# IV. SAMPLING METHODS AND ENVIRONMENTAL DATA

## Review of Sampling and Analysis Techniques for Asbestos

A variety of sampling and analysis techniques have been used to identify asbestos fibers and determine their concentrations in air, water, mineral samples, and biologic tissue. These include optical and electron microscopy, x-ray diffraction, and differential thermal analysis. Asbestos fiber identification and quantitation in occupational and environmental air samples is difficult for a variety of reasons:

1) Asbestos fibers are generally present in low mass quantities even though fiber number concentrations may be high.

2) Many instrumental analytical techniques cannot differentiate asbestos fibers from their nonfibrous mineralogic polymorphs.

3) Many airborne asbestos fibers are generally below resolution limits of the optical microscope. These fibers may only be detected by using electron microscopic methods.

4) For identification of the various asbestos fiber types by electron microscopy, electron diffraction and microchemical analyses must be performed which require expensive instrumentation and analysis time.

(a) Electron Microscopy and Microchemical Analysis

Both transmission and scanning electron microscopy have been used for asbestos fiber identification and quantitation. In addition to morphologic observation, selected area electron diffraction and microchemical

analytical techniques may be used for fiber identification.

In addition to superior resolution capabilities, most modern transmission electron microscopes are equipped with electron diffraction facilities. Crystalline materials scatter electrons in regular patterns related to their crystal structure. The image of the scattered electrons is mainly predicted by Bragg geometry. In the transmission electron microscope, the diffraction image is formed in the back focal plane of the objective lens and is focused in the viewing screen by defocusing the intermediate lens. Visual observation of single fiber (single crystal) electron diffraction patterns may be used to differentiate chrysotile fibers from amphibole fibers (Langer et al, 1974; Timbrell 1970). Chrysotile fibers produce streaked diffraction patterns (lattice defects), with the streaks or layer lines nearly perpendicular to the fiber length. The spacing between the layer lines denotes the fiber "a" axis of approximately 5.3 Å. Reflections along the layer lines are usually very streaked and Debye-Scherrer rings are common. With progressive electron beam bombardment, the diffraction pattern may change because of fiber damage. The "central core" of chrysotile fibers may also aid in fiber identification with the precaution that the central core is not always discernable and may disappear with the beam damage (Langer et al, 1974). Also, other fibrous minerals may have hollow cores.

The amphibole minerals are generally straighter in appearance than chrysotile fibers. Moreover, light and dark banding (diffraction images) may cross the fiber at right angles (Langer et al, 1974). Diffraction contrast figures have been observed on all amphibole fiber types. Selected area diffraction patterns for the amphibole asbestos minerals are all

similar in appearance; therefore, visual observation of these patterns is sufficient only to classify the fiber as being a fibrous amphibole (Langer et al, 1974; Cook et al, 1974). Amphibole electron diffraction patterns show layers and sometimes streaks perpendicular to the fiber length with the spacing between the layer lines or streaks representing the fiber "c" axis (Langer et al, 1974) of approximately 5.3 Å. In contrast to chrysotile, less streaking along the layer lines is observed with the spot repeat along the lines representing one of the two remaining lattice spacings ( "b" or "a") depending on fiber orientation relative to the electron beam. Typically, approximately 30 seconds is needed to perform a selected area electron diffraction analysis on a single fiber.

In addition to visual observation of electron diffraction patterns for fiber identification, photographs can be made of the diffraction patterns and crystal "d" spacings measured from the plate and calculated using the instrument camera constant (Timbrell, 1970). Both "spot" and polycrystalline patterns may be measured. It must be borne in mind that intensities may not be the same as those observed for x-ray powder patterns and additional reflections may be present.

Electron beam microchemical analytical techniques may sometimes be used to identify asbestos fibers from other fibrous particles (Rubin and Maggiore, 1974; Ferrell et al, 1975; Langer et al, 1975; Maggiore and Rubin, 1973). The most common system presently in use is the energy dispersive x-ray detector in combination with a scanning or transmission electron microscope. Wavelength x-ray analyzers and the conventional electron microprobe have been used; however, their routine application is limited because of data acquisition times (Langer et al, 1975). On the

other hand, data acquisition times with energy dispersive analyzers are far less, ranging from 20 to 80 seconds/analysis.

Semiquantitative microchemical analysis in the electron microscope is based on the fact that a beam of high energy electrons incident on an asbestos fiber generates x-rays characteristic of the elements present in that fiber. The generated x-rays are observed by means of a detector (lithium-drifted silicon crystal) placed in the electron microscope column close to the specimen. The energy of the x-ray photon is converted to a voltage pulse which is amplified, digitized and stored in a multichannel analyzer or a minicomputer. The content of the memory is usually displayed on a CRT (Maggiore and Rubin, 1973). With the energy dispersive detector, all elements with atomic numbers of sodium or higher may be analyzed. Continuous background or brehmsstrahlung radiation is always present with the x-ray spectrum.

Each of the asbestos minerals has an x-ray spectrum which is usually characteristic enough, when combined with fiber morphology, to allow its identification (Rubin and Maggiore, 1974; Ferrell et al, 1975; Dement et al, 1975). Visual observation of the semiquantitative fiber x-ray spectra is usually sufficient for fiber identification; however, three component diagrams have been used after subtracting the continuous background from the semiquantitative x-ray spectrum (Ferrell et al, 1975). For asbestos fiber analysis, matrix corrections are rarely used. Typically, iron, magnesium, and silicon are plotted on the three component diagram and compositional boundaries for the asbestos minerals established. This technique suffers from inability to use all compositional data obtained, such as presence or absence of sodium, calcium, aluminum and manganese, which aid in identification.



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With energy dispersive x-ray techniques, possession of proper elemental intensities may not be sufficient for positive identification as many fibrous minerals show similar elemental intensities. For example, chrysotile, anthophyllite, and fibrous talc, which have similar elemental compositions, may be difficult to differentiate. However, these materials may easily be distinguished by using selected area electron diffraction. In addition, unique identification of the various fibrous amphiboles usually requires both selected area diffraction and microchemical analysis. Transmission electron microscopes equipped with an energy dispersive x-ray detector are now available which allow simultaneous observation of morphology, crystal structure, and elemental composition. These microscopy systems have been used to study asbestos fibers in environmental and material samples. (Cook et al, 1974; Dement et al, 1975)

Quantitative analysis of asbestos fiber concentrations in environmental and tissue samples has been accomplished by electron microscopy. Environmental samples (water and air) are generally collected by first concentrating the sample by filtration, centrifuging, etc (Cook et al, 1974; Nicholson, 1974). The filters (Millipore) and polycarbonate filters (Nuclepore) are prepared for electron microscopic analysis by various methods. For scanning electron microscopy, Nuclepore filters, because of their smooth surface, may be directly coated with an appropriate metal (gold, etc) and analyzed (Porter and Berggren, 1974). Millipore filters have a rough surface texture and are not generally suitable for direct coating for scanning electron microscopy as small fibers may escape detection due to impaction below the filter surface (Nicolson, 1974).

For transmission electron microscopy, the filter substrate must be removed and the particles mounted on suitable electron microscopy grids. A wide variety of mounting techniques have been used. The two most commonly used methods are the Jaffe Wick and condensation washing techniques. The techniques offer simplicity in addition to maintaining the original particle size distribution of the sample. Different investigators have reported particle losses up to 60% with Millipore filters while using the condensation washing method with rapid filter dissolution, whereas losses with the Jaffe Wick method have been reported to be considerably less (>10%) (Beaman and File, 1975). Lesser particle loss has been observed with the condensation washing method when longer times for dissolution of the filter are used. Ortiz and Loom (1974) reported that a modification of the Jaffe Wick method, whereby the filter is first coated with silicon monoxide and carbon by vacuum evaporation prior to dissolving the Millipore filter, minimized particle loss. Several investigators have reported minimal particle loss with Nuclepore filters when the filter is first carbon-coated prior to dissolving the filter substrate (Cook et al, 1974; Maggiore and Rubin, 1973).

In addition to the so-called direct clearing/mounting techniques mentioned above, many other techniques have also been used for preparing environmental samples. Seikoff et al (1972) have used a so-called "rub-out" technique whereby the Millipore filter is ashed in a low temperature asher to remove organic or carbonaceous material. The residue is then dispersed on a microscope slide using a solution of 1% Nitrocellulose in amyl acetate. After grinding with a watch glass to liberate individual fibers, the sample is dispersed evenly between two microscope slides to



amyl acetate. After grinding with a watch glass to liberate individual

form a thin film which is transferred to standard electron microscope grids. Particle losses averaging 50% have been reported with this technique. This technique also increases the apparent number of fibers present due to breaking up of fiber bundles. Asbestos fiber levels in environmental samples and biologic tissue are usually expressed as asbestos fibers/unit volume of sample (fibers/$m^3$, fibers/liter, fibers/g dry lung, etc). These concentrations are determined by counting fibers within calibrated areas on the electron microscope viewing screen or counting fibers from photographs. Asbestos fiber concentrations in water samples determined by laboratories using the same mounting techniques have been reported to vary by a factor of 2-3 (Cook et al, 1974). Much larger variations have been reported between laboratories using different techniques.

Asbestos mass (chrysotile) concentrations in environmental samples have also been determined using electron microscopy. This is accomplished by measuring the length and diameter (volume) of each fiber and calculating the mass using the appropriate density (Selikoff et al, 1972). The accuracy of this technique has not been studied in detail.

Electron microscopic techniques represent the "best available" methods for asbestos fiber analysis. However, application of these techniques to routine samples is not practical because of extremely high analysis costs ($200-$400/sample), long analysis times, and limited equipment availability.

(b) X-Ray Diffraction

X-ray powder diffractometry is one of the standard mineralogic techniques used in the analysis of solid crystalline phases. X-ray

diffraction has been widely used for identification and quantitation of asbestos fibers in bulk materials such as talc (Stanley and Norwood, 1974; Rohl and Langer, 1974) and other industrial materials (Crable and Knott, 1968; Keenan and Lynch 1970).

X-ray diffraction has also been used to study amphibole asbestos contamination of water samples (Cook et al, 1974). X-ray diffraction is generally considered more sensitive for asbestos than light microscopy, although less sensitive than electron microscopy (Rohl and Langer, 1974).

Diffraction lines and relative intensities for each of the asbestos minerals have been published and may be found in the ASTM Powder Diffraction File. Variations in asbestos fiber chemical composition, especially for the amphiboles, may result in slight peak shifts from reported x-ray diffraction data.

Quantitative determinations of asbestos fiber levels in material samples (talc, etc) require that particle size first be reduced to an average of 0.1 - 10 $\mu m$. Preferred orientation and surface roughness must also be eliminated.

A number of techniques have been used to minimize preferred orientation effects including binder and slurry mounting methods, sifting and backloading of dry powders, and several others. To minimize preferred orientation, Rohl and Langer (1974) have developed a method for filtering an aqueous slurry through Millipore filters using a filtration adapter attached to a hypodermic syringe. Other investigators have used the backloading technique with multiple x-ray diffraction scans.

Using conventional scan rates (0.5 - 1 degree 2 theta/minute), lower limits of detection of asbestos by x-ray diffraction of 5% in bulk samples

have been reported (Crable and Knot, 1966). Automated step scanning procedures by which diagnostic reflections are slowly scanned and integrated counts recorded have been reported to significantly reduce detectable limits. Rohl and Langer (1974) have detected anthophyllite at 2.0%, chrysotile at 0.25%, and tremolite at 0.10% by wieght in a talc matrix using external dilution standards for calibration. Similar lower detectable levels have been reported by Stanley and Norwood (1974).

Application of x-ray diffraction for routine asbestos fiber analysis of environmental samples has been limited. Birks et al (1975) have reported a feasible study concerning quantitative analysis of airborne asbestos. Their technique involved alignment of the asbestos fibers in an electrostatic field to enhance diffraction intensity followed by x-ray counting in a specially designed diffraction apparatus with two x-ray detectors. A lower limit of detection of 0.4 - 0.5 μg was reported. This technique has not been applied to actual environmental samples.

Amphibole and cummingtonite-grunerite mass concentrations in water samples have been semiquantitatively determined using x-ray diffraction with step scanning (Cook et al, 1974). This technique involves filtering the water through 0.45-μm Millipore filters followed by step scanning a major amphibole diffraction peak (110) and a peak specific to cummingtonitegrunerite (310). The integrated peak count above background is recorded and mass concentrations are determined using external dilution standards.

Proper selection of diagnostic reflections to maximize detection sensitivity and minimize interference due to other mineral phases is necessary for proper use of x-ray diffraction. It must also be recognized

that x-ray diffraction methods are not capable of differentiating between asbestos fibers and their nonfibrous mineralogic polymorphs. This fact, combined with relatively poor detection levels, suggests that alternate techniques such as electron microscopy should be combined with x-ray analysis.

(c) Differential Thermal Analysis

Differential thermal analysis has been used to determine asbestos fiber levels in talc samples (Schlez, 1974) Chrysotile (serpentine minerals) shows a dehydroxylation endotherm at approximately 650 degrees C and an exotherm at approximately 820 degrees C, associated with the formation of forsterite. These peaks may be used for quantitative analysis. Using a 140-mg sample holder with an exposed loop differential thermcouple and a 10 degree C/minute heating rate, Schlez (1974) reported that a 1% concentration of chrysotile could be detected in pharmaceutical grade talc. A dynamic helium atmosphere was maintained to sweep out gaseous mineral decomposition products and to prevent oxidative reactions.

Differential thermal analysis has not been used for environmental samples as lower limits of mass detection are extremely poor. Differential thermal analysis, like x-ray diffraction, is not capable of differentiating between asbestos fibers and their nonfibrous mineralogic polymorphs.

(d) Optical Microscopy

A number of optical microscopic techniques have been used to identify and/or quantitate asbestos fibers in environmental samples. These include petrographic and phase contrast microscopy. Petrographic microscopic techniques may be used to identify asbestos fibers greater than approximately 0.2 - 0.3 μm in diameter. Using the polarizing microscope,

various optical crystallographic measurements such as refractive index, extinction angles, and sign of elongation may be measured and compared with data reported for standard asbestos reference samples. Typical optical data for selected asbestos minerals are shown in Table IV-1 (Julian and McCrone, 1970).

Dispersion staining with polarized light has been used to identify asbestos fibers, as reported by Julian and McCrone (1974). With this technique, the fibers are immersed in a mounting medium with a steeper dispersion curve than the fibers. A central or annular stop is used in the objective lens back focal plant to allow either the wavelength of light at which the index of the particle matches that of the mounting media, or complements to that color to reach the observer's eye. Using plane polarized light, asbestos fibers show two characteristic dispersion staining colors; one for the light vibration parallel to and the other for that perpendicular to the fiber length. The dispersion colors depend on the refractive index media in which the fibers are mounted, as shown in Table IV-2. Dispersion staining colors may change slightly depending on the geographic area from which the asbestos was mined and subsequent treatment. Fibers less than 0.5 μm in diameter may not be identified by this technique because of difficulties in distinguishing colors.

Phase contrast optical microscopy is the technique specified for determining the Occupational Safety and Health Administration asbestos standard (US Department of Labor 1975). The method consists of collecting breathing zone samples during 15-minute to 8-hour periods on membrane filters (millipore AA). Samples are analyzed by first clearing the membrane filter to make it optically transparent, then by fiber counts at

400-500X magnification by phase contrast optical microscopy. Asbestos fibers are defined as those particles with a length greater than 5 μm and a length-to-diameter ratio of 3:1, or greater. This technique, by which only fibers longer than 5 μm are counted, is recognized as only an index of total fiber exposure and does not imply that shorter fibers do not pose a health hazard. The relative proportion of airborne fibers longer than 5 μm has been shown by Dement et al (1975) to vary from 1 to approximately 50% depending on the industrial operation and asbestos fiber type. In addition to problems of detecting short fibers, phase contrast microscopy may not be specific for asbestos fibers in industrial operation where mixed fiber types are encountered.

Despite its limitations, phase contrast microscopy represents the only technique available that can reasonably be used for routine asbestos fiber sampling and analysis. It is adaptable to personal sampling where low air volumes are sampled and analysis equipment is readily available.

Minimum detectable fiber concentrations by phase contrast microscopy depend on a number of factors such as air volume sampled, microscope field counting area, number of microscopic fields counted, and presence or absence of nonfibrous particles. Theoretical minimum detectable concentrations may be calculated assuming one fiber longer than 5 μm is observed per 100 microscopic fields (after filter background subtraction). Table IV-3 shows theoretical minimum detectable fiber concentrations as a function of sample period for a typical microscope arrangement. For a 15-minute sampling period, 0.04 fibers >5 μm/cc may be detected; however, with an 8-hour sample, 0.001 fibers/cc can be detected. These minimum concentrations are similar to those reported by Corn and Sansone (1974).

These authors reported that 0.01 fibers/cc could be detected with a 2-hour sample period (40 microscopic fields counted).

The above calculations represent theoretical minimum detectable concentrations, not considering the many factors affecting precision and accuracy of the technique. There are many sources of variability in the laboratory analysis technique. The major sources of variability are as follows:

1) Variability of fiber distribution across the filter surface.
2) Variability of fiber distribution on a given filter wedge being analyzed.
3) Variability due to differences between microscopes.
4) Variability due to differences between individual counters.
5) Variability in laboratories.

Leidel and Busch (1974) found that the fiber distribution on a given filter section could best be described by the Poisson-distribution. However, Conway and Holland (1973) found that the distribution of fibers on filters was not uniform and were more disperse than predicted by the Poisson distribution, so that concentrations between sections could vary by as much as 50-60%. Similar results were found by Rajhans and Bragg (1975) in Series I of their study.

If the Poisson distribution is taken to adequately describe fiber distributions on filter sections, the standard deviation of the fiber count may be estimated from the square root of the count. In order to maintain an acceptable Coefficient of Variation (CV) (below 20%), a minimum of 25 fibers must be counted. For a typical industrial asbestos sample of 2

hours (2 lpm flow), this would correspond to a concentration of 0.13 fibers/cc.

The precision of the entire sampling and analysis procedure (all sources of variability) has been estimated by Leidel et al (1975). These authors estimated the total CV to be 22%.

Comparisons of Asbestos Mass Concentrations ($ng/m^3$) and Fiber Number Concentrations (fibers/cc)

In order to relate ambient asbestos levels, which are generally expressed as $ng/m^3$, to occupational exposures, which are expressed as fibers >5 $\mu m$ in length/cc, a conversion factor is needed. Attempts to formulate such a conversion have generally been unsuccessful because of exceptionally large variability. This is to be expected as ambient levels are generally determined using electron microscopy whereas phase contrast microscopy is used to measure occupational exposures. In addition, techniques used to prepare samples for electron microscope observation may cause alterations in fiber size (diameter and length) distributions.

Lynch and Ayer (1966) presented results of environmental studies in the asbestos textile industry where fiber concentrations were determined using phase contrast optical microscopy and fiber size distributions were determined using electron microscopy. The mass of chrysotile on the filter was estimated by using atomic absorption spectroscopy to determine the magnesium content of the sample and asbestos content was calculated, assuming a 25% magnesium content for chrysotile. These data are summarized in Table IV-4. Based on the magnesium analysis, the authors concluded that

one nanogram of asbestos was roughly equivalent to five fibers greater than 5 μm in length by optical microscopy, although much variability about this value was observed. By using fiber size data determined by electron microscopy to calculate the mass of a typical fiber, the authors concluded that one nanogram of asbestos corresponded to 8 fibers (all lengths) by optical microscopy.

In a subsequent paper, Lynch et al (1970) published results of count to weight comparisons for other industrial operations using the sample techniques previously described. These data are summarized in Table IV-5. Again, large variations in the relationships were observed, as evidenced by large geometric standard deviations. Table IV-5 shows that one nanogram of asbestos may be roughly equivalent to 6.7 - 46.5 fibers >5 μm, depending on the operation.

In their study of asbestos contamination in commercial building, Nicholson et al (1975a) compared the results of asbestos concentrations ($ng/m^3$) determined by electron microscopy to fiber concentrations determined by phase contrast microscopy for the same samples. These data were highly variant showing no consistent relationship. One nanogram of asbestos was shown to range from none detected to 6,570 asbestos fibers >5 μm by phase contrast microscopy. By averaging data, it was calculated that one nanogram was equivalent to 52 asbestos fibers >5 μm in length.

Air samples collected in communities surrounding the Reserve Mining Company, Silver Bay, Minnesota, have been analyzed by electron microscopy and concentrations expressed in $ng/m^3$ by mass calculation and fibers/$m^3$ by direct counts (Nicholson, 1973). These results showed one nanogram of

amphibole fibers to be equivalent to 640-108,000 total amphibole fibers by electron microscopy, with an average value of 30,600 fibers/ng.

A study recently published by Dement et al (1975) provides additional data for the conversion of mass concentration to fiber number for amphiboles. In this study, 22 air samples collected in an underground gold mine were analyzed by phase contrast optical microscopy and electron microscopy to determine fiber concentrations. A direct clearing technique which preserved the original fiber size distribution was used to prepare samples for electron microscopy. In addition to fiber counts by electron microscopy, each fiber was sized (length and diameter) so that the mass could be calculated (assuming a density of 2.5 g/cc). These data are summarized in Table IV-6. From these data, approximate relationships between mass concentrations and fiber count concentrations were calculated. One nanogram was calculated to be equivalent to approximately 1,200 total fibers by electron microscopy or 400 fibers >5 μm in length by phase contrast microscopy.

The above studies have not shown a consistent conversion factor for fiber mass to fiber count. Bruchman and Rubino (1975) have suggested a conversion ratio of 20 asbestos fibers >5 μm in length, as determined by optical microscopy, per nanogram of asbestos. Based on the above review, the validity of such a general conversion may be seriously questioned.

Nonoccupational Exposures - Ambient Levels

Asbestos air pollution in urban areas has been studied. Levels of chrysotile asbestos at various locations in New York City, Philadelphia,

Ridgewood, NJ, and Port Allegany, Pa, have been studied by electron microscopy (Selikoff et al, 1972). Sample sites were chosen which were distant from any known significant source of asbestos. Study results summarized in Table IV-7 show concentrations ranging from 11 to 100 nanograms/cubic meter of air ($ng/m^3$). These authors point out that one nanogram of asbestos could represent a million chrysotile fibrils.

Ambient samples have been collected in the cities of Reading and Rochdale, England, Bochum and Dusseldorf, Germany, Prague and Pilsen, Czechoslovakia, Johannesburg, South Africa, and Reykjavik, Iceland (Holt and Young, 1973). Although no effort was made to quantitate levels, electron microscopy studies revealed the presence of chrysotile asbestos in most samples.

Results of electron microscopy studies of ambient samples in the United Kingdom are summarized in Table IV-8. Chrysotile concentrations of 1/10 ng/m3 were observed (Richards, 1973).

Asbestos levels in major US cities during 1969-1970 have been determined under contract with the US Environmental Protection Agency (Nicholson, 1971).Samples were collected on three or four different occasions for each city and analyzed by electron microscopy. Results are summarized in Table IV-9 and show that mean concentrations for the samples range from 0.7 to 24.3 $ng/m^3$;however, 48% of the cities had average concentrations less than 2.0 $ng/m^3$. The highest mean, 24.3 $ng/m^3$, was observed in Dayton, Ohio, where numerous plants processing asbestos are located. The highest concentration of 95 $ng/m^3$ was also observed in Dayton.

Results of chrysotile measurements within buildings insulated with asbestos and ambient levels in the vicinity of these buildings have been presented (Nicholson et al, 1975). Crysotile concentrations were determined using electron microscopy techniques as in previous studies (Selikoff et al, 1972). Ambient levels were found to range from 0 to 46 ng/$m^3$. Using phase contrast optical microscopy, fiber levels (ambient and indoor) were found to range from 0.000 to 0.027 fibers >5 $\mu$m/cc, with an average of 0.006 fibers/cc. Average concentrations within the building sampled ranged from 2.5 to 200 ng/$m^3$, indicating the possibility of fiber erosion from insulated air plenums. The same report indicates that asbestos concentrations in excess of 100 ng/$m^3$ may often be found in the homes of asbestos workers, with the highest measured concentration being 5,000 ng/$m^3$. These authors suggest that exposure in excess of 100 ng/$m^3$ may be associated with an observable risk of asbestos disease.

Nicholson et al (1975a) published data indicating that 35 rooms in 17 office buildings in Boston, New York, Chicago, and San Francisco-Berkeley had a mean concentration of asbestos fibers in their airs of 11,600/$m^3$ whereas the intake airs for 15 of these buildings (all for which such data was given) contained a mean of 6,000 fibers/$m^3$. One room had a concentration of 102,800 fibers/$m^3$, all the others having fiber counts below 60,000/$m^3$. Samples of air from plenums in 11 of these buildings contained a mean concentration of 5,100 fibers/$m^3$. In an earlier report (1975b), the same investigators stated that two buildings in New York in which no asbestos was known to have been used as a fireproofing or anechoic material had a mean concentration of asbestos within their circulating airs considerably above that of the intake airs for these buildings. These

findings indicate that, although pick-up of asbestos from linings applied to air-ducts and plenums may be a factor in the distribution of these fibers within buildings, these linings are not a major source of the asbestos fibers found in the air circulating within buildings.

A survey carried out in the United Kingdom (Wagg, quoted by Meyer, 1976) has shown that 82% of 73 buildings examined had airborne concentrations of asbestos fibers of up to 20,000/$m^3$. Only 4% had concentrations of asbestos in the range 50,000-80,000 fibers/$m^3$. No higher concentrations were reported. The higher concentrations were found in office buildings, residences, and miscellaneous types of buildings. Really high concentrations of asbestos in air (of the order of 1-100 ng/$m^3$) have been found only within a few hundred meters downwind of asbestos processing plants (Richards and Badami, 1971, 1973;Simecek, 1967; Meyer, 1976).

Asbestos fiber levels in communities surrounding the Reserve Mining Company's milling operations in Silver Bay, Minnesota, have been reported by numerous investigators. Recent preliminary air sampling results have been reported for ten stations located between the Reserve Mining Company pollution source and several population centers (Fairless, 1974). Samples were collected each 6th day, beginning on November 6, 1974, (for a 1-year period). These samples were submitted blind to one or more of three laboratories where asbestos fibers concentrations were determined by electron microscopy. Results of these preliminary analyses are summarized in Table IV-10. Mean concentrations of amphibole fibers ranged from 2.6 to $8.9 \times 10^3$ fibers/$m^3$. In addition to amphibole fibers, chrysotile concentrations for individual samples ranged from none detected to $10.4 \times 10^4$ fibers/$m^3$. Analyses of all samples collected have not been completed.

Concentrations of amphibole fibers have also been reported near specific point emission sources of the Reserve Mining Company (Nicholson et al, 1974). Concentrations as high as 11 x $10^6$ fibers/m3 of air were reported.

NIOSH has performed two studies of fiber concentrations in the air of public buildings using the phase contrast microscopy counting technique (Wallingford et al, 1973; Zumwalde, 1973). Samples were collected over 6-8 hours at 7 - 10.5 liters/minute. These data are summarized in Table IV-11. Mean concentrations of 0.004 and 0.001 fibers >5 μm were observed, with the highest single concentration observed being 0.008 fiber >5 μm/cc.

In summary, ambient asbestos levels as determined by electron microscopy techniques are generally less than 10 ng/$m^3$ with occasional peaks as high as 100 ng/$m^3$. Only a few studies of ambient levels have been performed using phase contrast optical microscopy. These studies indicate ambient levels to be generally less than 0.01 fibers >5 μm/cc, with some peak values as high as 0.03 fibers >5 μm/cc.

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TABLE IV-1

TYPICAL OPTICAL DATA FOR ASBESTOS MINERALS

| Asbestos Type | Crystal System | Refractive Indices | Extinction Angles | Sign of Elongation |
|---|---|---|---|---|
| Chrysotile | monoclinic | 1.49-1.57 | yAL* = 0° | + |
| Anthophyllite | orthorhombic | 1.60-1.66 | yAL = 0° | + |
| Amosite | monoclinic | 1.66-1.70 | yAL = 14-21° | + |
| Crocidolite | " | 1.69-1.71 | yAL = 3-15° | - |
| Tremolite** | " | 1.60-1.65 | yAL = 10-21° | + |
| Actinolite ** | " | 1.62-1.68 | yAL = 10-15° | + |

*L = long direction of fibers
** Tremolite and actinolite form a continuous mineralogical series.
Values shown are for end members.

TABLE IV-2

DISPERSION STAINING COLORS FOR ASBESTOS MINERALS
USING PLANE POLARIZED LIGHT

| Asbestos Type | Refractive Index Liquid | Dispersion Staining Colors | |
|---|---|---|---|
| Chrysotile | 1.560 | light blue | magenta |
| Anthophyllite | 1.610 | blue-green | golden yellow |
| Amosite | 1.670 | red magenta | " |
| Crocidolite | 1.700 | magenta | blue magenta |

## TABLE IV-3

## THEORETICAL MINIMUM DETECTABLE FIBER CONCENTRATIONS BY PHASE CONTRAST OPTICAL MICROSCOPY

| Sampling Period (Minutes) | Minimum Detectable Conc. fibers >5 μm/cc |
|---|---|
| 15 | 0.04 |
| 30 | 0.02 |
| 60 | 0.01 |
| 90 | 0.007 |
| 120 | 0.005 |
| 240 | 0.003 |
| 480 | 0.001 |

*Based on a sample flow rate of 2.01 lpm and a microscope counting field area of 0.0071 $mm^2$.

## TABLE IV-4

## ASBESTOS COUNT/WEIGHT RELATIONSHIPS FOR ASBESTOS TEXTILE PLANTS

| Type Count By Phase Contrast Microscopy | Fibers per Nanogram of Asbestos |
|---|---|
| Total Fibers | 11 |
| >5 μm Fibers | 5 |

From Lynch and Ayer (1966)

TABLE IV-5

ASBESTOS COUNT/WEIGHT RELATIONSHIPS FOR VARIOUS INDUSTRIAL OPERATIONS

| Product | Type Fiber Count | Geometric Mean Fibers/ng | Geometric Standard Deviation |
|---|---|---|---|
| Textile | Total | 14.5 | 2.5 |
| | >5 μm | 6.7 | 3.3 |
| Friction | Total | 26.3 | 3.4 |
| | >5 μm | 13.9 | 3.6 |
| Pipe | Total | 46.5 | 2.8 |
| | >5 μm | 22.5 | 2.9 |

From Lynch and Ayer (1966)

TABLE IV-6

SUMMARY OF FIBER COUNT/MASS RELATIONSHIPS

| Analysis Method | Average Conc. (range) | Units of Measure |
|---|---|---|
| Total Fibers by Electron Microscopy | 4.82 (0.66 - 11.79) | fibers/cc |
| Asbestos Mass by Electron Microscopy | 3,900 (540 - 9600) | $ng/m^3$ |
| Fibers >5 μm by Optical Microscopy | 1.51 (0.16 - 2.8) | fibers/cc |

Approximate Relationships:
1 ng ≅ 1,200 total fibers by electron microscopy
1 mg ≅ 400 fibers >5 μm in length by phase contrast microscopy
From Dement et al (1975)

TABLE IV-7

SUMMARY OF AMBIENT ASBESTOS LEVELS IN VARIOUS CITIES

| Sample Site | Asbestos Conc. $10^{-9}$ gm/m$^3$ |
|---|---|
| New York City | 25-60 |
| Manhattan | 25-28 |
| Bronx | 19-22 |
| Queens | 18-29 |
| Staten Island | 11-21 |
| Philadelphia, Pa. | 45-100 |
| Ridgewood, N.J. | 20 |
| Port Allegany, Pa. | 10-30 |

From Selikoff et al (1972)

TABLE IV-8

SUMMARY OF AMBIENT CHRYSOTILE LEVELS IN THE UNITED KINGDOM

| Sample Site | Chrysotile Conc. $10^{-9}$ gm/m$^3$ |
|---|---|
| Rochdale (Factory Grounds) | 1-10 |
| Rochdale (Town Center) | 10 |
| Lancashire/Yorkshire | 1-10 |
| Industrial Site (Oldbury) | 10 |

From Richards (1973)

TABLE IV-9

SUMMARY OF AMBIENT ASBESTOS LEVELS
IN 49 CITIES FOR 1969-1970

| Conc. $10^{-9}$ gm/m$^3$ | Cumulative % of City Mean Conc. $\leq$ Given Conc. |
|---|---|
| 0.1-1.9 | 12 |
| 1.0-1.9 | 48 |
| 2.0-2.9 | 64 |
| 3.0-3.9 | 72 |
| 94.0-4.9 | 86 |
| 5.0-5.9 | 94 |
| >6.0* | 6% |

*Highest Mean - 24.3 ng/m$^3$ observed in Dayton, Ohio
From Nicholson et al (1971)

TABLE IV-10

SUMMARY OF AMPHIBOLE FIBER CONCENTRATIONS
FOR TEN SAMPLE SITES IN THE VICINITY OF RESERVE MINING

| Sample Site | Amphibole Conc. $10^{-9}$fibers/m$^3$ | |
|---|---|---|
| | Mean | Range |
| Duluth | 7.5 | 0-17 |
| Duluth (Residence) | 2.6 | 0- 8 |
| Silver Day (Residence) | 11 | 0-30 |
| Babbit (Residence) | 13 | 0-82 |
| Hoyt Lake | 8.5 | 0-31 |
| Hibbing | 5.6 | 0.19 |
| Cloquet | 6.8 | 0-30 |
| Pengilly | 6.6 | 0-17 |
| Virginia | 4.2 | 0-12 |
| Mt. Iron | 8.9 | 0-45 |

Overall Mean = 7.6 X $10^{-9}$fibers/m$^3$
From Fairless (1974)

TABLE IV-11

SUMMARY OF FIBER CONCENTRATION DETERMINATIONS IN THE AIR OF PUBLIC BUILDINGS USING PHASE CONTRAST OPTICAL MICROSCOPY

| Building Location | Fibers >5 μm in Length/cc<br>Mean and Range |
| --- | --- |
| Baltimore, Maryland<br>and Washington, D.C. | 0.004<br>(0.001-0.008) |
| Towson, Maryland | 0.001<br>(0.000-0.003) |

From Wallingford et al (1973) and Zumwalde (1973)