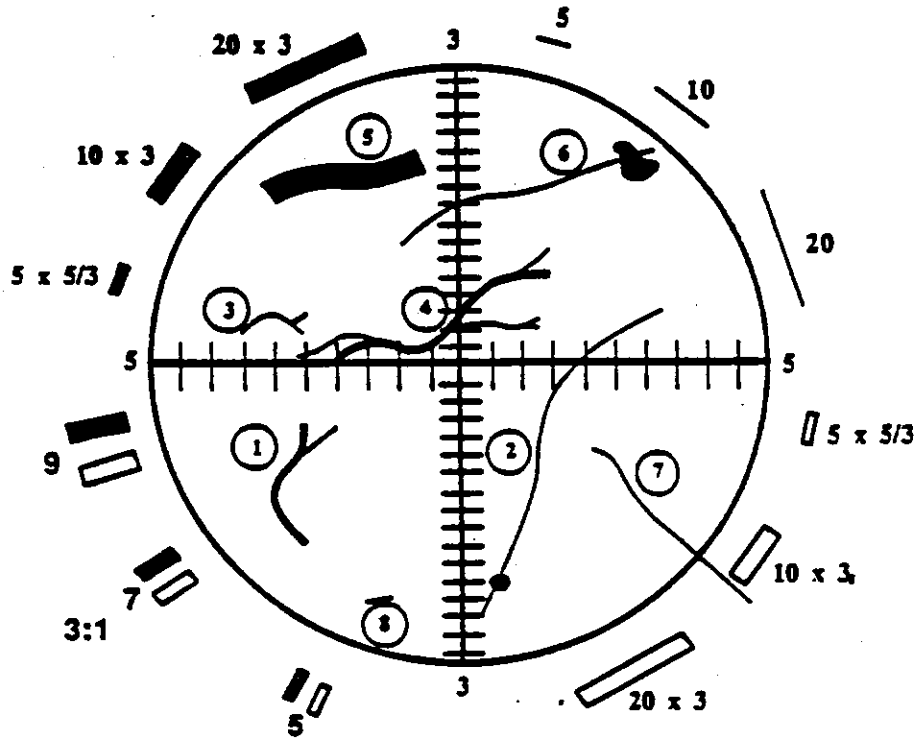

Figure 2. Walton-Beckett graticule with fibers.

FIBER COUNT

Fiber	A Rules	B Rules	DISCUSSION
1	1 fiber	3 ends	(A)"A" rules do not allow for split ends; therefore, count one fiber. (B) Under 'B' rules, first detemine whether the fiber meets dimensional criteria, (i.e., >5 µm, >5:1 aspect ratio, <3 µm diameter). Next determine and count which two ends are the main trunk of the fiber. Finally, count all split ends >5 µm as one end. Fiber #1 is counted as 3 ends.
2	1 fiber	2 ends	(A) Single fiber with small particle attached. The particle is treated as if it does not exist by the "A" rules. (B) The particle is <3 µm diameter and therefore ignored under "B" rules.
3	1 fiber	2 ends	(A) As with Fiber 1, count one fiber under "A" rules because it meets the >3:1 aspect ratio, >5 µm criteria. (B) The split end is <5 µm long so it is not counted under "B" rules.
4	1 fiber	5 ends	(A) Fiber ends all attached to a central large fiber or bundle; therefore, count one fiber under "A" rules. (B) Count two ends as belonging to the main fiber. Three of the remaining four split ends are >5 µm, giving a total of 5 ends.
5	1 fiber	Do not count	(A) No diameter limit under "A" rules; therefore count this thick fiber because it meets the >3:1, >5 µm counting criteria. (B) The fiber is >3 µm diameter; therefore not counted under "B" rules.
6	1 fiber	1 end	(A) Ignore non-fibrous particulate matter under the "A" rules; count this as a whole fiber. (B) The short end of the fiber is <5 µm long and obscured by a particle >3 µm in diameter; therefore, not counted under "B" rules.
7	1/2 fiber	1 end	(A) Fibers which meet rules a.1. and a.2. and cross the graticule boundary are counted as 1/2 fiber under "A" rules unless the fiber crosses the graticule boundary more than once, in which case the fiber is not counted no matter how many ends lie within the graticule area. (B) Fiber ends lying inside the graticule boundary are counted as one end provided that the entire fiber meets rules b.1. and b.2. and each end is >5 µm. The portion of the fiber lying outside the graticule boundary must be considered in order to make this determination. Under "B" rules, it does not matter how often the fiber crosses the graticule boundary.
8	Do not count	Do not count	The fiber is <5 µm long.