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Asbestos in Raw and Treated Water: An Electron Microscopy Study

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■ Recovery and identification of asbestos fibers from the Southern end of Lake Michigan reaffirm the concept that asbestos is present in Lake Michigan, which is used as the water supply for Chicago and other cities. The Chicago Water Filtration Plants remove most of the asbestos fibers present in the lake. A brief summary of problems associated with asbestos and methods for collection, preparation, and identification is given. The authors recommend continued monitoring of these fibers.

Studies indicate that asbestos fibers are a common part of most people's environment. An examination of lung sections of people living and working in New York City has shown some fibers in the lungs of every person examined (*1*). Similar results probably could be found in any other large city in the nation. In addition, recent studies indicate that asbestos occurs naturally in much of the drinking water in the U.S. Environmental exposure to it is increased by filtration of certain beverages and pharmaceuticals through asbestos filters (*1*). Cunningham and Pontefract found that Canadian beer and tap water contained chrysotile asbestos fibers (*2*). They also found, through the use of the electron microscope, that some beers, sherries, port, vermouths, soft drinks, and drinking water contained millions of fibers per liter of asbestos (*3*). Cancer from asbestos is an occupational health hazard for people who work around large amounts of asbestos dust for a long period of time (*1*). Few people will argue about the dangers of breathing asbestos fibers; there is too much evidence which supports the belief that it is harmful.

The evidence, however, is not so one-sided when we speak of the hazards of ingesting asbestos fibers. What effect does eating and drinking material which contains asbestos fibers have on our health? Nobody can say for sure, because what little evidence exists is often contradictory. Davis could detect no asbestos passing through the stomach or intestinal walls of rabbits fed asbestos fibers (*1*). However, Pontefract injected an asbestos sample directly into the stomachs of laboratory animals and was able to detect about 0.1% of his sample in the epidermis (*1*). Kuschner et al. state that asbestos can cause granulomatous and fibrotic reactions in the lungs, but there is no evidence that it does so in the gastrointestinal tract (*4*). At the same time Chatfield wrote that there is some evidence of increased incidence of gastrointestinal carcinoma where individuals have been exposed to asbestos fibers over a long period (*5*). The staff of the Ontario Ministry of Health concluded in 1973 that, based on information available at that time, there was no evidence that asbestos in water had an effect on health (*3*). In short, we have to conclude that we really do not know what effect, if any, ingested asbestos fibers have on people. The primary reason for this is the very long time between initial exposure and evidence of biological effects, perhaps as long as 25–35 years (*1*). Another problem is the lack of data over a number of years, which is necessary to gauge the long-range impact of asbestos fibers in water on the general public.

Objective of Study

Much concern has recently been voiced, both in the public media and in scientific circles, over the possible health hazards associated with asbestos fibers in drinking water. This became especially significant following the Reserve Mining disclosure and its potential effect on the water supply at Duluth, Minn. In an effort to investigate the possibility of asbestos in Chicago's water supply, the Microscopy Unit of the Water Purification Laboratory of the Chicago Bureau of Water Operations initiated asbestos studies of both raw and treated water early in 1973. Data were obtained in the southern end, along the western shore of Lake Michigan by monitoring and recording the number of fibers in both raw and treated water.

A search of early photographic files in the Unit revealed that needle-like objects which resembled asbestos fibers have been found in Lake Michigan water since 1960. At that time the presence of these fibers was not reported because the fibers were not confirmed as asbestos, nor were they then considered important (Figure 1).

The raw water samples are collected from various points along the shore and from crib intakes located 2½ miles from the shoreline. Additional samples are collected up to seven miles out into Lake Michigan. The treated water samples come from various clearwells, outlets, and distribution points (Figure 2). Each sample is collected in a 1-l. bottle which is cleaned, rinsed, and partially filled with triple distilled water which has been passed three times through a 0.22-μm membrane filter. A control bottle is run with each sample to determine the number of fibers in the sample count which may

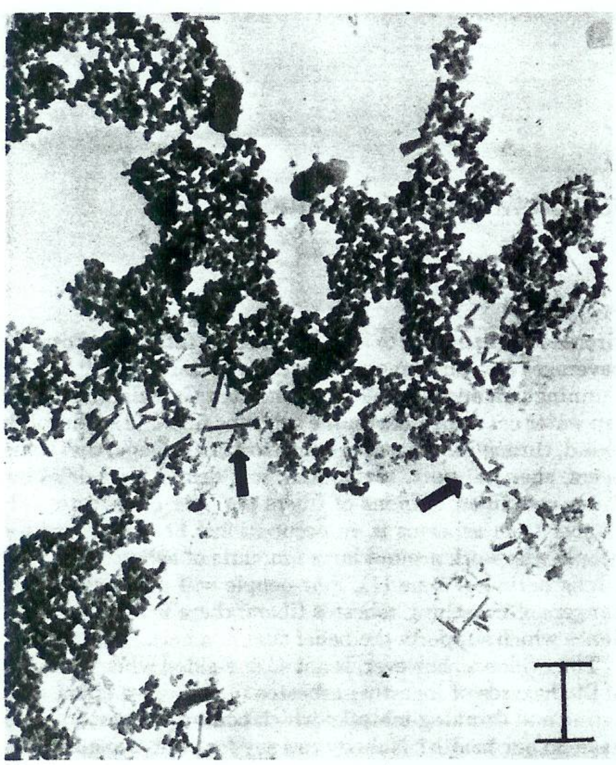

Figure 1. Raw Lake Michigan water before preparation. Arrows indicate possible asbestos fibers. Photomicrograph taken in October 1962. Bar represents 1 μm

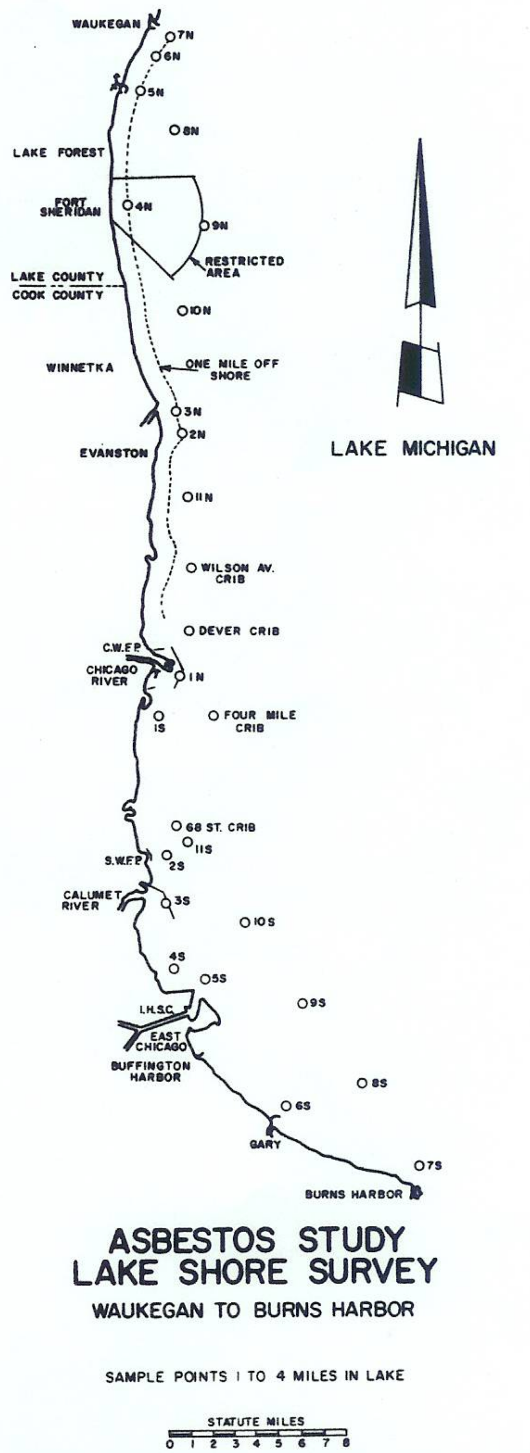

Figure 2. Points of sample collection along shore of Lake Michigan

be due to contamination during collection, preparation, and examination. This method has been used for several years, and contamination in the control bottles was essentially negative, and when detectable, its numerical value did not significantly affect the sample data listed in Figure 3.

Sample Preparation

Since the asbestos fibers are usually suspended throughout the water sample, it is necessary to concentrate the fibers by filtration so that they can be counted. A 200-ml portion of the sample is passed through a 0.22-μm membrane filter which is 47 mm in diameter, has a 35-mm effective filtration diameter, and an effective filtration area of 9.62 cm^2. All filtrations are performed under a controlled filtered atmosphere hood, which has a laminar air flow to reduce the possibility of airborne contamination. Occasionally, it is necessary to dilute a raw water sample with the corresponding control water if the raw turbidity is relatively high, about 2.50 FTU's or more. This is done to make the suspended material less concentrated, which in turn makes the fibers more visible and easier to count.

Identification and Counting Fibers

A transmission electron microscope was used exclusively during this study, due to the sublight microscopic size of the fibers: 2.0–8.0 μm in raw water and 0.1–6.0 μm in treated water. Approximately 50% of fibers in Lake Michigan raw water range from 2.0 to 5.0 μm in length, and 50% of the fibers in the finished water are between 0.5 and 2.0 μm long. The width of all fibers does not exceed 1.0 μm. (Figures 4–6).

There are difficulties involved in accurate size measurements. A useful analogy is to visualize the asbestos particles as a rope. The rope can be measured as one complete unit or may be separated into the individual strands and bits of material which make up the rope. The various stages of collection, preparation, and examinations may break down the large bundles of asbestos into the individual fibers. Therefore, it is difficult for the researcher to determine if he is measuring a complete bundle of asbestos, one single fiber, or just a broken splinter of one fiber. This problem obviously makes accurate measurements of fiber lengths very difficult.

Other researchers have reported a large range of fiber sizes. Chatfield states that no detailed study of fiber lengths has yet been made, but the peak of the number distribution appears to be about 1–2 μm, with fibers ranging from 0.2 to 30 μm (*6*). Chatfield examined asbestos in both air and water for his figures.

Cunningham and Pontefract state that most of the fibers found in Canadian beer and in filtered city water were less than 1.0 μm in length. Most of the samples of wine, American beer, and unfiltered melted snow or river water contained a considerable number of asbestos fibers ranging from 1 to 15 μm in length (*7*).

An EPA examination of western Lake Superior raw water indicated 55% of the amphibole fibers were between 0.4–1.7 μm long. For chrysotile fibers, 62% were between 0.3–1.3 μm in length (*8*).

To accurately count and identify the fibers present, it is necessary to remove the inorganic particles, diatoms, organic debris, and other extraneous material which may obstruct or cover the fibers. The removal of interferences is desirable when using x-ray or electron microscopy techniques (*9*). One-half of the membrane filter is placed on a sidearm condensation washer (Figure 7). Some authors (*10*) claim that substantial fiber loss occurs during preparation in the condensation washer. In our laboratory a number of samples were examined on several different occasions to determine the reproducibility of this procedure. The variation of the fiber count within each sample was less than 10%. This repeatability is good, considering the high multiplication factor involved. This device uses acetone as a solvent to dissolve the membrane, leaving just the suspended material in the sample on previously prepared carbon-coated copper screens with a 0.25% formvar film composed of the resin and ethylene dichloride. The sample is refluxed for 4 h. After drying, the screens are ready for electron microscopic examination. The second method is to place the other half of the membrane filter

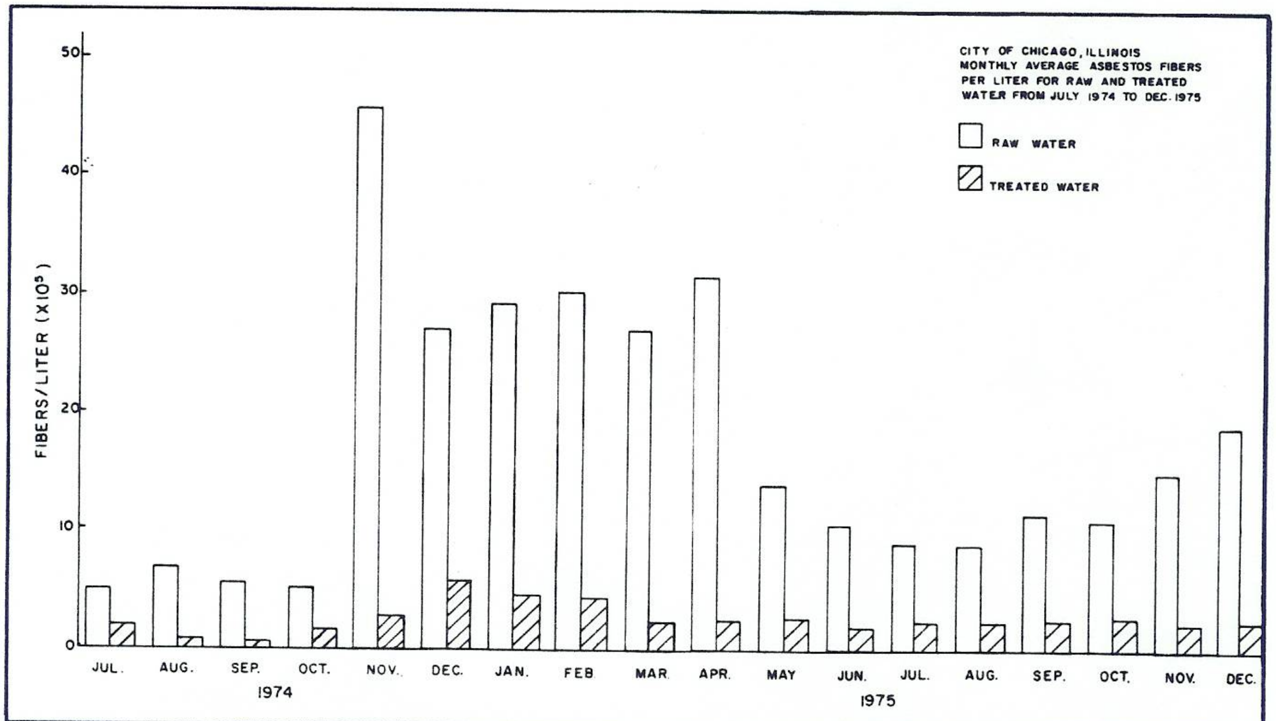

Figure 3. Graph of asbestos fibers per liter in raw and treated water from July 1974 to December 1975, using condensation washer

Figure 4. Raw lake water before preparation. Arrows indicate asbestos fibers. Bar represents 1 μm

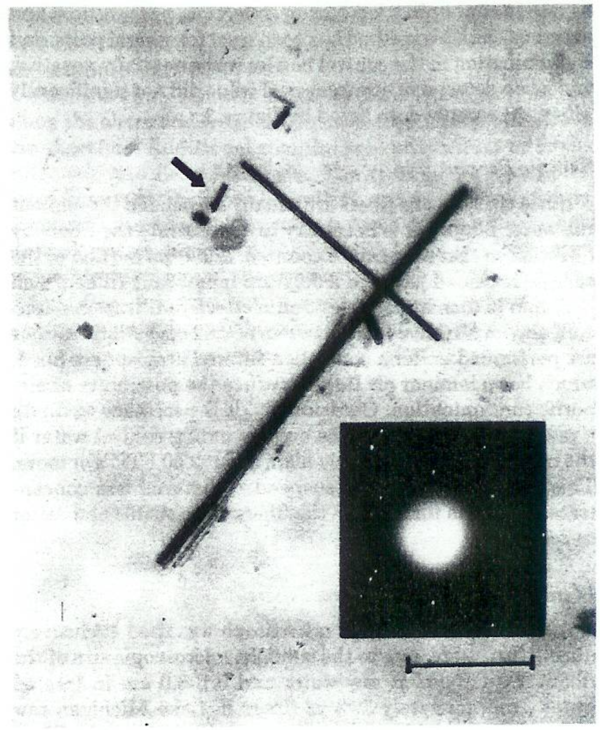

Figure 5. Chrysotile asbestos in raw water sample after ashing (insert). Selected area diffraction pattern. Bar represents 1 μm

in a ceramic crucible and to ash it at a temperature not to exceed 600 °C for 4 h. The ashed residual in the ceramic crucible is diluted with 10 ml of the corresponding control water and placed in an ultrasonic device for 30 min to disperse the residual. The suspended ashed material is then refiltered through a 13-mm diameter filter which has an effective filtration area of 60 mm^2 and a 0.22-μm pore size. Screens are prepared using the sidearm condensation washer as described above. The electron microscope is again used for final verification.

This is done only on raw water samples since organic matter and other suspended material make it difficult to obtain a fiber count. The fibers are left essentially intact and are more easily counted and identified. The treated water, having a turbidity of >0.20 FTU's, does not require ashing to remove the organic material. Only the method employing the condensation washer was used on the treated samples. On those occasions when both methods were used, the fiber counts obtained were reasonably close.

The following methods for identification and counting fibers are similar to the procedures used by the Environmental Protection Agency at the Taft Center in Cincinnati, Ohio (*11*). Standard samples, which are obtained commercially, of known asbestiform groups are suspended in known concentrations and examined under the electron microscope. There are two major groups known: chrysotile (serpentine) and amphibole (crocidolite, anthrophyllite, tramolite, and amosite) (*5*). Microphotographs of the various types were taken for future reference. The fibers were measured for both length and width, and their distinctive electron diffraction patterns were obtained. Similar methods were reported by Richards (*12*). Unknown fibers resembling asbestos are compared against these known standards for confirmation.

There is some interest as to which type of asbestos fibers, chrysotile and/or amphibole, is present in the water supply.

Durham and Pang indicated that the majority of fibers examined during 1973 from the central portion of Lake Superior were chrysotile (*2*). Fairless also reported various levels of amphibole fibers in his potable water intake investigation of the western arm of Lake Superior (*13*). Other researchers indicate a combination of chrysotile with fewer, but, still significant, amounts of amphibole also present at Duluth, Minn. (*8*).

The majority of fibers in our study, perhaps as much as 80% of the total, appear to be chrysotile. It should be emphasized that this assumption is based only on the raw water collected at the southwestern corner of Lake Michigan and does not necessarily apply to Lake Michigan as a whole.

To count the asbestos fibers using only the first method, two rows of open screen areas are counted. This is accomplished by counting 10 areas vertically and another 10 grids horizontally for a total of 20 open areas. The formula for counting the fibers using this method for the total count per liter is equal to the total number counted in 20 open areas multiplied by 3720.

To count the asbestos fibers using the second method, we follow this procedure: Because the opening of each square area used in this study is 85 μm on a side, the total open size of each area is $(85\ \mu m)^2$ or 0.007225 mm^2. Likewise, the effective Millipore filter area is $(4.4\ mm)^2 \times 3.14$ or 60.8 mm^2. With these figures and the average fiber count per grid, the number of fibers per liter can be calculated with the following formula (similar to EPA methods of Cincinnati, Ohio) (*11*):

$$\text{fibers/liter} = \frac{\text{av per open area} \times 60.8\ \text{mm}^2 \times 1000\ \text{ml}}{0.007225\ \text{mm}^2 \times \text{sample vol (usually 200 ml)}}$$

fibers/liter = total number of fibers in 20 fields $\times 4.1 \times 10^3$ (for a 200-ml sample) or fibers/liter = av fibers per open area $\times 8.2 \times 10^4$ (for a 200-ml sample).

Graph and Interpretation

The graph (Figure 3) gives the counts of asbestos fibers per liter of water. The raw water was considered those samples collected at the crib intakes, shore intakes, and headers.

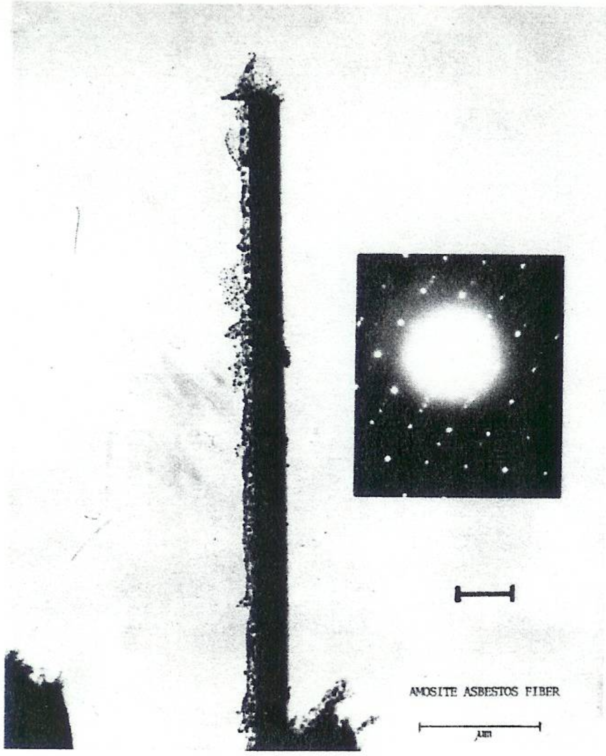

Figure 6. Amphibole asbestos fiber in raw water sample after ashing (insert). Selected area diffraction pattern. Bar represents 1 μm

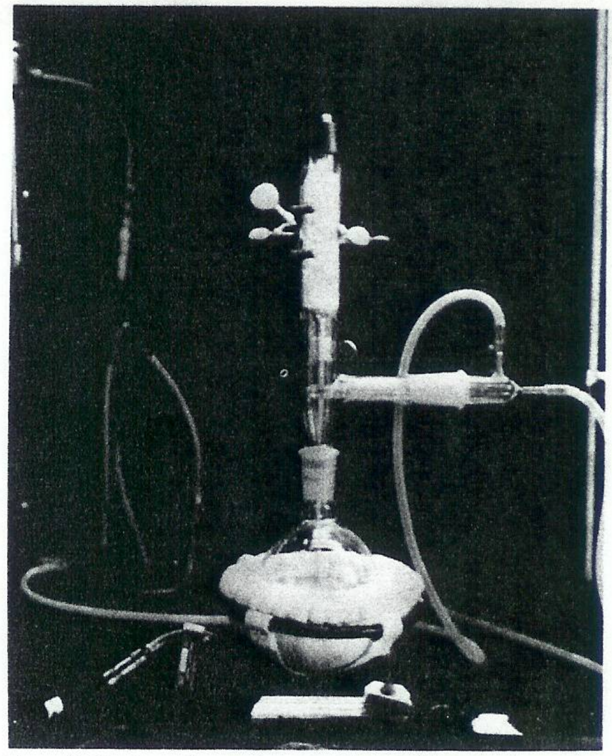

Figure 7. Condensation washer apparatus used for sample preparation

The treated water was considered those samples collected at the outlets, clearwells, and distribution system after the filtration process was complete. A somewhat bell-shaped curve resulted with the peak from November to April. During this time span the raw water count averaged about 3 million fibers per liter. During the rest of the year the raw water count was slightly less than 1 million fibers per liter (F/l.). The average count for the entire year was about 1.8 million F/l. The highest raw water count recorded during the test period was 4.2 million F/l.; the lowest count was 420 000 F/l.

The treated water counts generally followed the raw water fluctuations. The highest recorded treated water count was about 550 000 F/l.; the lowest treated water count was about 80 000 F/l. with an average treated water count of about 230 000 F/l.

Since data have not yet been collected over an extended length of time, we cannot state positively that this seasonal fluctuation is a yearly occurrence. However, we can state that the flocculation, sedimentation, and filtration process used at the Chicago Water Filtration Plants does remove from 70 to 90% of the asbestos fibers present in the raw water of Lake Michigan.

Summary

Asbestos fibers in both raw and treated water of the Chicago water system have been monitored and recorded weekly from July 1974 to the present.

Photographic files indicate possible asbestos fibers in Lake Michigan water for at least 15 years.

The health hazards of breathing asbestos dust are well documented, but not enough research has yet been done to determine possible health dangers from the ingestion of asbestos fibers.

Both raw and treated water samples are collected weekly, and several methods of sample preparation for examination by the electron microscope are utilized.

Data indicate a somewhat seasonal variation in the number of fibers in raw water, with the highest period from November to April, with a yearly average of about 1.8 million F/l. Treated water figures generally tend to follow the raw water curve, with a yearly average of about 230 000 F/l. The filtration process eliminates 70–90% of the fibers found in the raw water sample.

It is recommended that the presence of asbestos fibers in both raw and treated water continue to be monitored and recorded to build up a data base for future interpretation.

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