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**ASBESTOS IN COOLING-TOWER WATERS**

by

**Barbara-Ann G. Lewis**



U of C-AUA-USDOE

**ARGONNE NATIONAL LABORATORY, ARGONNE, ILLINOIS**

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Barbara-Ann G. Lewis

Division of Environmental Impact Studies

December 1977

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## CONTENTS

	<u>Page</u>
LIST OF FIGURES . . . . .	5
LIST OF TABLES . . . . .	6
ABSTRACT . . . . .	7
INTRODUCTION . . . . .	8
THE NATURE AND OCCURRENCE OF ASBESTOS IN THE ENVIRONMENT, AND SUMMARY OF HUMAN HEALTH EFFECTS . . . . .	11
Nature, Occurrence, and Utilization of Asbestos . . . . .	11
Health Effects of Asbestos . . . . .	13
Occupational Exposure . . . . .	13
Non-Occupational Exposure . . . . .	14
Theories for Pathogenicity of Asbestos . . . . .	18
Summary . . . . .	19
METHODS . . . . .	19
Collection of Industry Data . . . . .	19
Collection of Water Samples . . . . .	20
Sample Preparation and Analysis . . . . .	22
Water . . . . .	22
Sediments . . . . .	23
RESULTS AND DISCUSSION . . . . .	23
Asbestos Fill in Cooling Towers . . . . .	23
Film-type Asbestos Fill . . . . .	24
Splash-type Asbestos Fill . . . . .	24
Asbestos in Cooling-Tower Waters . . . . .	27
Asbestos-Fiber Dimensions . . . . .	33
Asbestos-Fill Erosion and Breakage . . . . .	33
Physical Breakage . . . . .	45
Chemical Deterioration due to Nature of the Circulating Water . . . . .	45
Acid Secretion by Attached Organisms . . . . .	49
Industry Studies on Erosion of Asbestos Material . . . . .	49
Goodyear Atomic Corporation . . . . .	49
Research-Cottrell . . . . .	50
Johns-Manville Corporation . . . . .	50
Asbestos Cement Pipe Producers Association . . . . .	50
Munters Corporation . . . . .	50
Pennsylvania Power and Light Company . . . . .	50
Pennsylvania Electric Company . . . . .	51
Summary . . . . .	51
APPLICATION OF A DRIFT-DEPOSITION MODEL TO ASBESTOS-FIBER EMISSIONS FROM A COOLING TOWER . . . . .	51

## CONTENTS

	<u>Page</u>
CONCLUSIONS AND IMPLICATIONS FOR ENVIRONMENTAL IMPACT ASSESSMENT . . .	55
ACKNOWLEDGMENTS . . . . .	56
APPENDIX A. EXCERPTS OF FEDERAL REGULATIONS AND STANDARDS FOR ASBESTOS . . . . .	59
APPENDIX B. QUESTIONNAIRE TO COOLING-TOWER VENDORS AND SUPPLIERS . . . . .	62
APPENDIX C. DESCRIPTIVE STATISTICS FOR ASBESTOS-FIBER ENUMER- ATION IN SAMPLES OF COOLING-TOWER WATER AND SEDIMENTS . . . . .	63
APPENDIX D. ESTIMATE OF ASBESTOS IN COOLING-TOWER WATER DUE TO AIR WASHING . . . . .	65
REFERENCES CITED . . . . .	67



## FIGURES

<u>Figure</u>		<u>Page</u>
1	Photographs of Natural-Draft and Mechanical-Draft Cooling Towers . . . . .	9
2	Four Basic Types of Wet Cooling Towers . . . . .	10
3	Naturally Occurring Asbestos in the United States . . . . .	12
4	Cooling-Tower Fill (ASBESdek) Manufactured by Munters Corporation . . . . .	25
5	Asbestos-Cement Sheets for Film-type Cooling-Tower Fill . . . .	26
6	Corrugated Asbestos-Cement Bars for Splash-type Cooling-Tower Fill . . . . .	27
7	Chrysotile-Asbestos Fibers in Makeup Water Collected at Site No. 17 . . . . .	34
8	Chrysotile-Asbestos Fibers in Blowdown Water Collected at Site No. 9 . . . . .	36
9	Chrysotile-Asbestos Fibers in Basin Water Collected at Site No. 11 . . . . .	38
10	Amphibole-Asbestos Fiber in Makeup Water Collected at Site No. 13 . . . . .	40
11	Amorphous Fibers in Blowdown Water Collected at Site No. 9 . . . . .	42
12	Photomicrograph of Organic Fibers and Other Organic Materials in Basin Water Collected at Site No. 7 . . . . .	43
13	Inorganic Fibers in Makeup Water Collected at Site No. 13 . . . . .	44
14	Damage to Cooling-Tower Fill and Drift Eliminators after Winter of 1976-1977 . . . . .	46

## TABLES

<u>Table</u>		<u>Page</u>
1	Asbestos in Ambient Air . . . . .	14
2	Asbestos in Surface Waters and Public Drinking Supplies . . . . .	16
3	Asbestos in Miscellaneous Environmental Samples . . . . .	18
4	Cooling-Tower Sampling Sites . . . . .	21
5	Surface Waters and Groundwaters Analyzed for Asbestos . . . . .	28
6	Asbestos in Cooling-Tower Waters . . . . .	30
7	Concentration and Fiber-Dimension Data for Asbestos in Cooling-Tower Water Samples . . . . .	32
8	Langelier Indices of Cooling-Tower Waters . . . . .	48
9	Parameters for the Application of a Drift-Deposition Model to Asbestos-Fiber Emissions from a Cooling Tower . . . . .	52
10	Asbestos in Air near Ground Level due to Drift Emissions from Cooling Towers at a Hypothetical Site . . . . .	53
11	Ratios for Near-Ground Airborne Concentrations of Asbestos Fibers due to Emissions in Drift from Natural-Draft and Mechanical-Draft Cooling Towers Relative to Standard, Round Mechanical-Draft Cooling Towers . . . . .	54

## ASBESTOS IN COOLING-TOWER WATERS

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### ABSTRACT

Fill material in natural- or mechanical-draft cooling towers can be manufactured from a variety of materials, including asbestos cement or asbestos paper. To aid in the environmental impact assessment of cooling towers containing these asbestos types of fill, information on these materials was obtained from cooling-tower vendors and users. Samples of makeup, basin, and blowdown waters at a number of operating cooling towers were obtained, and identification and enumeration of asbestos in the samples were performed by transmission electron microscopy, selected-area electron diffraction, and energy-dispersive x-ray analysis. Asbestos fibers were detected in cooling-tower water at 10 of the 18 sites sampled in the study. At all but three sites, the fibers were detected in cooling-tower basin or blowdown samples, with no fibers detected in the makeup water. The fibers were identified as chrysotile at all sites except one. Concentrations were on the order of  $10^6$  to  $10^8$  fibers/liter of water, with mass concentrations between  $< 0.1$   $\mu\text{g/liter}$  to  $37$   $\mu\text{g/liter}$ . The majority (65-100%) of the fibers were  $< 5$   $\mu\text{m}$  in length, with aspect ratios ranging from 3.5 to 1700. Settling ponds that receive cooling-tower blowdown containing asbestos appear to substantially reduce the fiber concentrations in the effluent to off-site receiving waters.

The maximum concentrations of asbestos fibers in air near ground due to drift from cooling towers were estimated (using models) to be on the order of asbestos concentrations reported for ambient air up to distances of 4 km downwind of the towers. Exceptions are rectangular mechanical-draft towers where the current occupational standard of 2 fibers per  $\text{cm}^3$  of air may be exceeded close to the towers.

Assuming that the methods of data collection and analysis were reasonably accurate with respect to orders of magnitude, it seems likely that the off-site hazard to human health due to asbestos emissions in drift from cooling towers is negligible. The human health hazard due to asbestos in drinking-water supplies is less clear. Based on current information, the concentrations of asbestos in natural waters after mixing with cooling-tower blowdown containing  $10^6$  to  $10^8$  fibers/liter will pose little health risk. These conclusions may need to be revised if future epidemiological studies so indicate.

## INTRODUCTION

Cooling towers are water-recycling devices that can reduce the quantity of waste heat discharged to surface waters from steam-electric power plants (Fig. 1). Their use is expected to increase as more power plants are built and competition increases for large sources of fresh water. Cooling towers are also employed at other industrial sites and for air-conditioning large buildings.

Prior to 1969, little attention was paid to environmental effects that might arise from installing and operating cooling towers. Primarily as a result of the National Environmental Policy Act and subsequent scrutiny of electric power production, a number of cooling-tower environmental effects have been identified. These effects include the potential for icing of adjacent structures, fogging, shadowing, emission of small amounts of salt, chemical and thermal discharges into surface waters, and aesthetic intrusion. An additional effect that has been only casually addressed is the discharge of asbestos fibers into the air and water from cooling towers that contain asbestos in the fill and other components or in the intake water. Asbestos fibers inhaled during occupational exposure are known to have adverse effects on human health.

*Fill* is the material which spreads the cooling water into films or breaks it up into drops to hasten the evaporation (cooling) process. Types of fill currently in use include asbestos-cement bars or sheets, asbestos paper, plastic, wood, and ceramic tile. Other components of a cooling tower that may include asbestos material are drift eliminators, casing, louvers, and water-distribution pipes. The four basic types of wet cooling towers are diagrammed in Figure 2.

In 1975, the U. S. Nuclear Regulatory Commission funded a study by Argonne National Laboratory on the magnitude of asbestos-fiber discharges from cooling towers, to aid in the Commission's ongoing assessment of the environmental effects of nuclear power stations. The project included the following activities:

1. Review of the literature relating to the nature, occurrence, utilization, methods for analysis, and health effects of asbestos.
2. Collection of relevant information from cooling-tower suppliers, vendors, and users.
3. Sampling of influent (makeup), circulating, and effluent (blowdown) waters at operating towers.
4. Analysis of the samples for the quantity and mineral type of asbestos using electron microscopy, selected-area electron diffraction, and energy-dispersive x-ray analysis.
5. Application of a drift-deposition model to the emission of asbestos from cooling towers at a hypothetical site.



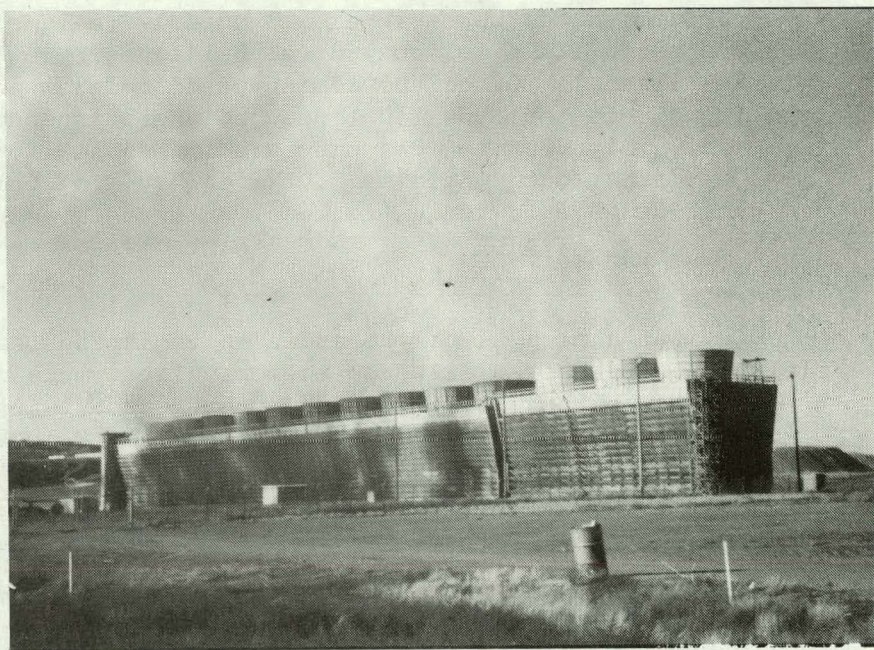
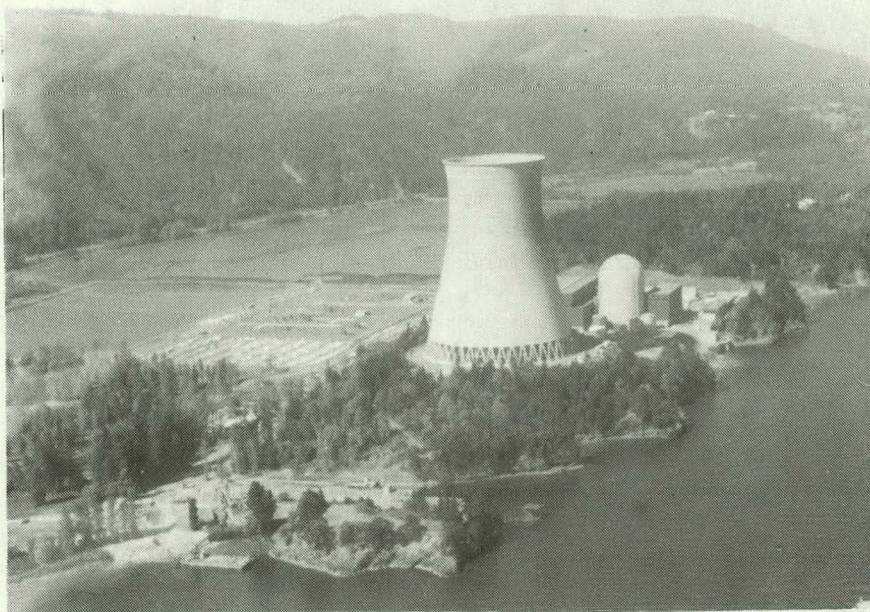


Fig. 1. Photographs of Natural-Draft (upper) and Mechanical-Draft (lower) Cooling Towers.



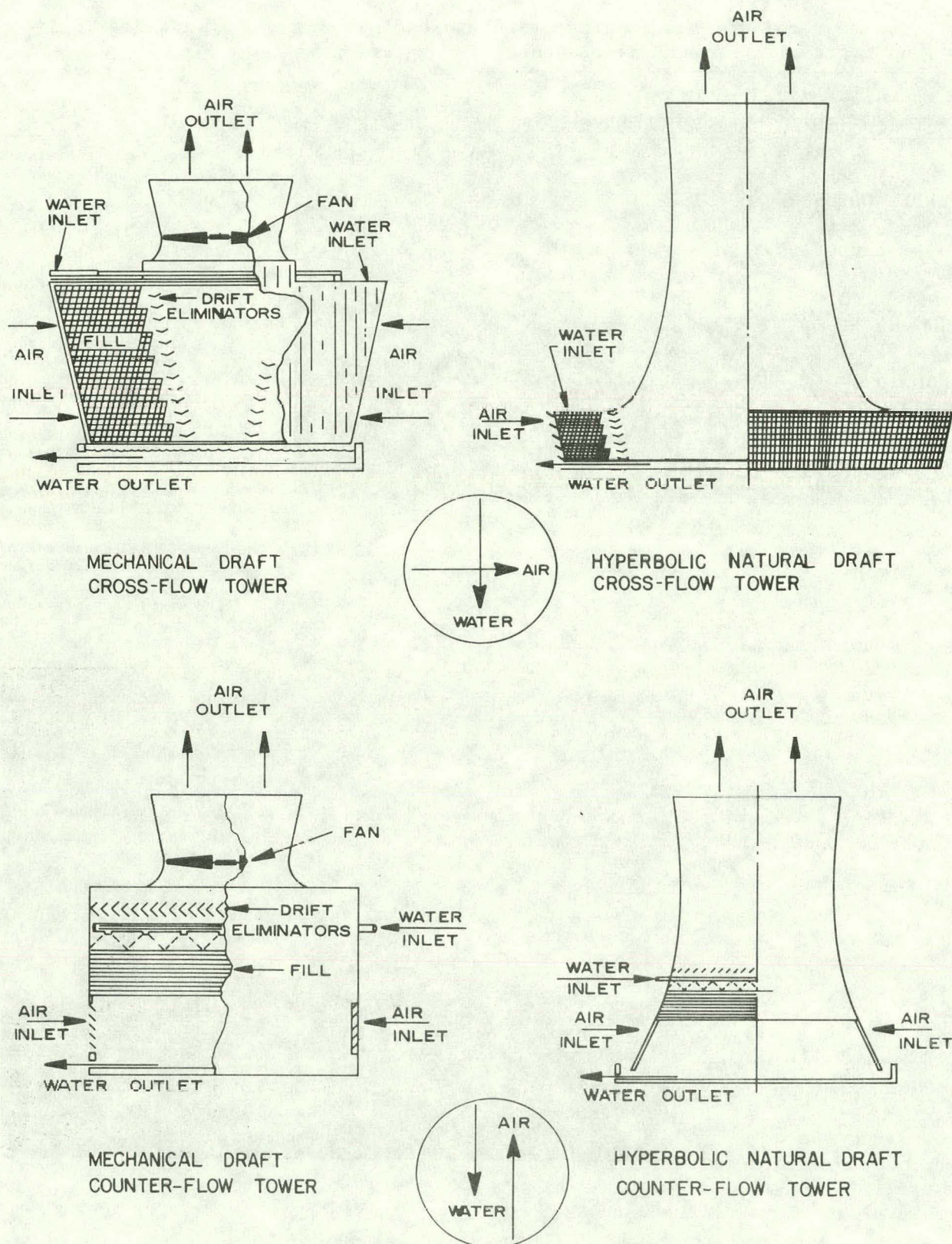


Fig. 2. Four Basic Types of Wet Cooling Towers. From Holmberg and Kinney (1973). Reprinted with permission of The Marley Company.

This document reports the results of the investigation, and discusses implications for cooling-tower environmental impact assessment.

## THE NATURE AND OCCURRENCE OF ASBESTOS IN THE ENVIRONMENT, AND SUMMARY OF HUMAN HEALTH EFFECTS

### NATURE, OCCURRENCE, AND UTILIZATION OF ASBESTOS

Asbestos is a general name for fibrous forms of the rock-forming minerals amphibole and serpentine, as follows:

<u>Mineral Type</u>	<u>Fibrous Form</u>	<u>Approximate Chemical Formula</u>
Serpentine	Chrysotile	$3\text{MgO} \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$
Amphibole	Actinolite	$2\text{CaO} \cdot 4\text{MgO} \cdot \text{FeO} \cdot 8\text{SiO}_2 \cdot \text{H}_2\text{O}$
Amphibole	Tremolite	$2\text{CaO} \cdot 5\text{MgO} \cdot 8\text{SiO}_2 \cdot \text{H}_2\text{O}$
Amphibole	Anthophyllite	$7\text{MgO} \cdot 8\text{SiO}_2 \cdot \text{H}_2\text{O}$
Amphibole	Amosite	$5.5\text{FeO} \cdot 1.5\text{MgO} \cdot 8\text{SiO}_2 \cdot \text{H}_2\text{O}$
Amphibole	Crocidolite	$\text{Na}_2\text{O} \cdot \text{Fe}_2\text{O}_3 \cdot 3\text{FeO} \cdot 8\text{SiO}_2 \cdot \text{H}_2\text{O}$

*Chrysotile* asbestos occurs worldwide in two different geologic settings: primarily in veins in serpentinized peridotite, pyroxenite, and dunite--termed "Quebec type" asbestos; and secondarily, in thin serpentine layers in limestone--termed the "Arizona type" (Shride, 1973). *Anthophyllite*, *actinolite*, and *tremolite* asbestos occur in schistose igneous and metamorphic rocks rich in hornblende or pyroxene. *Crocidolite* and *amosite* occur only in certain fine-grained cherty ferruginous metasediments ("banded ironstones").

The asbestos minerals occur either as cross-fiber veins (the parallel fibers are normal to the vein walls), as slip-fiber (fibers are oriented almost parallel to the plane of the vein), or as mass-fiber (an aggregate of variously oriented fibers). *Chrysotile* ("white asbestos"), *crocidolite* ("blue asbestos"), and *amosite* occur mainly as the cross-fiber type, while *anthophyllite*, *tremolite*, and *actinolite* occur mainly as mass-fiber or slip-fiber (Shride, 1973; Hendry, 1965).

Most of the world production of asbestos occurs in Canada, the U.S.S.R., and South Africa (in descending order of productivity). Although the United States is the principal fabricator and consumer of asbestos products, it imports most of the raw materials. Currently, about 15% of the *chrysotile* asbestos consumed in the United States is locally obtained (mostly from California), with the remainder coming from Canada. *Amosite* asbestos is obtained only from Transvaal, South Africa, whereas all but a small portion of *crocidolite* is obtained from Transvaal and Cape Provinces of South Africa. What little *anthophyllite* and *tremolite* is used in the United States is obtained from domestic resources (Shride, 1973).

Aside from California, substantial asbestos deposits in the United States occur in the Appalachian Belt and in Arizona; these and other areas with high content of asbestos minerals are indicated in Figure 3.

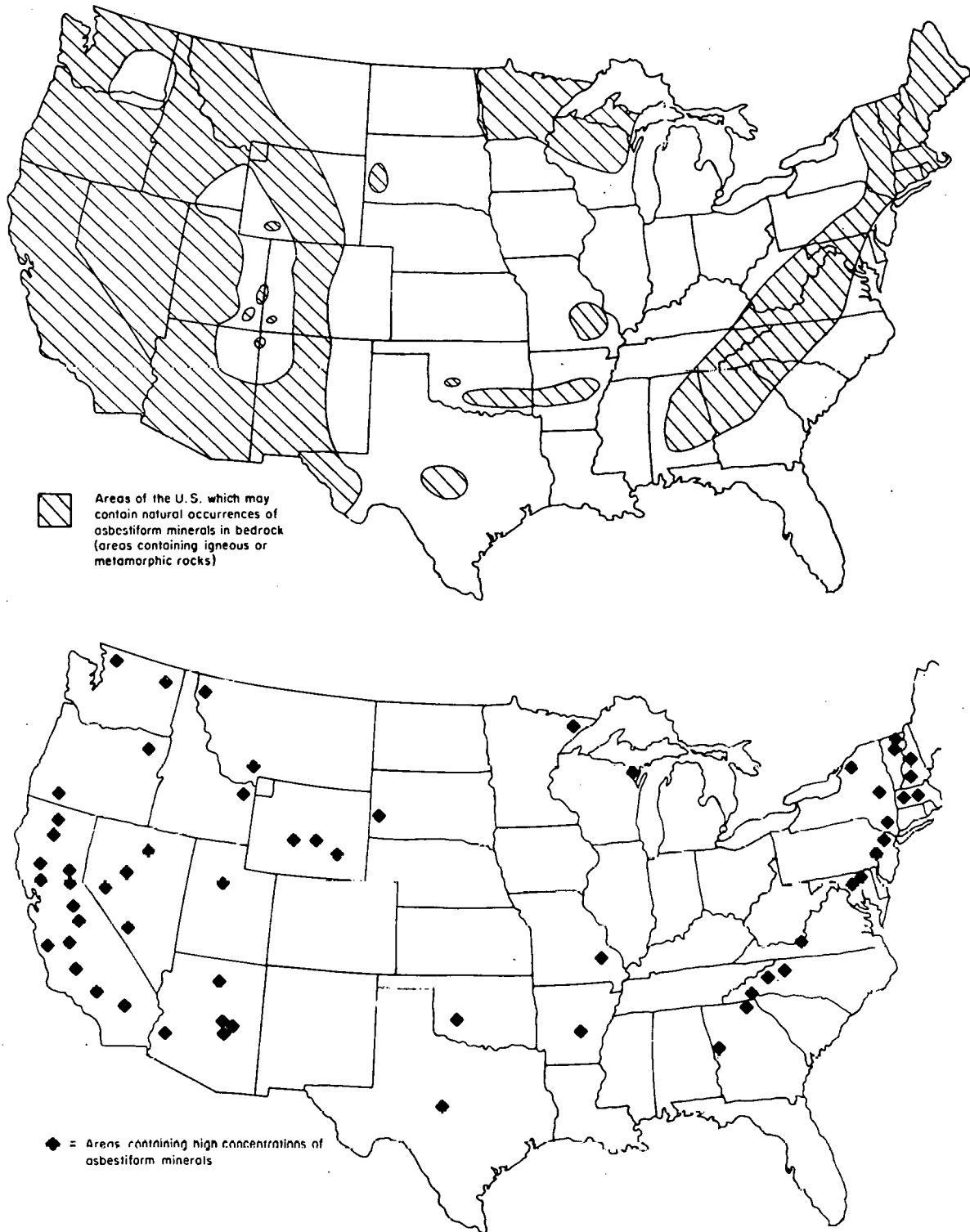


Fig. 3. Naturally Occurring Asbestos in the United States. From Kuryvial et al. (1974).



Additional general information on the geology and occurrence of asbestos can be found in Shride (1973) and Hendry (1965); more specific information regarding asbestos deposits in the United States can be found in Kuryvial et al. (1974).

It is estimated that asbestos has about 3000 separate commercial applications; major uses of the fibers are in asbestos textiles, asbestos-cement products, friction materials such as brake linings, gaskets, asbestos paper, floor tile, paints, roof coatings, caulks, plastics, and other miscellaneous products. About 95% of the asbestos used in industry is *chrysotile*, primarily due to its flexibility, high tensile strength, and spinnability compared to other forms of asbestos. *Tremolite* and *actinolite* are used to a limited extent as filters in the chemical industry, and as fillers in some manufactured products. *Anthophyllite* is used limitedly as reinforcement in asbestos cement, floor tile, etc., but principally as filler in rubber and plastic industries and in adhesives and cements. *Amosite* is used principally in pipe and boiler insulations and bulkhead linings in ships. *Crocidolite* is used chiefly in the manufacture of asbestos-cement products, as well as in filters, packings, and insulation (Rosato, 1959; Berger, 1963).

Briefly, then, asbestos fibers of several kinds can be expected to occur in natural waters flowing through rock formations containing asbestos. Additions to the asbestos load of the water can occur from industrial discharges, and from roads, domestic and commercial solid waste, and construction and demolition sites--via runoff, rain, and snow.

#### HEALTH EFFECTS OF ASBESTOS

It is not the purpose of this report to review in detail the health-effects literature on asbestos--extensive reviews on this subject are available (Zielhuis, 1977; Bogovski et al., 1973; Hammons and Huff, 1974; Natl. Inst. Environ. Health Sci., 1974; Wagner, 1976). However, a brief statement regarding that literature is in order.

#### Occupational Exposure

Asbestos has been known to pose an inhalation health hazard to asbestos workers since 1907. Asbestosis, a fibrous induration of the lungs, was first reported in the United States in 1930 (Hammons and Huff, 1974). Since then, asbestos inhalation has been shown to be a major factor in pleural calcification, pleural plaques, pleural and peritoneal mesotheliomas, lung cancer, and digestive-system cancers (Hammond and Selikoff, 1973). Cancers seem to occur primarily after 20 or more years of occupational exposure (Newhouse and Thompson, 1965). In 1968, extensive studies demonstrated the synergistic effect of cigarette smoking and occupational exposure to asbestos in the development of lung cancer (Selikoff et al., 1968). It was not until 1972, however, that an occupational standard for asbestos in the working environment was established: the 8-hr time-weighted average airborne concentrations of asbestos fibers to which any employee may be exposed shall not exceed 5 fibers, longer than 5  $\mu\text{m}$ , per cubic centimeter of air. In 1976, the standard was revised to 2 fibers, longer than 5  $\mu\text{m}$ , per  $\text{cm}^3$  of air (see Appendix A). This standard is intended to protect workers from asbestosis, but there are arguments that suggest the standard is inadequate to protect the worker against

other forms of asbestos-related disease, e.g., lung cancer (Zielhuis, 1977; Bruckman and Rubino, 1975).

### Non-Occupational Exposure

Airborne asbestos is not confined to the working environment. Due partly to the multitude of uses to which man has put these versatile fibers, they are virtually ubiquitous. Ambient concentrations of asbestos in air at specified sites, as reported in the literature, are presented in Table 1. Of related importance are two studies that reported the occurrence of "asbestos bodies" in the lungs of urban dwellers without occupational exposure to asbestos (Thompson and Graves, 1966; Selikoff et al., 1967). In 1970, the EPA established a national emission standard for asbestos (no visible emissions [see Appendix A]), but there is as yet no national ambient air-quality standard. Such a standard has been proposed, i.e., 30 nanograms per  $m^3$ , based on mesothelioma data (Bruckman and Rubino, 1975), but has been criticized as possibly being unreasonably low or perhaps even too high (Plumlee, 1975; Kantz, 1976).

Table 1. Asbestos in Ambient Air

Site or Area	Asbestos Mineral Type	Concentration*	Reference
Los Angeles, Calif.:			
Freeways (upwind)	Chrysotile	0 - 100 fibers/liter <sup>†</sup>	Murchio et al. (1973)
Freeways (upwind)	Amphibole	0 - 9 fibers/liter	Murchio et al. (1973)
San Francisco Bay Area, Calif.	Chrysotile	1 - 46 fibers/liter	Murchio et al. (1973)
Lancashire, England, near a large asbestos textile factory	Chrysotile	< 0.1 $\mu g/m^3$	Rickards and Badami (1971)
Inside a Yale Univ. building during removal of asbestos-containing material:			Sawyer (1977)
Dry demolition	Chrysotile	> 100 fibers/cm <sup>3</sup> (longer than 5 $\mu m$ )	
Wet demolition	Chrysotile	1.2 fibers/cm <sup>3</sup> (longer than 5 $\mu m$ )	
City of New Haven, Conn.	Not specified	12 fibers/cm <sup>3</sup> (longer than 5 $\mu m$ )	Sawyer (1977)
Urban (unspecified)	Not specified	0.5 - 15 ng/m <sup>3</sup>	Rohl et al. (1977)
Non-urban (unspecified)	Not specified	0.1 ng/m <sup>3</sup>	Rohl et al. (1977)
49 U.S. cities:			Rohl et al. (1977); Nicholson and Pundsack (1973)
1969 mean	Chrysotile	4.3 ng/m <sup>3</sup>	
1970 mean	Chrysotile	2.1 ng/m <sup>3</sup>	
Rockville, Md., in the vicinity of roads surfaced with quarried serpentinite	Chrysotile	500 - 4700 ng/m <sup>3</sup> (fibers longer than 5 $\mu m$ )	Rohl et al. (1977)
Vicinity of Grace Iron Mine, Pa. (0.5 - 2 mi [0.8 - 3.2 km])	Unspecified**	0.006 - 0.010 $\mu g/m^3$	Kuryvial et al. (1974)
Vicinity of Charman Roofing Plant, Pa.	Unspecified	0.0002 - 0.0012 $\mu g/m^3$	Kuryvial et al. (1974)
New York City	Chrysotile	8 - 30 ng/m <sup>3</sup> (range of averages)	Nicholson and Pundsack (1973)

\*Units of concentration are the same as reported in the reference.

<sup>†</sup>The samples also contained glass and unidentified fibers, 0 - 30 fibers/liter.

\*\*Probably chrysotile and tremolite; the iron ore contained 5% serpentine-tremolite.

Table 2 is a list of asbestos concentrations in surface waters and in a number of municipal water supplies, as reported in the literature. Asbestos concentrations in other environmental samples are listed in Table 3. The health effects of asbestos fibers in food and drink are unknown. The only conclusive evidence for an adverse effect of ingested asbestos is found in asbestos workers among whom an excess of digestive-system cancers occurred (Hammond and Selikoff, 1973); presumably, some inhaled asbestos is swallowed. A role of asbestos-contaminated talc has been proposed in the high incidence of stomach cancer among Japanese who consume rice treated with talc (Merliss, 1971); however, conflicting information--such as the high incidence of stomach cancer in Chile, Finland, and Iceland where large amounts of talc-coated rice are not consumed--suggests that some other factor(s) is also involved in the development of stomach cancer, or that asbestos-contaminated talc is present in other foods in those countries.

Death certificates for all persons who died from cancer in the United States from 1950 to 1969 were examined (Masson et al., 1974). The data extracted were studied to determine if fibers present in the drinking water of the city of Duluth were related to cancer mortality. The authors concluded that no carcinogenic effect was apparent in the 14 years following 1955 (when asbestos-contaminated mine tailings were first dumped into Lake Superior), but cautioned that the period of observation was short compared to the latent period for occupationally induced asbestos carcinogenesis.

Another study of Duluth found that the incidence rates of stomach cancer in males were significantly higher during 1969-1971 in Duluth than in Minneapolis, but cancer of the large intestine was significantly lower in Duluth than in either Minneapolis or St. Paul (Levy et al., 1976).

A study of 22 municipalities in Quebec concluded that no excess cancer mortality could be related to the presence of asbestos fibers in drinking-water supplies (Wigle, 1977).

Again, cancer mortality was examined in relation to occurrence of asbestos deposits in the United States with an attempt to control for a number of other effects; no evidence was found that naturally occurring asbestos deposits result in excess cancer mortalities (Fears, 1976). Fears cautioned, however, that a number of complicating factors should be taken into account, i.e., lack of exposure information, migration within the United States, use of populations as a unit of study, other sources of asbestos, and the presence of other epidemiological features that could modify cancer mortality.

These results must be weighed against conclusive evidence derived from studies of asbestos workers and their households (see review references cited above), coupled with the decades-long induction period for asbestos-related cancers of the lung and digestive system, plus possible synergistic effects of the increasing number of carcinogens identified in air, food, and water. It is obvious that a correct statement regarding the health hazard posed by non-occupational exposure to asbestos cannot presently be made, but it seems equally obvious that such exposure should be kept as low as reasonably possible.

It can also be suggested that perhaps a "threshold" concentration for inhaled or ingested asbestos exists, below which no adverse effects occur.

Table 2. Asbestos in Surface Waters and Public Water Supplies\*

Site or Area	Asbestos Mineral Type	Concentration, fibers/liter <sup>†</sup>	Comments	Reference
Ontario, Canada, water distribution system (22 cities and towns)	Chrysotile	0.093 - 2.13 ng/liter		Kay (1974)
Great Lakes-St. Lawrence River area, including filtered municipal water (1974 data)	Chrysotile, amphiboles	$1.7 \times 10^6$ (average) $10 \times 10^6$ (highest)		Gr. Lakes Res. Advis. Board (1975)
N. Ontario mining and milling area at Timmins (1974 data):	Chrysotile			Gr. Lakes Res. Advis. Board (1975)
Untreated water		$1.8 \times 10^6$		
Treated water		$0.26 \times 10^6$		
Lake Erie at Leamington:	Not specified			Gr. Lakes Res. Advis. Board (1975)
Untreated water		$2.2 \times 10^6$ - $5.2 \times 10^6$		
Treated water		$0.96 \times 10^6$		
Ashland, Wis., groundwater	-	N.D.	Lower limit of detection was $4 \times 10^4$ fibers/liter	Cooper and Murchio (1974)
Toronto municipal water supply	Not specified	$0.7 \times 10^6$ - $4 \times 10^6$		Kay (1974)
Quebec tap water	Chrysotile	$2.9 \times 10^6$ - $172.7 \times 10^6$		Cunningham and Pontefract (1973)
Five rivers in Ontario, Canada (1973-74 samples)	Chrysotile	$1.8 \times 10^6$ (mean)		Gr. Lakes Res. Advis. Board (1975)
California	Chrysotile	N.D. - $200 \times 10^6$	High fiber counts occurred in water from lakes in serpentine area; no fibers detected in groundwater sources or in coagulated, filtered water	Cooper and Murchio (1974)
Houston, Tex., groundwater supplies	-	N.D.		Cooper and Murchio (1974)
Lake Superior and Duluth water system	Amphiboles	$1 \times 10^6$ - $10 \times 10^6$	The higher counts occurred in water not coagulated or filtered	Cooper and Murchio (1974)
Lake Superior at Duluth (1973-74 samples)	Amphiboles	$44 \times 10^6$ (average) (190 $\mu\text{g/liter}$ )		Gr. Lakes Res. Advis. Board (1975)



Table 2. Continued

Site or Area	Asbestos Mineral Type	Concentration, fibers/liter <sup>†</sup>	Comments	Reference
Duluth, Minn.	Amphiboles	$1 \times 10^6 - 30 \times 10^6$ (1 - 30 $\mu\text{g/liter}$ )	Occasional peak concentrations up to $10^3$ fibers/liter were suggested	Cook et al. (1974)
Duluth water system	Amphiboles	$20 \times 10^6 - 75 \times 10^6$ (5 - 30 $\mu\text{g/liter}$ )	50-60% cummingtonite-grunerite; 20% actinolite-tremolite	Nicholson (1974)
Lake Superior	Mainly chrysotile	$< 0.1 \times 10^6 - 87.3 \times 10^6$	Cummingtonite present at western arm of lake	Gr. Lakes Res. Advis. Board (1975)
Detroit River at Windsor:	Not specified			Kay (1974)
Raw water		$18 \times 10^6 - 25 \times 10^6$		
Filtered water		$1.7 \times 10^6 - 1.8 \times 10^6$		
Lake Michigan, southwest end:	80% chrysotile			McMillan et al. (1977)
Raw water (yearly average)		$1.8 \times 10^6$	Peak concentrations ( $3 \times 10^6 - 4 \times 10^6$ fibers/liter) in raw water occur from November to April	
Filtered water (yearly average)		$0.23 \times 10^6$		
Vermont (30 water-supply systems using asbestos cement pipe)	Not determined	$< 1 \times 10^3 - 164 \times 10^3$	Analyses performed using optical microscopy	Sargent (1974)
Juniata River, Pa.	Chrysotile	0 - 15 $\mu\text{g/gal}$ (0 - 4 $\mu\text{g/L}$ )		Nicholson and Pundsack (1973)
Connecticut River	Chrysotile	0 - 23 $\mu\text{g/gal}$ (0 - 6 $\mu\text{g/L}$ )		Nicholson and Pundsack (1973); Speil (1974)

\*Unless otherwise specified, transmission electron microscopy was employed in the analyses.

<sup>†</sup>Units of concentration are the same as reported in the reference and are fibers/liter unless otherwise specified.

N.D. = none detected.

Table 3. Asbestos in Miscellaneous Environmental Samples

Sample	Asbestos Mineral Type	Concentration*	Reference
Beer, wine, and soft drinks from several countries	Chrysotile	$1.1 \times 10^6 - 12.2 \times 10^6$ fibers/liter	Cunningham and Pontefract (1973)
Wine from France	Chrysotile	$2 \times 10^6 - 64 \times 10^6$ fibers/liter	Bignon et al. (1977)
Parenteral drugs	Chrysotile	0 - 1 $\mu$ g/dose	Maggiore (1974)
Melted snow in Ottawa, Canada (top 30 cm from 2-3 weeks precipitation)	Chrysotile	$33.5 \times 10^6$ fibers/liter	Cunningham and Pontefract (1973)
Talc-coated rice	Not specified <sup>†</sup>	$3.7 \times 10^6$ fibers/gram	Merliss (1971)
Soil from Rhodope Mountains in Bulgaria: Asbestosis endemic	Anthophyllite, tremolite, sepiolite	Present**	Burilkov and Michailova (1970)
Asbestosis not endemic		None detected	

\*Units of concentration are as reported in the references.

<sup>†</sup>Optical microscopy employed in the analysis.

\*\*Percent fibrous minerals in the respective size traction of the soil samples were: 5% in the 1-5  $\mu$ m fraction, 5% in the 6-10  $\mu$ m fraction, 21% in the 11-50  $\mu$ m fraction, and 25% in the 51-100  $\mu$ m fraction.

Schneidermann has addressed the question of such a threshold using human data that indicate a dose-response relationship between industrial exposure to asbestos and later development of cancer of the bronchus and lung and of the digestive tract. He concluded that the data "did not provide much evidence for a threshold or for the existence of a clearly safe level of exposure" (Schneidermann, 1974).

On the other hand, in reference to inhaled asbestos, a National Academy of Sciences study (cited by the Gr. Lakes Res. Advis. Board, 1975) concluded that "there are levels of asbestos exposure that will not be associated with any detectable risk. What those levels are is not known, but there is no evidence that persons in the general population--without occupational, household, or neighborhood exposures--have any risk of neoplasm, even though there may be ferruginous[\*] bodies of fibers in their lungs." Fiber mineral type, fiber length, fiber-associated chemicals, and environmental variables may be important factors in the existence of a threshold.

#### Theories for Pathogenicity of Asbestos

Theories on the cause of adverse health effects from inhaled and ingested asbestos invoke the physical and/or chemical nature of the material. Some of these properties are discussed here in relation to health effects.

Asbestos, as the word implies, is a fibrous material. Non-fibrous forms of serpentine and amphibole exist, but it is believed that only the fibrous forms pose a hazard to human health. Chrysotile fibers consist of bundles of fibrils (for example, 1 chrysotile fiber of 1  $\mu$ m diameter can yield 1000 fibrils of the same length in lung liquids [Murphy, 1971; Gr. Lakes Res.

\*Iron-containing protein and apatite deposited upon and around inhaled or injected particles of microscopic dimensions (Davis and Gross, 1973).

Advis. Board, 1975]). The literature is inconsistent with regard to the use of the terms "fiber" and "fibril," and the two are often used interchangeably. Individual fibrils can be detected only by electron microscopy; for these reasons, the term "fiber" will be used in this report to denote either fiber or fibril.

Zielhuis (1977) has reviewed the information regarding pathogenicity in relation to type of asbestos. Asbestosis can develop after exposure to the four major types (crocidolite, amosite, chrysotile, and anthophyllite); the incidence of mesothelioma, however, appears to be related to fiber type in the order crocidolite > amosite > chrysotile > anthophyllite. The differences in pathogenicity seem to be due more to the physical sizes of the fiber types than to their chemical differences. Information on the physical and chemical properties of asbestos mineral types can be found in Hendry (1965), Great Lakes Research Advisory Board (1975), Zielhuis (1977), Gaze (1965), and Harington (1965). It is interesting to note that rats injected intrapleurally with non-asbestos material, such as glass fibers and aluminum silicate, developed mesotheliomas (Stanton, 1973; Timbrell, 1973).

One theory suggests that the pathogenicity of asbestos is related to the polyfilamentous nature of the fibers (Gross and Harley, 1973; Timbrell, 1973); others suggest that trace metals and/or polycyclic aromatic hydrocarbons associated with the fibers cause the pathogenicity (Roy-Chowdhury et al., 1973; Harington, 1973). A recent report suggests that the principal factor in hemolysis by asbestos is the surface charge on the fiber (Light and Wei, 1977). The work by Selikoff on the synergistic effect of cigarette smoking (Hammond and Selikoff, 1973) suggests that factors external to the fiber may be involved in the development of asbestos-related disease.

### Summary

In summary, it has been clearly demonstrated that *occupational exposure* to asbestos can result in a number of diseases, including lung and digestive system cancer. It has not been conclusively demonstrated that inhalation or ingestion of asbestos in quantities currently known to be present in the non-working environment pose a health hazard. It will be difficult to demonstrate such a health hazard without intensive and extensive epidemiological studies, due to the multitude of factors that may influence the pathogenicity of asbestos fibers as well as individual susceptibility to an asbestos-related disease.

## METHODS

This section describes the collection of cooling-tower industry data, selection of sampling sites, methods of sampling, and analysis for asbestos in the collected water samples.

### COLLECTION OF INDUSTRY DATA

Questionnaires (see Appendix B) were sent to 19 cooling-tower suppliers and vendors, requesting information on the use and sources of asbestos materials in cooling towers, operating experience regarding erosion or breakage of fill, and a list of at least five locations where their cooling towers were in

operation. The information received from the industry ranged from *very good\** (i.e., included laboratory and field data, and/or other detailed information) to *fair* (sales brochures only) to *none*. A number of responses were verbal (telephone replies), due to an understandable suspicion regarding the motives of the project and the use to which the information would be put.\*\* The companies which responded to the questionnaire are listed in the Acknowledgments.

As responses were received, sampling sites were selected, with the aim of including both natural- and mechanical-draft cooling towers, a range of tower ages, geological variation (i.e., to include areas of expected high and low ambient asbestos), and climatic differences. Where possible, larger size towers were selected.

Letters were then sent to the selected sites requesting permission to obtain water samples. The letters were usually preceded by telephone calls to explain the nature of the project and to determine the person in authority to whom the letter was to be addressed. Responses ranged from refusal to full cooperation. Reluctance to allow sampling was evident; in most cases, the reluctance seemed to stem more from the possible end use of the data than from any fear that hazardous amounts of asbestos were being discharged. Final sampling-site selection was based, therefore, primarily on accessibility.

The agencies and electric utility companies that cooperated in this study either provided water samples as directed or allowed access to their sites. They also provided information on operational experiences, water-quality data, and cooling-tower design details. These companies are listed in the Acknowledgments.

#### COLLECTION OF WATER SAMPLES

Single, duplicate, or triplicate water samples (500-1000 ml each) were obtained from several locations at each selected cooling-tower site. Due to design differences among the sites, sampling locations varied from site to site; in general, samples were obtained at the locations defined as follows:

*Makeup* - Water entering the cooling towers to replace evaporative and other losses. Water sources included rivers, creeks, municipal water, reservoirs, lakes, and groundwater.

*Blowdown* - Water discharged from the cooling towers into natural surface waters. Where a settling pond was sited between the cooling towers and the natural waterway, samples were usually taken only from the pond effluent to the waterway.

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\*The information supplied by the Munters Corporation, Research-Cottrell, Ceramic Cooling Tower Company, and Johns-Manville Corporation was especially detailed.

\*\*Digression from a purely technical discussion is included for the benefit of those who will attempt similar studies in the future, and to point out the need to establish a more open relationship among regulatory agencies, the industry, and the public.

*Basin* - Water in the basin of the cooling tower, or in a flume or pond combining water from the basins of more than one tower.

*Other* - Water taken from locations other than those specified above.

Sampling consisted of one of the following:

1. Submerging a rinsed polyethylene or glass bottle in the water and withdrawing it when full.
2. Submerging a plastic bucket into the water, and transferring one portion into a rinsed polyethylene bottle (procedure was repeated for each replicate).
3. Withdrawing the water from a valve in the pump house or other sampling line into a rinsed, polyethylene bottle.

The bottles were capped, packed in boxes, and returned to the laboratory for filtration and analysis.

Natural-draft towers at 12 sites and mechanical-draft towers at 7 sites were included in the sampling program. The sites are listed in Table 4. Due to the sensitive nature of the subject, specific sites are not identified in this report.

Table 4. Cooling-Tower Sampling Sites

Site No.	General Location	Type of Tower*	Cooling-Tower Blowdown to
1	Central Pennsylvania	Natural-draft	Off-site creek
2	Central Pennsylvania	Natural-draft	Ash-settling pond
3	Central Pennsylvania	Natural-draft	On-site lagoon
4	West central Pennsylvania	Natural-draft	Off-site river
5	Long Island	Mechanical-draft	On-site sewage system
6	West central Pennsylvania	Natural-draft	Off-site river
7	Near Harrisburg, Pa.	Natural- and mechanical-draft	Off-site river
8	Near Toledo, Ohio	Natural-draft	Off-site lake
9	Maryland, west of the intracoastal waterway	Natural-draft	Off-site river
10	Northwestern Indiana	Natural-draft	Off-site lake
11	North of Harrisburg, Pa.	Natural-draft	Ash-settling basin
12	Near Pennsylvania/New Jersey border	Natural-draft	On-site pond
13	South central Ohio	Mechanical-draft	Off-site river
14	Western Kentucky	Mechanical-draft	Off-site river
15	Southeast of Sacramento, Calif.	Natural-draft	Off-site creek
16	South central Pennsylvania	Mechanical-draft	On-site ponds
17	Germantown, Md.	Mechanical-draft	Storm drain
18	McLean, Va.	Mechanical-draft	Storm drain

\*All towers except one have asbestos fill; the tower at Site 16 contains plastic fill, but has asbestos louvers.

## SAMPLE PREPARATION AND ANALYSIS

Enumeration and identification of asbestos fibers can be achieved using a number of methods, including optical microscopy, infrared spectroscopy, differential thermal analysis, x-ray diffraction, electron microscopy and electron diffraction, and electron microprobe analysis. Reviews of methods can be found in Great Lakes Research Advisory Board (1975), Zielhuis (1977), and Champness et al. (1976). Choice of a method will depend on the concentration of fiber expected in the sample, purity of the sample, and fiber mineral type, among other factors. For example, optical microscopy (dispersion staining) is useful for quantification of bulk asbestos fibers, but individual chrysotile fibrils can be detected only by electron microscopy. This plus the fact that concentrations of asbestos in environmental samples are usually low (microgram amounts) dictate the use of electron microscopy. A combination of transmission electron microscopy, selected-area electron diffraction (SAED), and energy-dispersive x-ray analysis (EDXRA), provide fiber quantification and identification through morphological, crystallographic, and chemical analysis. These were the methods used to enumerate and identify asbestos fibers in the samples collected during this study.\* Treatment of the samples is described below.

### Water

A 200-ml aliquot of the sample was filtered onto a 0.45  $\mu\text{m}$  pore-size membrane filter. Sections of the filter, approximately 2-3 mm square, were placed facedown on previously carbon-coated electron-microscope grids, and the membrane filter was dissolved using acetone in a Soxhlet extractor. The sample grids were examined on the electron microscope (EMMA 4)\*\* using a magnification such that the intermediate lens aperture was in focus in the specimen plane. When a fiber was located, the aperture was inserted and the instrument switched to the diffraction position, to obtain a selected-area electron-diffraction pattern of the fiber. The length and width of each asbestos fiber was recorded. Interpolation from intervals scribed on the screen allows an accuracy of measurement on the screen of approximately 0.05 cm. This corresponds to an accuracy in size measurement of about 0.02-0.03  $\mu\text{m}$ .

Measurements of the individual fibers were computer processed to give listings of length and width of fibers, together with the mass of each fiber computed on the basis of density, D, and dimensions, L and W (mass =  $D \times L \times W^2$ ). A value of 2.3 was used for the density of chrysotile, and 3.4 for the density of grunerite amphibole fibers. The computer program automatically assigns the longest dimension to the fiber length and excludes all fibers with an aspect ratio (ratio of length to width) below three. The computer printout included the calculated number of fibers per unit volume, the calculated mass of fiber per unit volume, the size distribution of the fibers (based on length, width, and aspect ratio), together with relevant statistical information on these parameters. Normally, either 40 or 80 grid

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\*Sample analysis was performed by Walter C. McCrone Associates, 2820 S. Michigan Ave., Chicago, Illinois 60616.

\*\*Combined 100 kv Transmission Electron Microscope-Microprobe Analyzer manufactured by Associated Electrical Industries.

squares were counted, and the lower limit of detection (LLD) for any sample calculated as follows:

$$LLD = \frac{\pi (R_e)^2 (1000)}{N A_g V}$$

where  $R_e$  is the effective radius of the filter in  $\mu\text{m}$ ,  $N$  is the number of grid squares counted,  $A_g$  is the area of one grid square in  $\mu\text{m}^2$ , and  $V$  is the volume of sample filtered in ml. For all cases in this report,  $R_e = 17.5 \times 10^3 \mu\text{m}$ , and  $A_g = 1914 \mu\text{m}^2$ .

### Sediments

A number of the water samples contained appreciable amounts of sediments. The settled material was treated as follows:

1. An aliquot of each sample was pipetted out and allowed to air dry under gentle heating in a clean bench.
2. A portion of each dried sediment was placed in a clean preweighed vial and its weight determined.
3. The samples were then subjected to low-temperature ashing to remove organic films and other such material that might hinder analysis.
4. Finally, in a clean-room environment, the samples were dispersed in particle-free water and filtered onto membrane filters for normal sample preparation.

Aliquots of the settled material were also examined for bulk fibers using optical microscopy (dispersion staining).

## RESULTS AND DISCUSSION

This section discusses the information obtained from industry and results of the water sampling program.

### ASBESTOS FILL IN COOLING TOWERS

The function of a wet cooling tower is to dissipate heat from water; this is accomplished by exposing as much of the water surface to air as possible, either by creating drops (splash-type fill) or thin films (film-type fill). The splash-type fill consists of several decks of material; the water splashes downward with the air moving either horizontally (cross-flow type) or vertically (counter-flow type). As the water repeatedly splashes onto the individual bars, it breaks up into droplets. Splash-type fill can be made of wood, plastic, asbestos-cement bars, steel, aluminum, or ceramic tile (Marley Co., 1969). The film-type fill spreads the water over large areas in a thin film, thus exposing it to the air. Film-type fill can consist of asbestos paper, polyvinyl or polypropylene plastics, cellulose, aluminum, steel, and asbestos-cement sheets (flat or corrugated). The description that follows includes only asbestos-containing material.

### Film-type Asbestos Fill

Film-type fill can be made from asbestos paper or consist of asbestos-cement sheets. The paper type is manufactured by Munters Corporation (Figure 4) and Baltimore Air Coil. The Munters fill (trade name ASBESdek) is made from asbestos paper prepared by Nicolet Industries in Ambler, Pa. The asbestos is obtained by Nicolet from two sources in Quebec, Canada, and consists of a blend of 2 grades of chrysotile. The paper is a 19-mil (0.5 mm)\* grade in which the asbestos is bound with 9% DuPont neoprene latex.

The Munters operation consists of impregnating the paper with about 20% of a saturant formulated on a chlorinated rubber base. The fluted sheets are bonded together with neoprene latex to form packs, the edges of which are reinforced with 3/4-in. (2-cm) deep neoprene (Trademark TUFedg). The suitable operating range for continuous operation is pH 5 to 11 and a maximum temperature of 180°F (82.2°C) (Skold, 1976--personal communication). The maximum size of individual packs is 12 × 12 × 72 in. (30 × 30 × 183 cm). Munters asbestos-type drift eliminators are made of two 2-in. (5-cm) thick layers of cross-corrugated 19-mil (0.5 mm) asbestos paper containing DuPont neoprene impregnated with chlorinated rubber (Trademark Hercules PARLON). The two layers are glued together cross-wise with neoprene and then coated about 1/8 in. (0.3 cm) deep on both top and bottom. Stiffener bars, made of polyvinyl chloride (PVC), are placed on 12 in. (30 cm) centers. A standard size is 4 × 24 × 60 in. (10 × 61 × 152 cm). Munters fill is used mainly in mechanical-draft towers, either cross-flow or counterflow.

Baltimore Air Coil manufactures asbestos fill (MNA) for use mainly in air conditioning of buildings, machinery, and computers. The fill is made from asbestos paper bound with neoprene latex, purchased from Nicolet, and consists of 90% chrysotile and 10% binder. Baltimore Air Coil treats the paper with a thermosetting resin (Melamine). The resin tends to hydrolyze below about pH 5 (Honchar, 1976--personal communication).

Asbestos-cement sheets for film-type fill (Figure 5) are manufactured by Johns-Manville Corporation, GAF, and National Gypsum. These sheets have the same composition as the splash-type, and are described below.

### Splash-type Asbestos Fill

Splash-type asbestos fill is manufactured mainly by Johns-Manville, GAF, and National Gypsum. The fill consists of 1/8- to 1/4-in. (0.3- to 0.6-cm) thick flat or corrugated asbestos-cement bars or boards (Figure 6). The asbestos is 100% chrysotile, obtained from Johns-Manville in Canada. Air-cured asbestos-cement board contains about 20% asbestos fiber and 80% portland cement; steam-cured asbestos-cement board consists of 20% asbestos fiber, 54% portland cement, and 16% powdered silica. The figure of 20% asbestos fiber is a rounded maximum number--actual percentages appear to range from 10 to 16%. Additional fillers may be silica or dolomite. The asbestos fibers in this type of fill function as "reinforcing," to bind the cement in place and increase its tensile strength.

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\*In this report, conversions to metric units have been rounded to the nearest tenth or unit.



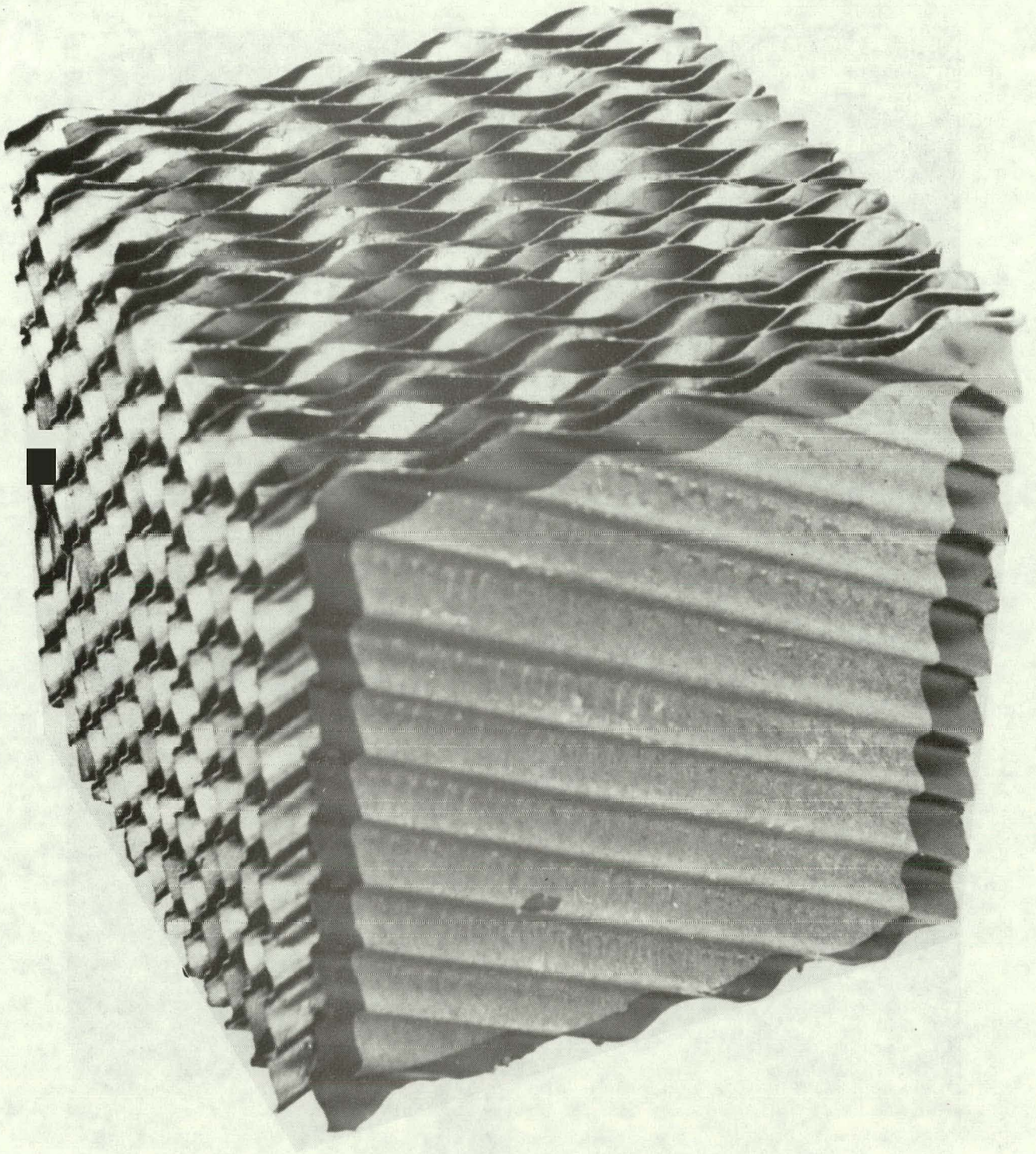


Fig. 4. Cooling-Tower Fill (ASBESdek) Manufactured by Munters Corporation. Photo courtesy of Munters Corporation.



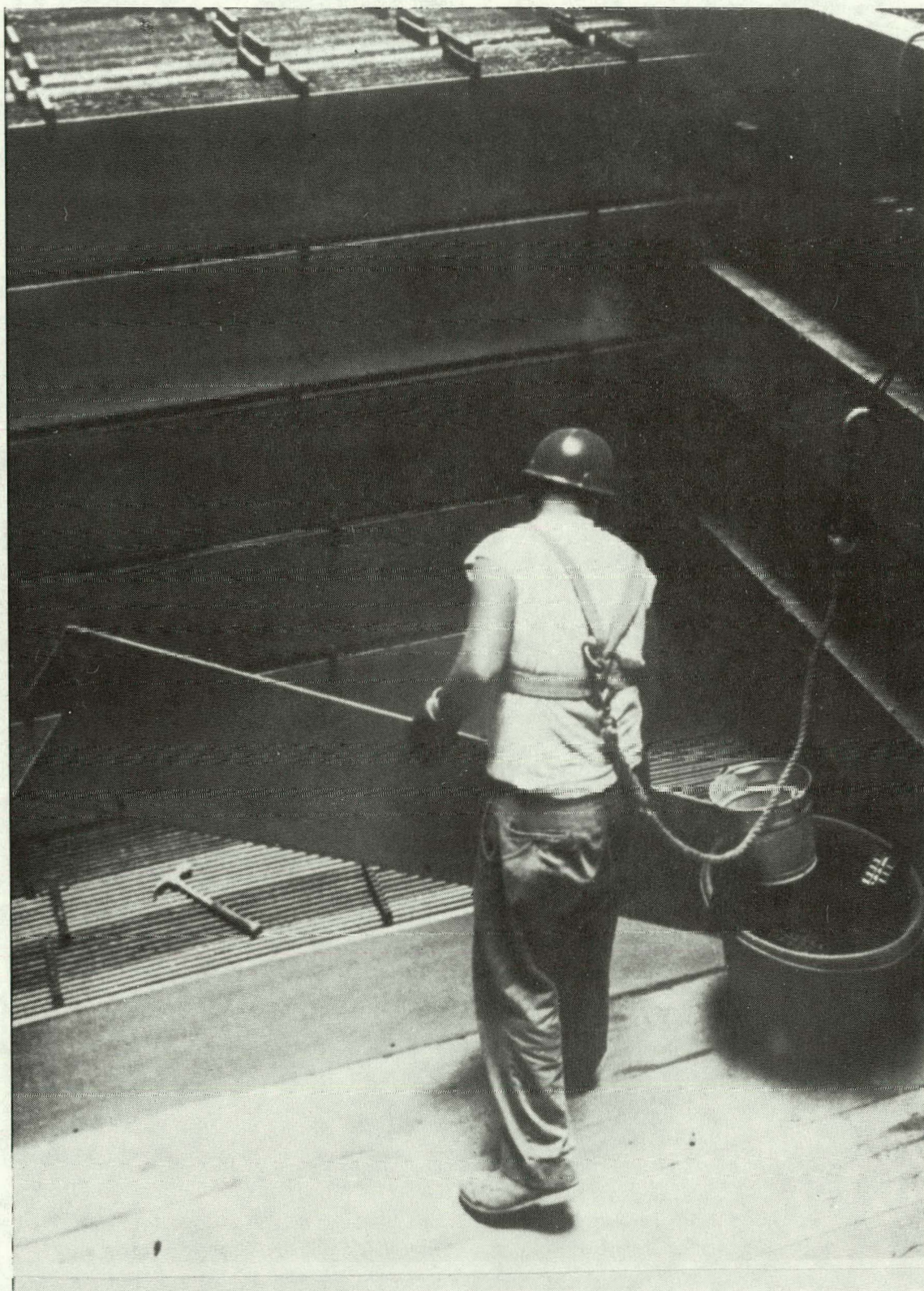


Fig. 5. Asbestos-Cement Sheets for Film-type Cooling-Tower Fill. Photo from Research-Cottrell brochure, "Natural Draft Cooling Towers," with permission of Research-Cottrell, Hamon Cooling Tower Division.





Fig. 6. Corrugated Asbestos-Cement Bars for Splash-type Cooling-Tower Fill. Photo reprinted from The Marley Cooling Tower Company brochure "Round Towers," with permission of The Marley Cooling Tower Company.

The quantity of asbestos fill in a given tower will depend on design considerations. The asbestos paper-type fill weighs between 3 to 5 lb/ft<sup>3</sup> (48 to 80 kg/m<sup>3</sup>), with asbestos comprising about 63% of the total weight. At one installation, 120,000 ft<sup>3</sup> (3,398 m<sup>3</sup>) of paper-type fill was required. The asbestos-cement bars in a single large cooling tower can weigh on the order of 500 metric tons, of which 10-16% by weight is asbestos.

#### ASBESTOS IN COOLING-TOWER WATERS

Surface waters and groundwaters analyzed for content of asbestos fibers during the course of this study are listed in Table 5. No asbestos was found above detection limits in any of the surface-water samples. Samples of well water collected from two sites contained asbestos fibers slightly above detection limits. The asbestos was identified as an amphibole at the Ohio site and as chrysotile at the New York site.

With three exceptions, the waters listed in Table 5 serve as sources of makeup to operating cooling towers. The exceptions (Stanislaus, Trinity, and Verdigris rivers) are relatively large rivers that may eventually serve as cooling-water sources. The Stanislaus River is of particular interest due to the fact that chrysotile asbestos mining occurs in one county (Calaveras) through which the river flows. Samples were taken several miles upstream and downstream of an operating asbestos mine. (It may be of interest to note that tailings from this asbestos mine may eventually be used in a dam now under construction in the vicinity of the mine.)

Data on the asbestos fiber concentrations in cooling-tower water samples collected during this study are listed in Table 6. Individual sample data are listed to indicate the order of variation among the samples. The precision of asbestos analysis using electron microscopy is discussed by Hallenbeck et al. (1977). The errors in such analyses are large, due to the large multiplication



Table 5. Surface Waters and Groundwaters Analyzed for Asbestos

Sampling Location	Date	No. of Samples	Asbestos, fibers/liter	
			Amount Detected	Lower Limit of Detection
Stanislaus River in Calaveras County, Calif.	Jun 1977	6	None	$6.3 \times 10^4$
Trinity River near Douglas, Calif.	Jun 1977	8	None	$6.3 \times 10^4$
Verdigris River near Inola, Okla.	Aug 1977	6	None	$3.14 \times 10^5$
Conemaugh River in central Pennsylvania	May 1977	3	None	$6.3 \times 10^4$
Ohio River in west central Pennsylvania	May 1977	7	None	$6.3 \times 10^4 - 1.57 \times 10^5$
Ohio River in western Kentucky	1976	1	None	$1.2 \times 10^5$
Scioto River in south central Ohio	1976	2	None	$4.7 \times 10^5$
Folsom South Canal, south-east of Sacramento, Calif.	Jun 1977	3	None	$6.3 \times 10^4$
Reservoir near Clay, Calif.	Jun 1977	2	None	$6.3 \times 10^4$
Delaware River near Easton, Pa.	Aug 1977	3	None	$0.6 \times 10^5 - 2.3 \times 10^5$
Two-Lick Creek at Homer City, Pa.	May 1977	3	None	$6.3 \times 10^4$
Crooked Creek at Shelocta, Pa.	May 1977	3	None	$8.4 \times 10^4$
Susquehanna River near Harrisburg, Pa.	Jul 1976, Aug 1977, Sep 1977	7	None	$6.3 \times 10^4 - 6.3 \times 10^5$
West Branch Susquehanna River, north of Harrisburg, Pa.	Aug 1977	3	None	$2.3 \times 10^4 - 2.9 \times 10^4$
Lake Michigan in north-western Indiana	Aug 1976	3	None	$4.2 \times 10^5 - 6.3 \times 10^5$
Lake Erie near Toledo, Ohio	Aug 1976	2	None	$1 \times 10^5$
Swanson's Creek in Maryland*		3	None	$1.88 \times 10^6$
Well water (softened) in south central Ohio	Feb 1976	2	$1.4 \times 10^5$ (amphibole)	$4.7 \times 10^4$
Well water (raw) in Long Island	May 1976	1	$5 \times 10^5$ (chrysotile)	$1.2 \times 10^5$

\*The lower limit of detection was relatively high due to the high concentration of salts in the (brackish) water.

factors involved in extrapolating from an area measured in square micrometers to a 1-liter bulk sample size. However, as pointed out above, only electron microscopy can detect individual chrysotile fibrils at concentrations found in most ambient waters.

As seen in Table 6, cooling-tower water at 10 of the 18 sites contained detectable concentrations of chrysotile asbestos at the time of sampling. Most of the samples containing detectable chrysotile were taken from cooling-tower basins or blowdown rather than from the makeup water, indicating that the sources of the chrysotile were the respective cooling towers. One exception was Site No. 17 (see Fig. 7a, b, c), which had an extremely high number of chrysotile fibers in the makeup water coming from the city water supply (Gaithersburg, Md.). Subsequent resampling and analysis of the makeup water, however, found no detectable chrysotile. This result suggests either that the first samples were inadvertently contaminated (despite careful attention to prevent contamination), or that "slugs" of asbestos fibers may occasionally be present in the water supply, either from dislodging of fibers from asbestos distribution pipes or due to the presence of asbestos in the original water source (Potomac River). Further study of the Gaithersburg city water supply is suggested, particularly in view of a report indicating that runoff from roads paved with serpentine rock in Maryland may contribute to the asbestos load of surface waters in that state (Rohl et al., 1977).

The absence of detectable chrysotile in the basin or blowdown water samples from Site No. 17 suggests that the fibers may be settling out of the water into the basin sediment. (Chrysotile in sediments is discussed further, below.) Alternatively, the sampling procedure did not "catch" the occasional slug of asbestos that may have been present in blowdown.

Table 6 indicates an important point: where a settling pond or lagoon is interposed between the cooling towers and the off-site receiving water (Site Nos. 3, 11, and 12), no asbestos was detected in the effluent to the receiving water, despite its presence in the cooling-tower waters. In relatively clean water, settling of the tiny chrysotile fibers (or fibrils) is unlikely; the presence of fly ash, iron hydroxides, or other constituents of settling ponds may act to collect the fibrils via the electric charges on the fibers, or by mechanical entrapment of the fibers by floccules. The 99.8% removal of asbestos in water achieved by treatment with ferric chloride and alum (Lawrence and Zimmerman, 1976) is additional evidence for existence of a flocculating mechanism in settling of asbestos fibers.

Analytical data for the ten sites where asbestos was detected are given in more detail in Table 7. As indicated in the table, chrysotile asbestos was detected in water at mechanical- and natural-draft towers. The chrysotile most likely originated from the asbestos fill, although asbestos distribution pipes, drift eliminators, and incoming air cannot be excluded as sources. At the sites (Nos. 5 and 13) using well water as makeup, the asbestos present was identified as chrysotile and amphibole, respectively. At Site No. 13 where amphibole was detected in the makeup, chrysotile was detected in the basin and riser, indicating a tower source of the chrysotile.

At two of the sites (Nos. 1 and 4), chrysotile asbestos was found in solids suspended in the water. Energy-dispersive x-ray analysis of these

Table 6. Asbestos in Cooling-Tower Waters

Site No.	Sampling Date	Repliates <sup>†</sup>	Asbestos, fibers/liter or $\mu\text{g/g}$ (sed) <sup>1*</sup>								
			Makeup Water		Basin Water		Blowdown		Other		
			Lower Limit of Detection	Conc.	Lower Limit of Detection	Conc.	Lower Limit of Detection	Conc.	Sample	Lower Limit of Detection	Conc.
1	26 May 77	a	$6.3 \times 10^4$	B.D.L.	$8.4 \times 10^4$ sup	B.D.L.	$6.3 \times 10^4$ sup	B.D.L.			
		b	$6.3 \times 10^4$	B.D.L.	$5.2 \times 10^6$ sed	B.D.L.	$6.4 \times 10^6$ sed	B.D.L.			
		c	$6.3 \times 10^4$	B.D.L.	$6.3 \times 10^4$ sup	B.D.L.	$6.3 \times 10^4$ sup	B.D.L.			
2	26 May 77	a	$6.3 \times 10^4$	B.D.L.	$4.8 \times 10^6$ sed	B.D.L.	$6.4 \times 10^6$ sed	B.D.L.			
		b	$6.3 \times 10^4$	B.D.L.	$6.3 \times 10^4$ sup	B.D.L.	$6.3 \times 10^4$ sup	B.D.L.			
		c	$6.3 \times 10^4$	B.D.L.	$83 \times 10^6$ sed	$44 \times 10^8$	$7.5 \times 10^6$ sed	B.D.L.			
3	26 May 77	a	$8.4 \times 10^4$	B.D.L.	$6.3 \times 10^4$ sup	B.D.L.			Settling-pond effluent	$6.3 \times 10^4$ sup	B.D.L.
		b	$8.4 \times 10^4$	B.D.L.	$11 \times 10^6$ sed	B.D.L.			"	$4.9 \times 10^6$ sed	B.D.L.
		c	$8.4 \times 10^4$	B.D.L.	$6.3 \times 10^4$ sup	B.D.L.			"	$6.3 \times 10^4$ sup	B.D.L.
4	25 May 77	a	$8.4 \times 10^4$ sup	B.D.L.	$6.3 \times 10^4$ sup	B.D.L.	$8.7 \times 10^4$	$1.3 \times 10^6$	"	$5.6 \times 10^6$ sed	B.D.L.
		b	$7 \times 10^6$ sed	B.D.L.	$220 \times 10^6$ sed	$130 \times 10^8$			"	$6.3 \times 10^4$ sup	B.D.L.
		c	$8.4 \times 10^4$ sup	B.D.L.	$8.4 \times 10^4$ sup	B.D.L.	$3.4 \times 10^6$	$160 \times 10^6$	"	$5.6 \times 10^6$ sed	B.D.L.
5	13 May 76	a	$8.4 \times 10^4$ sup	B.D.L.	LM sed	$< 0.5\%$			"	$6.3 \times 10^4$ sup	B.D.L.
		b	$7 \times 10^6$ sed	B.D.L.	$8.3 \times 10^4$ sup	$1.9 \times 10^6$	$1.7 \times 10^5$ sup	B.D.L.	"	$4.8 \times 10^6$ sed	B.D.L.
		c	$7 \times 10^6$ sed	B.D.L.	$140 \times 10^6$ sed	$78 \times 10^8$	LM sed	$< 0.5\%$	Sediment from sump	$2.1 \times 10^6$ sed	B.D.L.
6	Oct 76	a	$8.4 \times 10^4$ sup	B.D.L.	$8.4 \times 10^4$ sup	B.D.L.	$8.4 \times 10^4$ sup	B.D.L.	Lagoon effluent:	$8.4 \times 10^4$	B.D.L.
		b	$8.4 \times 10^4$ sup	B.D.L.	$8.4 \times 10^4$ sup	B.D.L.	$8.4 \times 10^4$ sup	$0.92 \times 10^6$	"	$8.4 \times 10^4$	B.D.L.
		c	$8.4 \times 10^4$ sup	B.D.L.	$8.4 \times 10^4$ sup	B.D.L.	$7 \times 10^6$ sed	B.D.L.	"	$8.4 \times 10^4$	B.D.L.
7	6 Jul 76	a	$8.4 \times 10^4$ sup	B.D.L.	$8.4 \times 10^4$ sup	B.D.L.	$2.6 \times 10^6$ sup	$110 \times 10^6$	"	$8.4 \times 10^4$	B.D.L.
		b	$8.4 \times 10^4$ sup	B.D.L.	$8.4 \times 10^4$ sup	B.D.L.	$8.4 \times 10^4$ sup	B.D.L.			
		c	$8.4 \times 10^4$ sup	B.D.L.	$8.4 \times 10^4$ sup	B.D.L.	$8.4 \times 10^4$ sup	B.D.L.			
8	9 Jul 76	a	$8.4 \times 10^4$ sup	B.D.L.	$8.4 \times 10^4$ sup	B.D.L.	$8.4 \times 10^4$ sup	B.D.L.			
		b	$8.4 \times 10^4$ sup	B.D.L.	$8.4 \times 10^4$ sup	B.D.L.	$8.4 \times 10^4$ sup	B.D.L.			
		c	$8.4 \times 10^4$ sup	B.D.L.	$8.4 \times 10^4$ sup	B.D.L.	$8.4 \times 10^4$ sup	B.D.L.			
9	2 Sep 76	a	$8.4 \times 10^4$ sup	B.D.L.	$8.4 \times 10^4$ sup	B.D.L.	$8.4 \times 10^4$ sup	B.D.L.			
		b	$8.4 \times 10^4$ sup	B.D.L.	$8.4 \times 10^4$ sup	B.D.L.	$8.4 \times 10^4$ sup	B.D.L.			
		c	$8.4 \times 10^4$ sup	B.D.L.	$8.4 \times 10^4$ sup	B.D.L.	$8.4 \times 10^4$ sup	B.D.L.			
10	31 Aug 76	a	$8.4 \times 10^4$ sup	B.D.L.	$8.4 \times 10^4$ sup	B.D.L.	$8.4 \times 10^4$ sup	B.D.L.			
		b	$8.4 \times 10^4$ sup	B.D.L.	$8.4 \times 10^4$ sup	B.D.L.	$8.4 \times 10^4$ sup	B.D.L.			
		c	$8.4 \times 10^4$ sup	B.D.L.	$8.4 \times 10^4$ sup	B.D.L.	$8.4 \times 10^4$ sup	B.D.L.			

Table 6. Continued

Site No.	Sampling Date	Replicates <sup>†</sup>	Asbestos, fibers/liter or ug/g (sed)*								
			Makeup Water		Basin Water		Blowdown		Other		
			Lower Limit of Detection	Conc.	Lower Limit of Detection	Conc.	Lower Limit of Detection	Conc.	Sample	Lower Limit of Detection	Conc.
11	15 Aug 77 (1 of 2 towers)	a	$2.3 \times 10^4$	B.D.L.	$6.38 \times 10^6$	$370 \times 10^6$			Settling-basin effluent	$1.8 \times 10^5$	B.D.L.
		b	$2.5 \times 10^4$	B.D.L.	$6.47 \times 10^6$	$330 \times 10^6$			"	$2.5 \times 10^5$	B.D.L.
		c	$2.9 \times 10^4$	B.D.L.					"	$6.3 \times 10^4$	B.D.L.
11	15 Aug 77 (2nd of 2 towers)	a			$2.9 \times 10^5$	B.D.L.					
		b			$2.5 \times 10^5$	B.D.L.					
		c			$6.36 \times 10^6$	$210 \times 10^6$					
12	16 Aug 77 (Unit 3 tower)	a	$6.3 \times 10^4$	B.D.L.	$2.5 \times 10^5$	B.D.L.			Ash-pond effluent	$6.3 \times 10^4$	B.D.L.
		b	$2.3 \times 10^5$	B.D.L.	$1.3 \times 10^5$	B.D.L.			"	$6.3 \times 10^4$	B.D.L.
		c	$1.2 \times 10^5$	B.D.L.	$5.1 \times 10^5$	$24 \times 10^6$			"	$2.8 \times 10^5$	B.D.L.
12	16 Aug 77 (Unit 4 tower)	a			$2.5 \times 10^5$	B.D.L.					
		b			$2.3 \times 10^5$	B.D.L.					
		c			$2.4 \times 10^5$	B.D.L.					
13	17 Feb 76	a	$1.2 \times 10^5$	B.D.L.	$2.5 \times 10^5$	$4.3 \times 10^6$	$4.7 \times 10^5$	B.D.L.	Cooling-tower riser	$2.5 \times 10^5$	$1.5 \times 10^6$
13	28 Apr 76	a	$4.7 \times 10^4$	$1.4 \times 10^5$ (amphibole)	$2.5 \times 10^5$	$2.5 \times 10^6$			"	$2.5 \times 10^5$	B.D.L.
14 <sup>c</sup>	7 May 76	a	$5.9 \times 10^5$ raw	B.D.L.	$1.04 \times 10^6$	B.D.L.	$1.04 \times 10^6$	B.D.L.			
		b	$1.2 \times 10^5$ trtd	B.D.L.			$1.04 \times 10^6$	B.D.L.			
		c					$1.04 \times 10^6$	B.D.L.			
		d					$1.04 \times 10^6$	B.D.L.			
15	20 Jun 77	a	$6.3 \times 10^4$	B.D.L.	$6.3 \times 10^4$	B.D.L.	$6.3 \times 10^4$	B.D.L.	Park reservoir	$6.3 \times 10^4$	B.D.L.
		b	$6.3 \times 10^4$	B.D.L.	$6.3 \times 10^4$	B.D.L.	$6.3 \times 10^4$	B.D.L.	"	$6.3 \times 10^4$	B.D.L.
		c	$6.3 \times 10^4$	B.D.L.	$6.3 \times 10^4$	B.D.L.	$6.3 \times 10^4$	B.D.L.			
16	26 Aug 77	a	$8.4 \times 10^4$ sup	B.D.L.			$6.3 \times 10^4$ sup	B.D.L.	Discharge canal	$6.3 \times 10^4$ sup	B.D.L.
		b	$8.4 \times 10^4$ sup	B.D.L.			$6.3 \times 10^4$ sup	B.D.L.	"	$6.3 \times 10^4$ sup	B.D.L.
		c	$8.4 \times 10^4$ sup	B.D.L.			$6.3 \times 10^4$ sup	B.D.L.	"	$6.3 \times 10^4$ sup LM sed	B.D.L. 0.5% <sup>d</sup>
17	21 May 76	a	$1.2 \times 10^5$	$>> 5 \times 10^6$	$6 \times 10^4$	B.D.L.	$6 \times 10^4$	B.D.L.			
17	Aug 76	a	$1 \times 10^5$	B.D.L.			$1 \times 10^5$	B.D.L.			
		b	$1 \times 10^5$	B.D.L.			$1 \times 10^5$	B.D.L.			
18	21 May 76	a	$1.2 \times 10^5$	B.D.L.	$1.2 \times 10^5$	B.D.L.					

\*Concentrations are listed as fibers/liter for bulk water samples (no postscript). In cases where the bulk samples contained appreciable amounts of suspended solids, the samples were shaken, allowed to stand 4 hours, and the supernatant analyzed by electron microscopy; results are listed in fibers/liter (sup). The sediment was analyzed either by electron microscopy or light microscopy (LM); the results of sediment analysis by electron microscopy are listed as ug/g (sed), and by light microscopy as a percent of the sediment mass by weight. Concentrations (Conc.) below detection limits are indicated by B.D.L. Except as otherwise noted, all asbestos was identified as chrysotile.

<sup>†</sup>Replicates taken at a given sampling date.

<sup>a</sup>Site 7 has four natural-draft towers. For basin-water analyses, two samples were taken from each of the four tower basins. The lower limit of detection ranged from  $6.3 \times 10^4$  to  $3.0 \times 10^5$  for all eight samples.

<sup>b</sup>The lower limit of detection is relatively high due to high salt content in the water.

<sup>c</sup>Blowdown samples are from four separate mechanical-draft towers, one of which contains redwood fill.

<sup>d</sup>Chrysotile was found by light microscopy in the sediment suspended in the bulk water sample. Fibers were 2-5  $\mu$ m in diameter, 60-130  $\mu$ m in length, in small bundles.

Table 7. Concentration and Fiber-Dimension Data for Asbestos in Cooling-Tower Water Samples

Site No.	Type of Tower*	Sample	Fiber Count, <sup>†</sup> fibers/liter	Mass Conc.,** µg/liter	Fiber Length, µm		% Distribution		Largest Group		Aspect Ratios, range
					Minimum	Maximum	<5 µm	≥5 µm	% all fibers	Length µm	
1	NDCT	Basin: sed	44 × 10 <sup>8</sup> f/g	17.3 µg/g	0.0-0.5	6.5-7.0	96.2	3.8	43.4	0.0-0.5	8.0-113
3	NDCT	Blowdown:									
		sup	0.92 × 10 <sup>6</sup>	0.005	1.0-1.5	3.5-4.0	100.0	0.0	36.4	1.5-2.0	10.0-184
		sed	110 × 10 <sup>6</sup>	36.5	0.0-0.5	14.5-15.0	93.0	7.0	39.5	0.0-0.5	4.8-280
4	NDCT	Basin: sed	130 × 10 <sup>8</sup> f/g	92.15 µg/g	0.0-0.5	4.5-5.0	100.0	0.0	50.0	0.0-0.5	4.0-120
		sup	1.9 × 10 <sup>6</sup>	0.03	0.5-1.0	7.0-7.5	91.3	8.7	21.7	3.0-3.5	34-140
		sed	78 × 10 <sup>8</sup> f/g	1498 µg/g	0.0-0.5	45.5-46.0	98.1	1.9	25.9	0.0-0.5	5.2-150
		sed		<0.5% (LM)	20	30					
		Blowdown:	1.3 × 10 <sup>6</sup>	0.009	0.0-0.5	3.0-3.5	100.0	0.0	40.0	0.5-1.5	22-122
		sed	160 × 10 <sup>6</sup>	17.5	1.0-1.5	29.0-29.5	48.9	51.1	12.8	1.0-1.5	48-1440
				<5% (LM)	20	30					
5	MDCT	Makeup	0.5 × 10 <sup>6</sup>	0.12							19-134
9	NDCT	Blowdown	37 × 10 <sup>6</sup>	3.15	0.5-1.0	22.5-23.0	36.4	63.6	18.0	1.0-1.5	7.6-800
11	NDCT	Basin	370 × 10 <sup>6</sup>	5.24	0.0-0.5	30.5-31.0	94.8	5.2	31.0	0.0-0.5	3.5-380
			330 × 10 <sup>6</sup>	31.5	0.0-0.5	43.0-43.5	65.4	34.6	19.2	1.0-1.5	5.3-1700
			210 × 10 <sup>6</sup>	1.53	0.0-0.5	16.5-17	87.9	12.1	24.2	1.0-1.5	8.4-420
12	NDCT	Basin	24 × 10 <sup>6</sup>	0.18	0.0-0.5	5.5-6.0	91.5	8.4	21.3	1.0-1.5	8.5-192
13	MDCT	Makeup	1.4 × 10 <sup>5</sup>	0.034	0.0-0.5	1.0-1.5					8.5-12.6
		Basin	4.3 × 10 <sup>6</sup>	0.242	0.0-0.5	17.0-17.5	88.2	11.8	35.3	0.0-0.5	5.7-215
			2.5 × 10 <sup>6</sup>	0.059	0.0-0.5	6.0-6.5	90.0	10.0	40.0	1.5-2.5	10.0-160
		Riser	1.5 × 10 <sup>6</sup>	0.105	0.0-0.5	11.5-12.0	66.7	33.3	66.7	0.0-1.0	5.7-124
16	MDCT	Discharge Canal: sed		0.5% (LM)	60	130					
17	MDCT	Makeup	>>5 × 10 <sup>6</sup> (too numerous to count)		(Too dense to allow measurement of individual fibers.)						

\*NDCT = Natural-draft cooling towers; MDCT = Mechanical-draft cooling towers.

<sup>†</sup>All counts for bulk water samples (no postscript) and supernatants (sup) are in fibers/liter. Counts in sediments (sed) are in fibers/gram of dry sediment (f/g).

\*\*Concentrations are in micrograms/liter (µg/liter) unless otherwise specified. Concentrations in sediments (sed) are in micrograms/gram of dry sediment (µg/g). The results of sediment analysis by light microscopy (LM) are listed as a percent of the sediment mass by weight.



solids indicated high concentrations of iron, probably iron hydroxides. Examination of sediments in the water at several other sites, using both optical and electron microscopy, yielded negative results except at Site No. 16 where chrysotile was found in a sediment sample from the discharge canal. The cooling towers on Site 16 do not contain asbestos fill, but asbestos-cement louvers are used at some of them. However, construction in progress near the towers may have served as a source of contamination.

Examples of photomicrographs, diffraction patterns, and EDXRA data obtained from cooling-tower water samples containing asbestos are shown in Figures 7, 8, 9, and 10. Other inorganic and organic fibers occasionally found in some of the samples are illustrated in Figures 11, 12, and 13.

#### ASBESTOS-FIBER DIMENSIONS

Fiber-dimension data, aspect ratios, and percent distribution are summarized in Table 7. Statistics of the measurements are summarized in Appendix C. The table indicates that the majority (65-100%) of fibers detected at all but two sites (Nos. 4 and 9) were less than 5  $\mu\text{m}$  in length; none of the fibers were over 46  $\mu\text{m}$  long. Aspect ratios ranged from 3.5 to 1700. This information is of interest in regard to the potential health hazard associated with the presence of these fibers in drinking-water supplies or in ambient air. A number of studies involving inhalation, or intratracheal or intra-abdominal injection, of short (< 5  $\mu\text{m}$ ) asbestos fibers into experimental animals, suggest that these short fibers are incapable of causing fibrosis or cancer (Gross, 1974), compared to long ( $\geq$  5  $\mu\text{m}$ ) fibers. One explanation for this result is that short fibers can be engulfed by macrophages\* and transported away (Harrington, 1974). However, there is little confirmatory evidence for this suggestion, and the subject of short-fiber pathogenicity remains controversial.

#### ASBESTOS-FILL EROSION AND BREAKAGE

If one discounts asbestos in the incoming makeup water and in the ambient air drawn through a cooling tower,\*\* the source of chrysotile in cooling-tower circulating water can reasonably be assumed to derive from asbestos fill, drift eliminators, and/or asbestos pipes for water distribution.

At least three mechanisms for the release of chrysotile from cooling-tower materials into the circulating water can be suggested:

1. Physical breakage of the fill due to alternate freeze-thaw cycles or to the weight of ice during a severe winter.
2. Chemical deterioration due to components in the circulating water, leading to dissolution of the cement and release of asbestos fibers from asbestos-cement board, bars, sheets, or pipes.

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\*Macrophages are large phagocytes, i.e., cells that function in the body to remove and consume debris and foreign bodies.

\*\*See Appendix D for a sample estimate of asbestos in cooling-tower water due to incoming air.







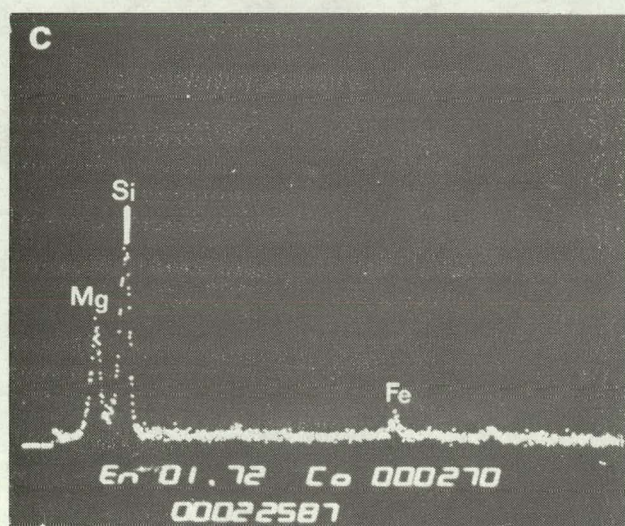
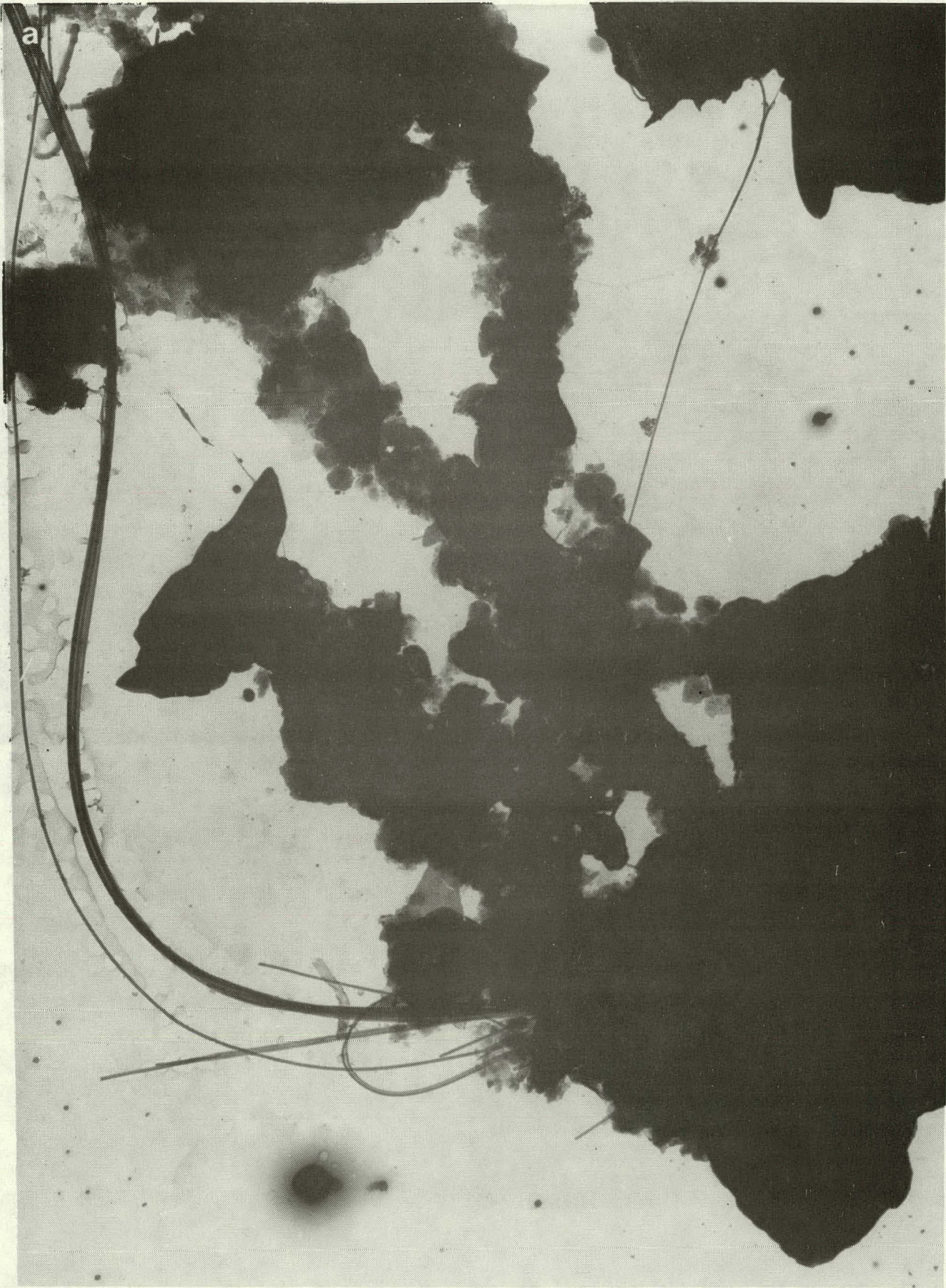


Fig. 7.

Chrysotile-Asbestos Fibers in Makeup Water Collected at Site No. 17. (a) Photomicrograph (30,000 $\times$ ) showing bundles; (b) Electron-diffraction pattern of fibers in Fig. 7a; (c) EDXRA of fibers in Fig. 7a.







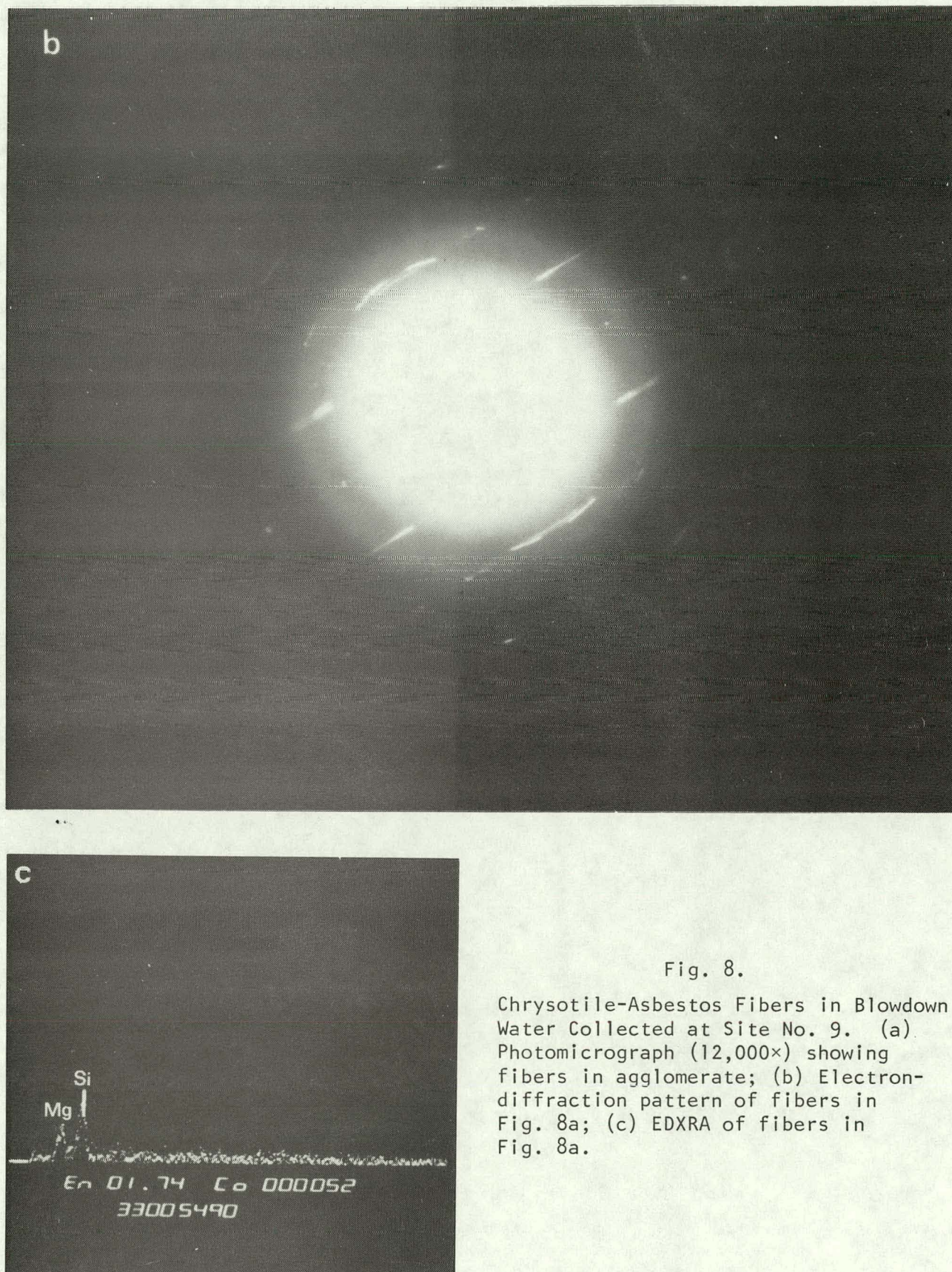
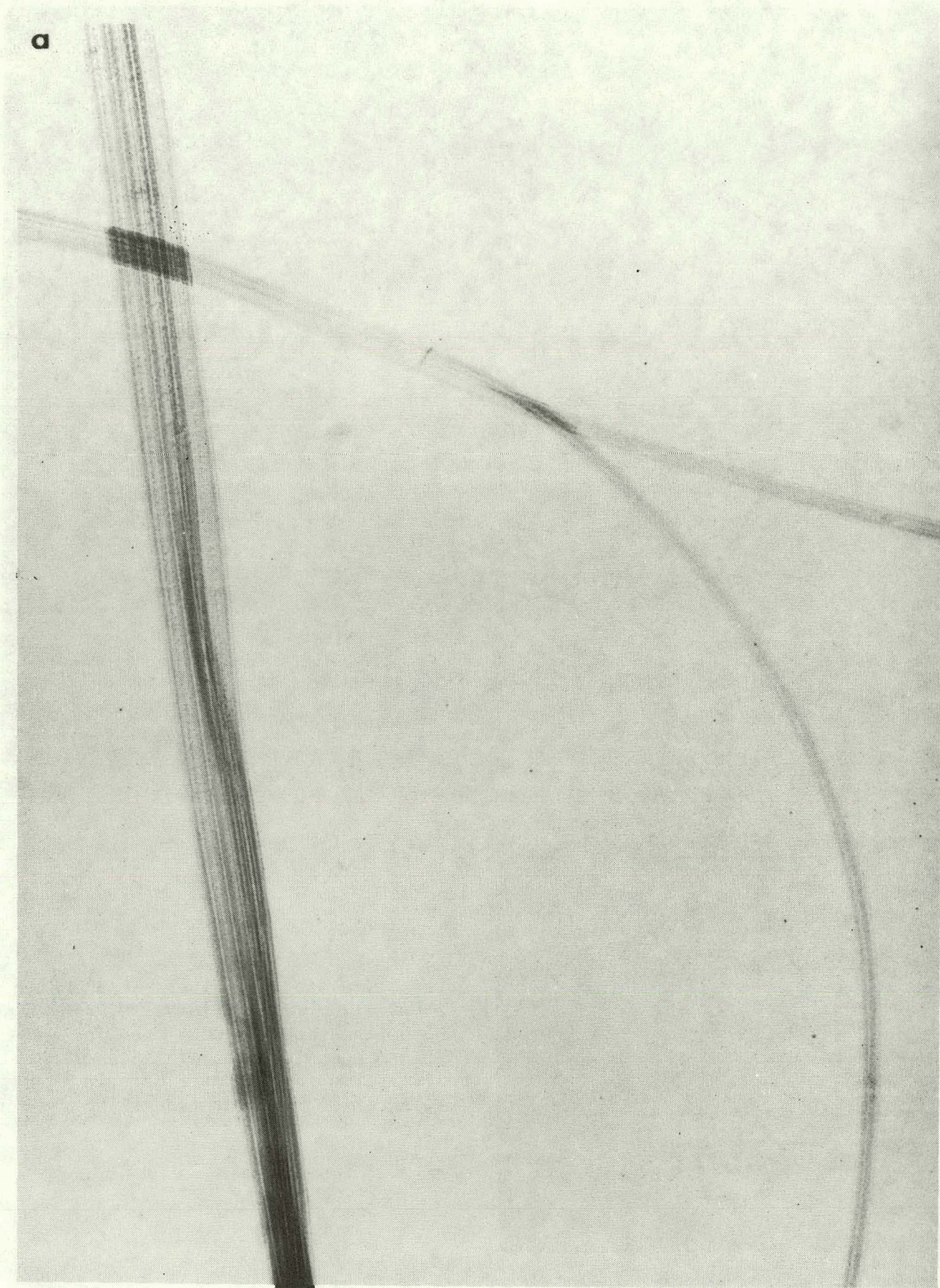


Fig. 8.

Chrysotile-Asbestos Fibers in Blowdown Water Collected at Site No. 9. (a) Photomicrograph (12,000 $\times$ ) showing fibers in agglomerate; (b) Electron-diffraction pattern of fibers in Fig. 8a; (c) EDXRA of fibers in Fig. 8a.







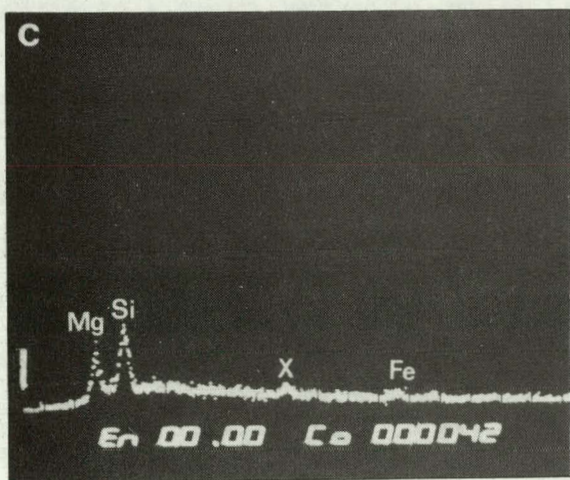
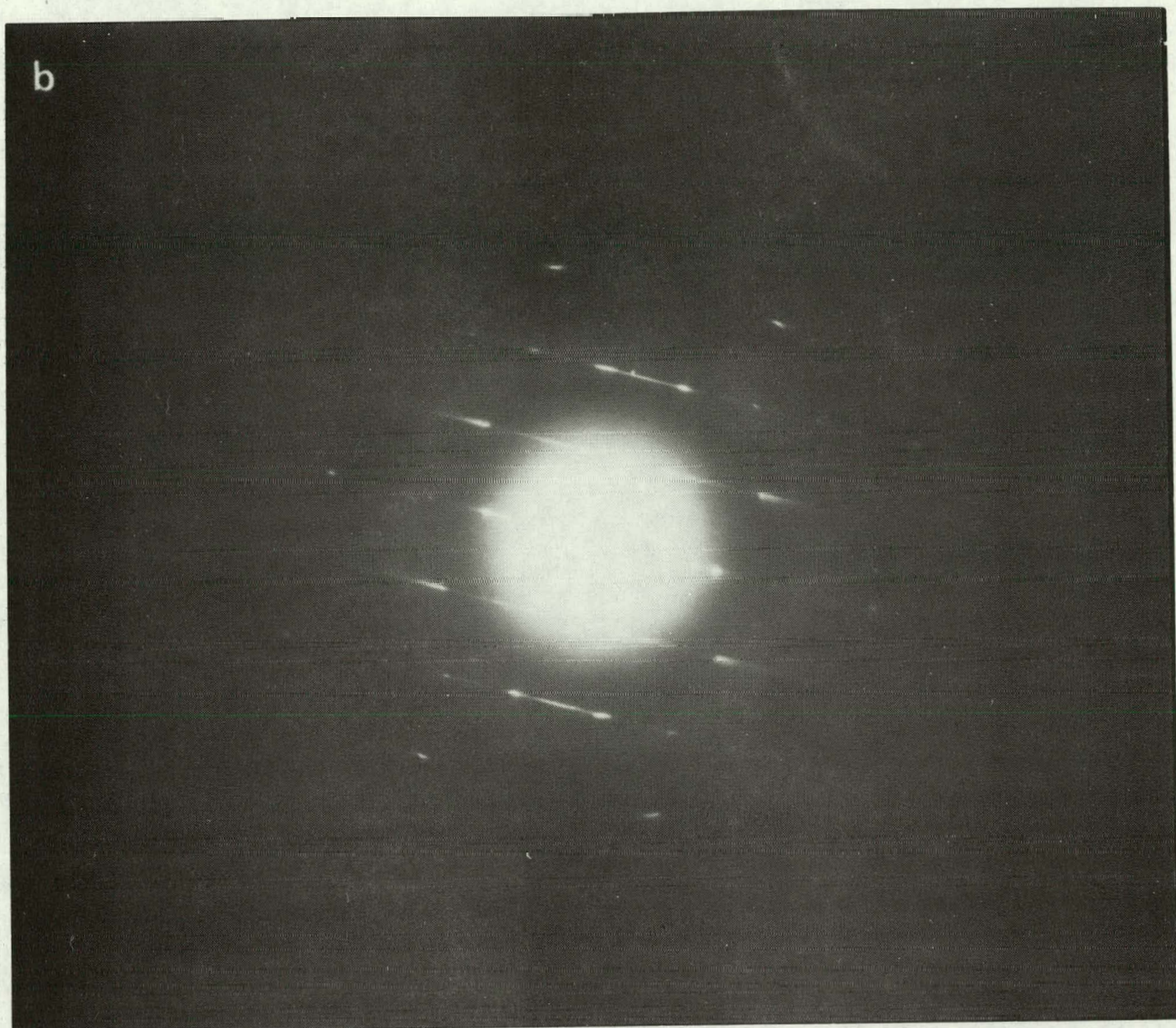
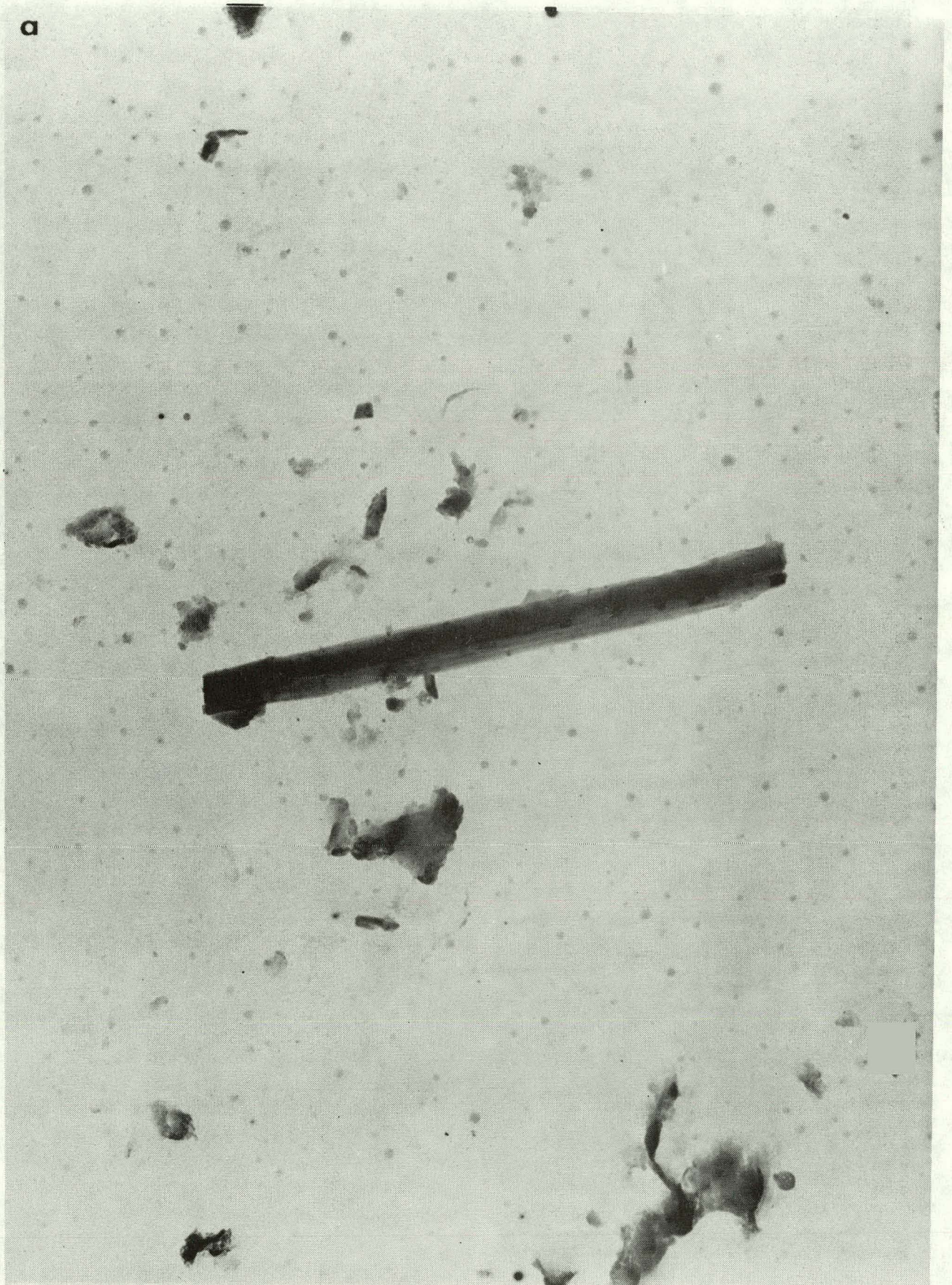


Fig. 9.

Chrysotile-Asbestos Fibers in Basin Water Collected at Site No. 11. (a) Photomicrograph (87,000 $\times$ ); (b) Electron-diffraction pattern of fibers in Fig. 9a; (c) EDXRA of fibers in Fig. 9a.







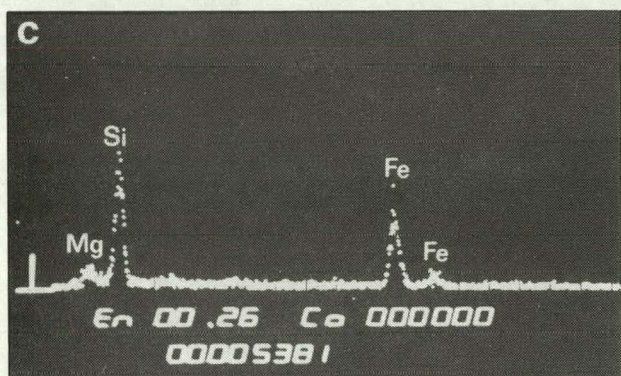
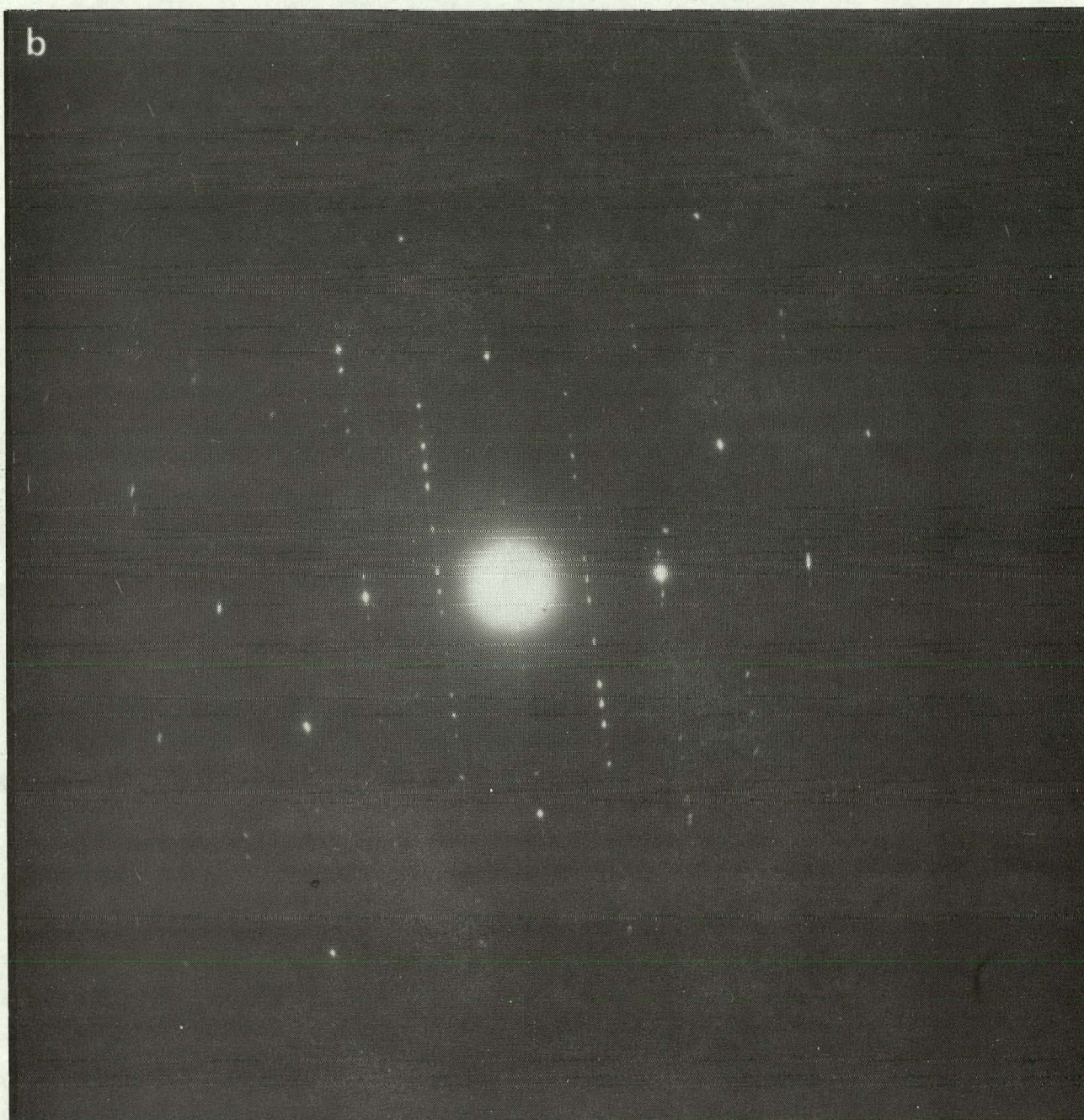


Fig. 10.

Amphibole-Asbestos Fiber in Makeup Water (Well Water after Softening) Collected at Site No. 13. (a) Photomicrograph (30,000 $\times$ ); (b) Electron-diffraction pattern of fiber in Fig. 10a; (c) EDXRA of fiber in Fig. 10a.



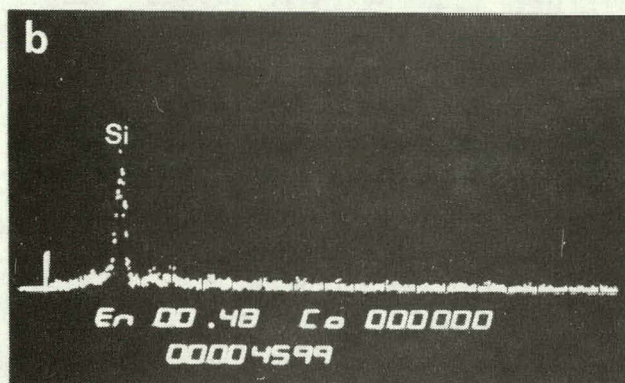
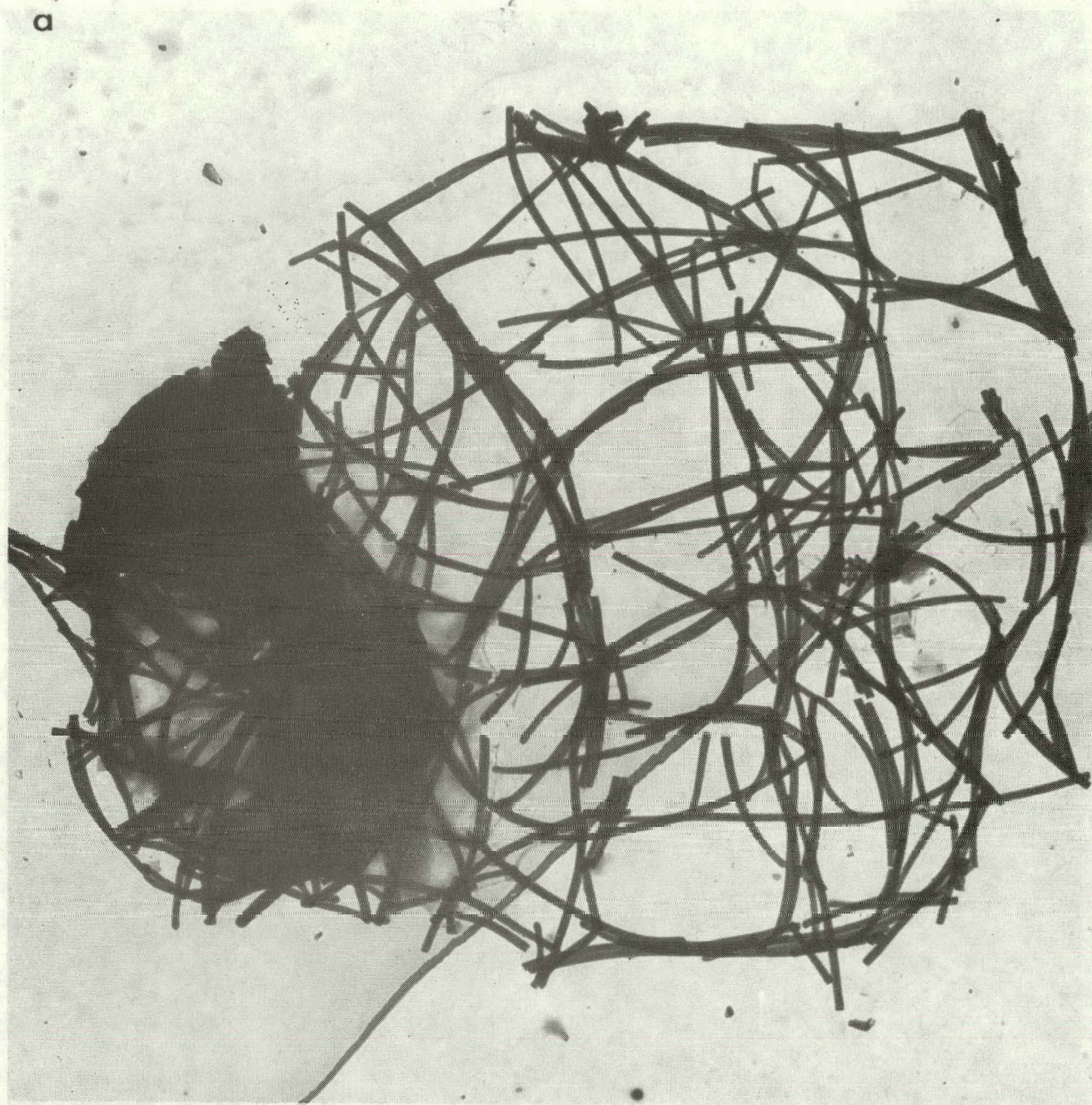


Fig. 11.

Amorphous Fibers in Blowdown Water  
Collected at Site No. 9. (a) Photo-  
micrograph (12,000 $\times$ ) showing tangle  
of fibers; (b) EDXRA of fibers in  
Fig. 11a.



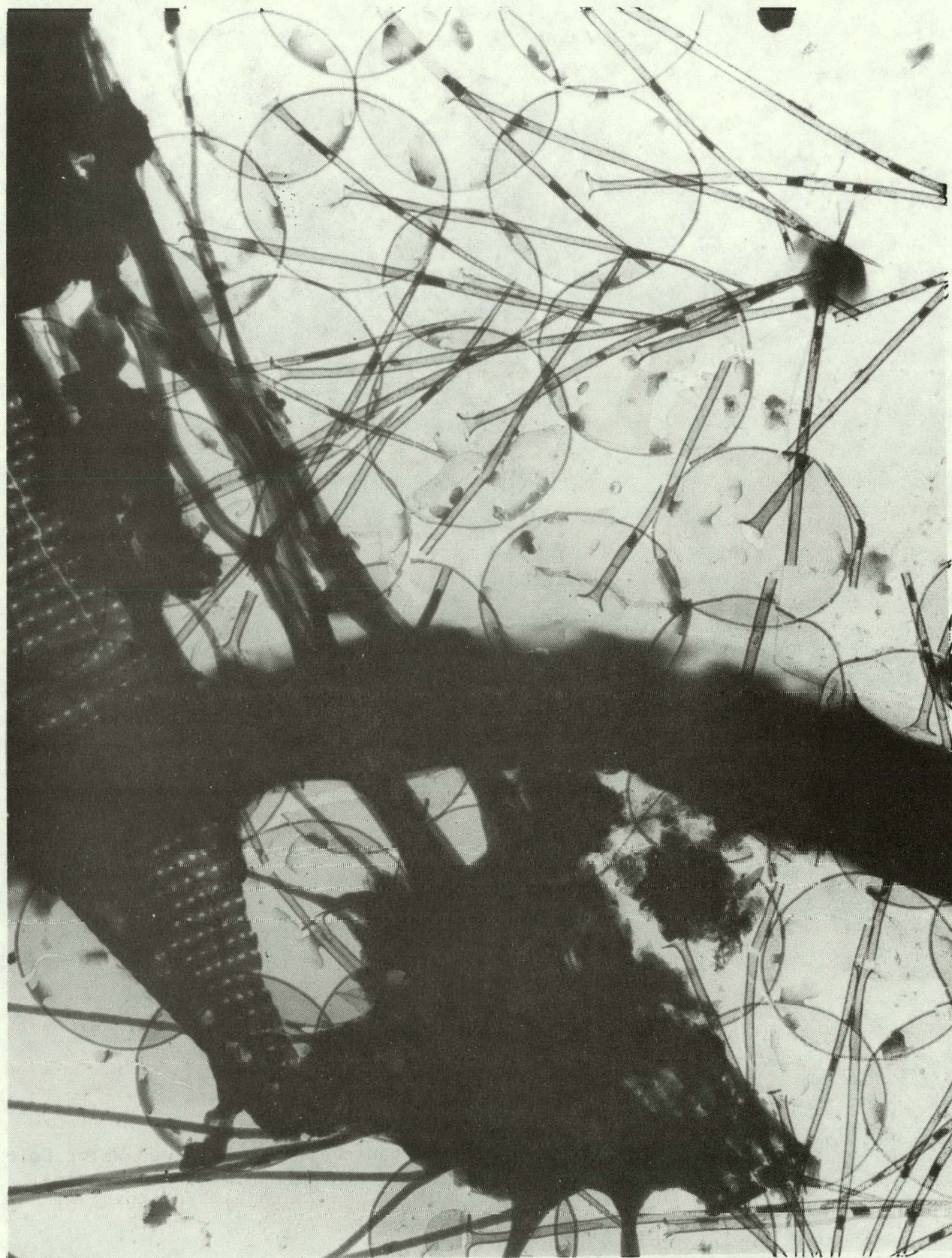


Fig. 12. Photomicrograph (12,000 $\times$ ) of Organic Fibers and Other Organic Materials in Basin Water Collected at Site No. 7.



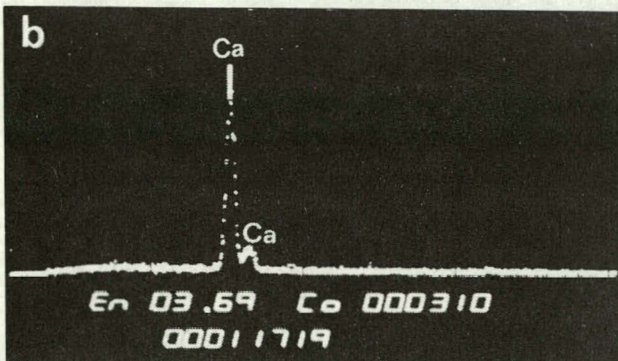
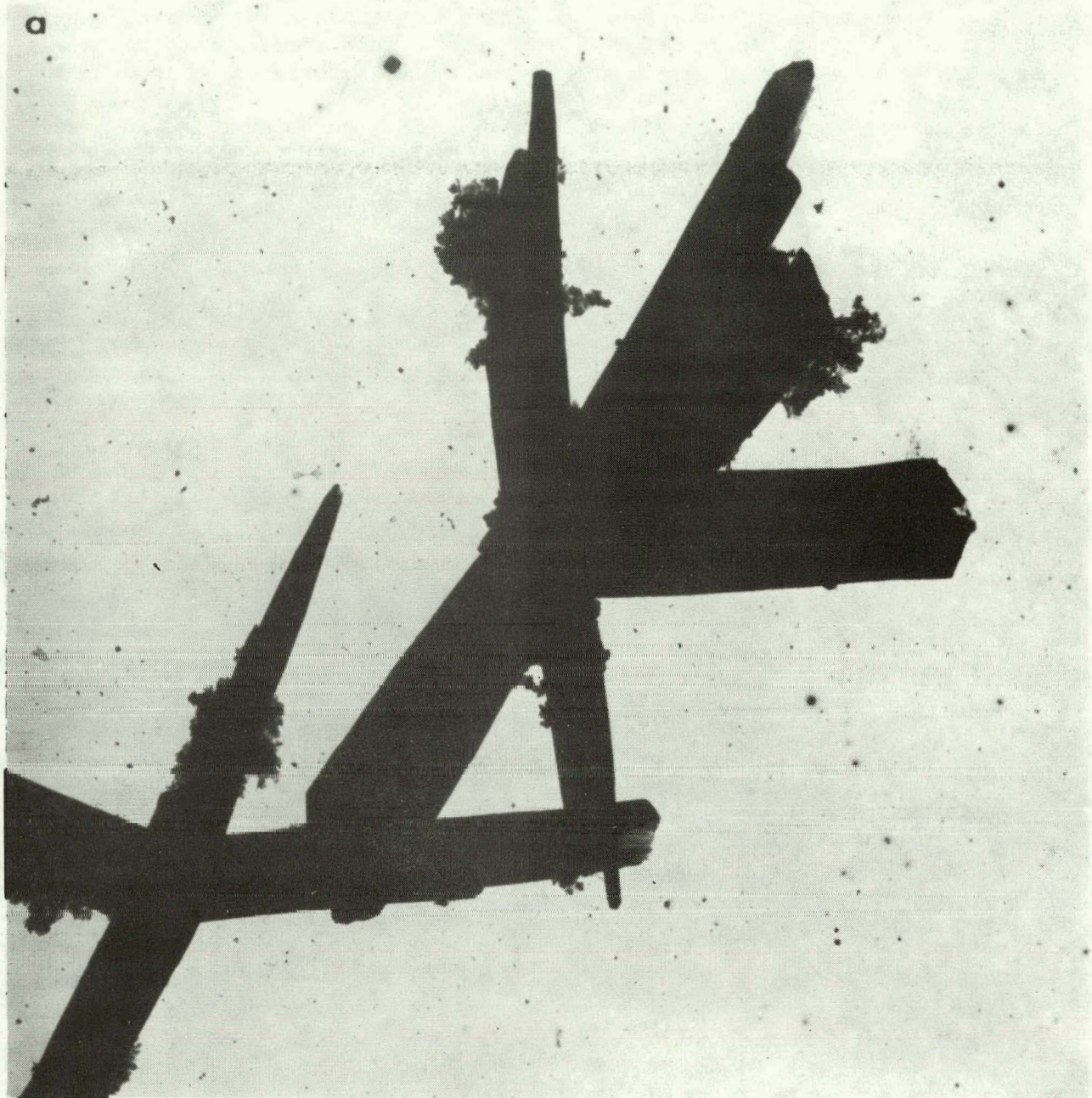


Fig. 13.

Inorganic Fibers in Makeup Water Collected at Site No. 13. (a) Photomicrograph (7,500 $\times$ ); (b) EDXRA of fibers in Fig. 13a.



3. Dissolution of the cement and subsequent release of asbestos fibers to the circulating water as a result of acid formation by micro-organisms, fungi, or algae attached to fill surfaces.

These mechanisms, acting singly or in concert, can be expected to result in addition of chrysotile fibers to the circulating water, and thence into surface waters via blowdown, or to ambient air via drift. These mechanisms are further discussed below.

### Physical Breakage

Analogous to the exfoliation phenomenon in rock disintegration, cycles of freezing and thawing can cause fill material to alternately shrink and expand, thus subjecting the fill to stress and eventual disintegration. Additionally, seepage of water into fill crevices, cracks, and pores--with subsequent volume expansion when the water freezes--can be assumed to accelerate the disintegrating effect of the freezing and thawing action.

One series of laboratory tests (using ASTM C112-60\* as a guide) was performed on corrugated asbestos sheets under the auspices of a cooling-tower vendor. A weight loss of 0 to 1.6% was measured after 10 freeze-thaw cycles, and a weight loss of 1.5 to 2.2% after 30 freeze-thaw cycles. [A freeze-thaw cycle consisted of saturating the samples with water, freezing for 3.5 hr at -20°F (-28.9°C), and thawing for 0.5 hr in water.] Slight flaking of the material was observed (Furr, 1976--personal communication).

Interviews with personnel at the cooling-tower sites surveyed in this study, and the author's personal observation of ice damage at cooling towers, indicated that replacement of portions of asbestos-cement-board fill and/or louvers was sometimes necessary at sites that experienced severe winters (Figure 14, for example).

Physical breakage of fill, however, may contribute only a small number of individual asbestos fibers to circulating water if the fill breaks off in large pieces and lodges in the tower basin. It is usually common practice to drain and clean cooling towers about once a year; during cleaning, sludge and sediment are removed from the basins and disposed of.\*\*

### Chemical Deterioration due to Nature of the Circulating Water

As indicated above, one type of asbestos fill used in cooling towers consists of asbestos-cement bars or sheets, in which portland cement is bound with asbestos fibers. Portland cement is the product obtained by pulverizing

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\*A standard procedure developed by the American Society for Testing and Materials.

\*\*Careful attention to the method of cooling-tower sludge disposal, such that the material does not find its way into surface waters or groundwaters, seems called for.





Fig. 14. Damage to Cooling-Tower Fill and Drift Eliminators after Winter of 1976-1977.



"clinker," a mixture with the following average composition:

3CaO•SiO <sub>2</sub>	51.7%
2CaO•SiO <sub>2</sub>	21.4
3CaO•Al <sub>2</sub> O <sub>3</sub>	10.5
4CaO•Al <sub>2</sub> O <sub>3</sub>	8.7
CaSO <sub>4</sub>	2.9
MgO	2.47

After setting and hardening (a complex process of hydration and hydrolysis), the end product has very low solubility in water (Bogue, 1947; Shreve, 1967).

If the circulating water in a cooling tower has free carbon dioxide, the portland cement can be dissolved through the reaction between the calcium hydroxide formed during the hardening process and carbonic acid in water. Dissolution of the cement would then result in release of the asbestos fibers into the water. One measure of the tendency of a water to contain free carbon dioxide is the Langelier Index (also referred to as the Saturation Index, S.I.). A positive value of the index indicates a lack of excess carbon dioxide such that precipitation of calcium carbonate from the water occurs; a negative value of the index indicates an excess of carbon dioxide and a tendency for calcium carbonate to dissolve in the water. This index is used in industry to indicate whether a given water will cause deposition of "scale" (mainly calcium carbonate) or corrosion of iron pipes; the latter tends to occur in the presence of excess carbon dioxide (a negative value of the index). Due to the complex chemistry of calcium carbonate, carbonic acid, and carbon dioxide in water, measurement of pH alone is not an adequate indicator of the corrosiveness of a particular water.

The Langelier Index is calculated as follows (Clark et al., 1971):

$$\begin{aligned} \text{S.I.} &= \text{pH} - \text{pH}_s \\ &= \text{pH} - [(\text{pK}'_2 - \text{pK}'_s) + \text{pCa}^{++} + \text{pAlk}] \end{aligned}$$

where      pH = actual pH of the water

            pH<sub>s</sub> = pH at saturation with calcium carbonate

(pK'<sub>2</sub> - pK'<sub>s</sub>) = empirical constants based on water temperature and ionic strength

pCa<sup>++</sup> = the negative logarithm of the calcium ion concentration (moles/liter), and

pAlk = the negative logarithm of the total alkalinity (equivalents/liter).

At steam-electric generating stations, it is the usual practice to maintain the Langelier Index around zero, or at a slightly negative value, to prevent the deposition of excessive amounts of calcium carbonate (scale) on condenser-tube surfaces; such deposits interfere with heat transfer across the tubes. Too negative a value of the index would result in corrosion of the metal tubes.

At a number of the sites sampled for this study, water-chemistry data and Langelier indices were obtained from the station chemists. The ranges of the index for several stations, over a given period of time, are indicated in Table 8. At Site No. 2, the makeup water (river) is highly corrosive (S.I. = -4 to over -5) due to additions of acid mine drainage. In late 1974, the company initiated its own investigations on asbestos when cooling-tower fill was observed to be deteriorating. At that time, chrysotile asbestos fibers at concentrations ranging from less than  $0.17 \times 10^6$  to  $3.30 \times 10^6$  fibers/liter were consistently found in effluent from one of the cooling towers on the site, but not in effluent from an adjacent tower. During that period the Langelier Index ranged to -2.75. In this present study, no chrysotile was detected in any of the samples taken from those same towers. It is also puzzling to note that at Site No. 15, where the index ranges to -2.2, no asbestos was detected in the water samples.

Table 8. Langelier Indices of Cooling-Tower Waters\*

Site No.	Raw Makeup		Circulating Water			
	Indices	Sampling Date	Indices		Sampling Date	Asbestos Detected
			Tower A	Tower B		
2	-4.05 to -5.86 <sup>a</sup>	Feb-Jun 1975	-2.75 to +0.75	-2.27 to +0.74	Aug 1974-Aug 1975	Yes (1974) <sup>†</sup>
4	-1.22 to -2.2	Feb-Aug 1977	-1.38 to -0.81		Feb-Aug 1977	Yes
7	-0.93	1969**	-0.12 to +1.26		May-Jun 1977	No
11	-1.1 to -2.6	Jan-Jul 1977	-1.0 to 0.0	-1.2 to 0.0	Jan-Jul 1977	Yes
12	-1.20 to -1.60	Mar-May 1977	+1.2 to -0.8	+0.2 to +1.5	Mar-Aug 1977	Yes
15	Not determined		-2.2 to +0.62		Apr 1976-Jan 1977	No

\*Indices were determined several times a month during the period indicated by sampling date. The values listed indicate the range between which the index fluctuated during the given period. Determinations made on two separate cooling towers at the site are listed under Tower A and Tower B.

<sup>†</sup>Data obtained by the cooling-tower user in 1974. No asbestos was found in the samples taken at this site during this study.

\*\*Calculated from 1969 river chemistry data.

<sup>a</sup>Source of makeup is a river that receives acid mine drainage.

From a knowledge of the chemistry of cement and from these few observations, it seems reasonable to conclude that allowing the index to fall to high negative values (e.g., more negative than about -2) will accelerate the erosion of asbestos-cement fill. It is also possible that wide fluctuations in the index may enhance this effect. The inconsistencies in the Langelier Index as related to asbestos detected in the waters suggest either that the sampling and analytical procedures need to be improved, or that there are other factors involved in the erosion of asbestos-cement fill from particular towers. Controlled laboratory experiments seem called for, if this question is to be conclusively answered.

A high concentration of salts in the water, such as would occur in marine or estuarine locations, can cause delamination of asbestos-cement board if wet on one side only. Asbestos-cement casing and louvers are particularly vulnerable,

and it is recommended that these components be coated for salt-water cooling towers, or manufactured with sulfate-resistant portland cement (Nelson, 1973). Such a salt-water effect may be partly responsible for the appearance of chrysotile asbestos fibers in cooling-tower blowdown at Site No. 9 (see Tables 6 and 7), where the circulating water is brackish.

#### Acid Secretion by Attached Organisms

Certain species of microorganisms are known to corrode concrete under certain conditions, particularly in the presence of  $H_2S$  (Parker, 1945a, 1945b); asbestos-cement fill at some of the study sites was observed to have attached growths. It is conceivable that acidic substances--excreted by microorganisms, fungi, or algae, or acid substances formed due to reactions mediated by these organisms--can have a corrosive effect on the cement binder. On the other hand, a study conducted in Germany, on asbestos-cement sheets that had been in operating cooling towers for 20 years, indicated that an organic (fatty) film on the surfaces of the sheets appeared to protect the sheets from direct contact with the flowing water. The 3/16-in. (0.5-cm) asbestos sheets were still within tolerances (McGee, 1975--personal communication).

#### INDUSTRY STUDIES ON EROSION OF ASBESTOS MATERIAL

Studies conducted by several companies on the erosion of cooling-tower fill or asbestos-cement pipe are briefly described here. The units of asbestos-fiber concentration are the same as reported in the references and can be either on a mass basis or as numbers of fibers. (Conversion from one basis to the other is not possible without a knowledge of fiber dimensions and densities.)

#### Goodyear Atomic Corporation (Cooling-Tower User)

The cooling towers at Goodyear Atomic Corporation's Ohio site contain corrugated chrysotile-asbestos sheets impregnated with a chlorinated rubber binder. Laboratory tests of this product indicated that the rubber binder can be removed by action of the tower circulating water, exposing asbestos fibers on the fill surface.\* The towers also contain asbestos-cement board (Trademark TRANSITE) as tower siding. Chrysotile fibers were found in water samples taken from the towers in December 1975 thru July 1976; concentrations ranged from  $14.0 \times 10^6$  fibers/liter to below detection limit ( $0.7 \times 10^6$  fibers/liter) in water samples from one tower (asbestos-cement siding only), and from  $14.0 \times 10^6$  fibers/liter to  $1.4 \times 10^6$  fibers/liter for the tower containing both asbestos-cement siding and asbestos-rubber fill. Water samples from a third tower that contained no asbestos material had  $11.3 \times 10^6$  fibers/liter (Riepenhoff, 1977a). Follow-up studies by the company in August 1976 to July 1977 had similar results, i.e., asbestos-fiber concentrations ranging from below detection limits ( $0.7 \times 10^6$  fibers/liter) to  $17.0 \times 10^6$  fibers/liter were found in water samples from all the cooling towers (Riepenhoff, 1977b).

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\*It has been suggested by the manufacturer that exposure of the fibers occurred when the material was cut into smaller sizes for the laboratory tests and the cut edges were not resealed (Skold, 1976--personal communication); however, GAC maintains that the edges had been resealed before testing.

### Research-Cottrell (Cooling-Tower Vendor)

In 1972, Research-Cottrell carried out measurements on cooling-tower water at two sites in the United States. At one site, after 4 to 5 years of operation, the circulating water was found to contain 13.2  $\mu\text{g}$ /liter; makeup water was found to contain 26.7  $\mu\text{g}$ /liter. At another site, after 1.5 to 2 years of operation, cooling-tower circulating water was found to contain 0.6  $\mu\text{g}$ /liter, while the makeup was found to contain 0.8  $\mu\text{g}$ /liter. The mineral type of asbestos was not specified, but it is assumed to be chrysotile (McGee, 1977--personal communication).

### Johns-Manville Corporation (Asbestos-Cement Pipe and Board Manufacturer)

At Johns-Manville Corporation, a 33-ft (10-m) test-line loop constructed of 3-in. (8-cm) asbestos-cement (TRANSITE) water pipe was subjected to a water-flow volume of about 150 gpm during weekly tests for erosion of asbestos fibers from the pipe. Using millipore-filtration techniques and electron microscopy, it was found that the average asbestos-fiber content of the water ranged from  $1.4 \times 10^{-5}$  to  $16.8 \times 10^{-5}$   $\mu\text{g}/\text{gal}$  ( $0.4 \times 10^{-5}$  to  $4.4 \times 10^{-5}$   $\mu\text{g}/\text{L}$ ). The average pH of the water ranged from 7.2 to 4.9 in a series of runs (Gray, 1975--personal communication).

### Asbestos Cement Pipe Producers Association

In 1973, the Asbestos Cement Pipe Producers Association contracted with the American Water Works Association Research Foundation to study the problem of asbestos in water, specifically with relation to the use of asbestos-cement pipe. A committee was formed, consisting of university, EPA, National Cancer Institute, medical, and engineering personnel. The committee reviewed the literature and experimental studies on asbestos-fiber content of two municipal water systems. It was concluded that the probability of risk to health as a result of ingestion of potable water from asbestos-cement pipe systems "is *small--approaching zero*" (Kuschner et al., 1974).

### Munters Corporation (Asbestos-Fill Manufacturer)

At the Munters Corporation laboratory in Sweden, erosion tests indicated that the minimum TUFedg depth on the top side of the fill packs for "no erosion" is 3/8 in. (1 cm). A 10 psig (69 kPa) water pressure at the spray nozzles was used in the erosion tests (Skold, 1976--personal communication).

### Pennsylvania Power and Light Company (Cooling-Tower User)

In 1976 and 1977, the Pennsylvania Power and Light Company collected water samples at two power-station sites for asbestos analysis using electron-microscopy techniques (Herre, 1977--personal communication). Results indicated that at one site, chrysotile-asbestos concentrations ranged from  $3 \times 10^6$  fibers/liter in the makeup water to  $7 \times 10^6$  fibers/liter in cooling-tower basin water; at the other site, where "chemical attack" of the asbestos-cement fill was suspected, chrysotile-asbestos concentrations ranged from  $1 \times 10^6$  fibers/liter in makeup water to  $3 \times 10^9$  fibers/liter in basin water. At both sites, the settling basins located between the cooling towers and the off-site receiving streams appeared to markedly reduce the asbestos concentrations in

the effluent. At the first site, the concentration of chrysotile-asbestos fiber in the waste-basin effluent was a factor of about four less than in the cooling-tower basin water; at the second site, the asbestos-fiber concentration in the detention-basin effluent was two orders of magnitude less than the maximum concentration found in cooling-tower basin water (author's summary of raw data provided by Herre, 1977--personal communication).

#### Pennsylvania Electric Company (Cooling-Tower User)

In 1974, chrysotile-asbestos fibers were found in water samples taken at cooling towers on one of the Pennsylvania Electric Company's sites. Fiber concentrations ranged from less than  $0.17 \times 10^6$  to  $3.3 \times 10^6$  fibers/liter (Tierney, 1977--personal communication).

#### SUMMARY

At ten sites sampled in this study, concentrations of chrysotile-asbestos fibers found in cooling-tower water were on the order of  $10^6$  to  $10^8$  fibers/liter, with mass concentrations ranging from less than  $0.1 \mu\text{g/liter}$  to about  $40 \mu\text{g/liter}$ . Results from a given site were extremely variable; often only one out of three replicate samples was positive for asbestos. Despite such variability, however, this study provides an order-of-magnitude estimate for asbestos-fiber concentrations that can occur in cooling-tower basin water. Chrysotile-asbestos fiber concentrations in effluents to off-site receiving waters were reduced by waste- or ash-settling basins.

Assuming the presence of asbestos fibers in cooling-tower basin water, a reasonable question that might be asked is whether these amounts of fibers could pose a public health hazard by virtue of emission of these fibers to ambient air via cooling-tower drift. No field sampling of asbestos in drift from cooling towers was attempted in this present study; however, in view of current interest in this matter, an estimate of such emissions was made, using one model for cooling-tower drift deposition. This topic is addressed in the following section.

#### APPLICATION OF A DRIFT-DEPOSITION MODEL TO ASBESTOS-FIBER EMISSIONS FROM A COOLING TOWER

A fraction of the circulating water in cooling towers is emitted as droplets into the atmosphere by air currents. This fraction is termed "drift" and can range from 0.2% of the circulating water in older towers to less than 0.002% of the circulating water in towers of more recent design.

Included in the drift are any constituents present in the circulating water. As the drops are carried away from the tower by wind, the water in the drop evaporates, depending on factors such as relative humidity of the ambient air and the salt content of the water. The particles of drift are transported to various distances from the tower, again depending on a number of factors including wind speed and droplet size. If asbestos fibers were present in the circulating water, a fraction would thus be transported away from the cooling tower and eventually fall to the ground. Persons situated at the point of deposition could conceivably inhale some of the fibers.



To estimate the order of magnitude for concentrations in the air at ground level, the drift-deposition model of Hanna (1974) was applied to a hypothetical site on which six round mechanical-draft wet cooling towers are in operation. The towers contain asbestos-cement bars as fill. Calculations were made assuming that (a) the circulating water in each tower contains 37  $\mu\text{g}$  chrysotile/liter (the maximum concentration found in cooling-tower water in this study), (b) the concentration of chrysotile in the drift as it exits from the tower is the same as the concentration in the circulating water, i.e., 37  $\mu\text{g}$ /liter, and (c) the chrysotile fibers are carried in the drift in the same manner as the salt present in the drift. Additional assumptions and parameters for the application of the model to this case are listed in Table 9.

Table 9. Parameters for the Application of a Drift-Deposition Model to Asbestos-Fiber Emissions from a Cooling Tower

Parameters	Engineering Unit	Metric Conversion
<u>Cooling-tower Design*</u>		
Tower diameter	290 feet	88 m
Tower height	60 feet	18 m
Number of fans per tower	13	
Design wet bulb	78°F	25.6°C
Design approach	14°F	7.8°C
Inlet temperature	117.4°F	47.4°C
Outlet temperature	92.0°F	33.3°C
Design range	26.1°F	14.5°C
Exit air velocity	11.43 ft/sec	3.5 m/sec
Exit air temperature	107.1°F	41.7°C
Air-flow rate per fan	1,342,000 cfm	38,000 m <sup>3</sup> /sec
Maximum drift rate per tower	10 gal/min (0.005% of circ. water)	0.6 L/sec
<u>Hypothetical Site<sup>†</sup></u>		
Relative humidity	80%	
Ambient temperature	83°F	28.3°C
Isothermal atmosphere (slightly stable)		
Wind speed	4 m/sec	
Salt content of water	2200 mg/L	
Effective radius of tower (assuming instantaneous merging of plumes from the tower cells)	12.5 $\sqrt{13}$ feet	13.7 m
Droplet size distribution as per Environmental Systems Corporation composite spectrum measured at the Turkey Point single cell MDCT (Schrecke, 1977--personal communication).		

\*Based on real towers.

<sup>†</sup>These assumptions are not necessarily the most conservative nor the least conservative.

The results of the model calculation are presented in Table 10. Concentrations of chrysotile in air are calculated as ng/m<sup>3</sup> at ground level. For comparison with the occupational standard (2 fibers/cm<sup>3</sup> ...), the mass

concentrations were converted to fiber concentrations by assuming that 1  $\mu\text{g}$  of chrysotile contains  $60 \times 10^6$  fibers.\*

Table 10. Asbestos in Air near Ground Level due to Drift Emissions from Cooling Towers at a Hypothetical Site

Downwind Distance, km	Near-Ground Airborne Concentration*	
	ng/m <sup>3</sup>	fibers/cm <sup>3</sup>
0.1	1.5	$90 \times 10^{-3}$ (<1)
0.5	0.13	$7.8 \times 10^{-3}$ (<1)
1.0	0.14	$8.4 \times 10^{-3}$ (<1)
2.0	0.14	$8.4 \times 10^{-3}$ (<1)
4.0	0.07	$4.0 \times 10^{-3}$ (<1)
6.0	0.03	$1.9 \times 10^{-3}$ (<1)
8.0	0.03	$1.9 \times 10^{-3}$ (<1)
10.0	0.03	$1.9 \times 10^{-3}$ (<1)
15.0	0	0

\*Based on total emissions from six towers assumed to behave as one tower. The emission rate is taken to be 23.3  $\mu\text{g}/\text{sec}/\text{tower}$ . Fiber numbers were calculated by assuming  $60 \times 10^6$  fibers/ $\mu\text{g}$  asbestos (see text).

The calculations show that at any distance greater than about 0.1 km from the six cooling towers, there will be essentially no fibers in the air at ground level. When the mass concentration of chrysotile as calculated by the model is compared to the concentration of 30 ng/m<sup>3</sup> proposed by Bruckman and Rubino (1975) as an ambient air-quality standard, the concentrations at ground level are, at the most, 20 times less than that standard. If the calculated mass concentrations are compared to the concentration of asbestos in ambient air as cited by Rohl et al. (1977), the concentrations up to 0.1 km downwind of the towers are on the order of those found in urban air, i.e., 1 to 2 ng/m<sup>3</sup>; the concentrations between 0.1 and 4 km are about the same as found for non-urban air, i.e., 0.1 ng/m<sup>3</sup>. The towers are thus adding a measurable increment

\*Obviously, the number of fibers in a given mass will depend on fiber densities and dimensions. For purposes of the model calculations, the number of fibers per microgram of chrysotile was calculated by dividing the number of fibers per liter by the mass concentration of chrysotile in each water sample obtained from the cooling towers in this study, and calculating the arithmetic mean of all the quotients.

of asbestos to the air in the area of the hypothetical site. Beyond about 5 km downwind of the towers, the tower contribution of asbestos to the ambient air will probably be undetectable.

The Hanna (1974) model was selected only to demonstrate the application of models to the case in point; use of other models, or other assumptions and parameters in the same model (e.g., droplet-size spectrum, ambient wind speed, lapse rate, etc.), will produce different results. Despite the proliferation of models on cooling-tower plume dispersion and drift deposition, few, if any, have been validated. Several such models are currently under evaluation at Argonne National Laboratory (Policastro et al.--unpublished).

The cooling towers selected for the above model were round mechanical-draft towers. To obtain an estimate of asbestos in air near ground level due to drift from natural-draft and rectangular mechanical-draft towers, the work of Laskowski and Woodard (1976) was used to calculate ratios of asbestos concentrations in drift from several tower types, using "standard" round mechanical-draft towers as the base case. The calculations are summarized in Table 11.

Table 11. Ratios for Near-Ground Airborne Concentrations of Asbestos Fibers due to Emissions in Drift from Natural-Draft and Mechanical-Draft Cooling Towers, Relative to Standard, Round Mechanical-Draft Cooling Towers\*

Downwind Distance (km)	Round Mechanical-Draft		Natural-Draft		Rectangular Mechanical-Draft	
	Standard (0.003%, Base)**	State-of-the-Art (0.001%)	(0.002%)	(0.001%)	Standard (0.01%)	State-of-the-Art (0.001%)
0.25	1	0.15	0.45	0.025	320	0.17
1.2	1	1.28	0.17	0.14	1.0	0.07
2.	1	0.14	0.14	0.11	5.7	0.7
4.8	1	0.24	0.31	0.2	2.2	1.0
8.0	1	0.23	0.48	0.27	0.14	0.28
16.0	1	0.23	0.86	0.46	0.33	0.13

\*Values in the table were derived from work of Laskowski and Woodard (1976), assuming that asbestos fibers in drift behave as salt in drift. The data of Laskowski and Woodard were obtained for a site on the eastern seaboard where winds are from the SW. For details, salt concentrations, and site parameters, see the reference.

\*\*Percentages in column headings are drift rates.

The data in Table 11 indicate that, in general, for a given set of conditions, airborne asbestos concentrations near ground due to drift from natural-draft or state-of-the-art mechanical-draft cooling towers will be less than concentrations found for standard, round mechanical-draft towers (drift rate = 0.003%). Roughly extrapolating from Table 10, in which values were calculated for round mechanical-draft towers with drift rates of 0.005%, it is estimated that asbestos concentrations in air near ground due to drift from natural-draft and state-of-the-art mechanical-draft cooling towers will also be several orders of magnitude lower than either the current Occupational Safety and Health Administration (OSHA) standard of 2 fibers/cm<sup>3</sup> of air, or the proposed ambient air-quality standard of 30 ng/m<sup>3</sup>, for distances of 0.25 km and beyond. Drift



from "standard" mechanical-draft towers, with drift rates of 0.01% of the circulating water flow, is expected to be higher than for the base case under a given set of conditions, for distances up to 5 km from the towers. In particular, close to the towers, asbestos-fiber concentrations may exceed the occupational standard by an order of magnitude.

## CONCLUSIONS AND IMPLICATIONS FOR ENVIRONMENTAL IMPACT ASSESSMENT

Chrysotile asbestos was detected in cooling-tower water at 10 of the 18 sites sampled in this study. Concentrations were on the order of  $10^6$  to  $10^8$  fibers/liter, with mass concentrations between less than 0.1  $\mu\text{g/liter}$  to about 37  $\mu\text{g/liter}$ . The majority (65-100%) of the fibers were less than 5  $\mu\text{m}$  in length, with aspect ratios ranging from 3.5 to 1700. Settling ponds interposed between cooling-tower blowdown and the receiving water appear to substantially reduce the fiber concentrations in the effluent.

The concentrations of asbestos fibers in air at ground level due to emissions from cooling towers were calculated (using a salt drift-deposition model) to be on the order of asbestos-fiber concentrations reported for ambient air, up to distances of 4 km downwind of the towers. Assuming that the methods of data collection and analysis were reasonably accurate with respect to orders of magnitude, the off-site hazard to human health due to asbestos emissions in drift from cooling towers is probably negligible. However, asbestos-fiber concentrations in air near ground level close to a standard mechanical-draft tower may exceed the current OSHA standard.

The human health hazard due to asbestos discharges to surface waters that eventually serve as drinking water supplies is not as clearly defined, due primarily to the paucity of health-effects data on ingested asbestos. It is reasonable to assume that cooling-tower blowdown will not be consumed undiluted by anyone. After mixing of the discharge with the receiving water, asbestos concentrations will likely be reduced by several orders of magnitude, depending on streamflow. If the asbestos concentrations in the discharge are on the order of those found in this study--i.e.,  $10^6$  to  $10^8$  fibers/liter (or a maximum of about 40  $\mu\text{g/liter}$ )--the resulting concentration in the receiving water after mixing will be on the order of  $10^6$  fibers/liter or less (or mass concentrations on the order of nanograms per liter), and will probably be difficult to detect using current state-of-the-art techniques.

Methods (e.g., filtration through sand or diatomaceous earth) used at municipal water-treatment plants have been shown to remove more than 90% of asbestos fibers (Lawrence et al., 1974, 1975). Studies on coagulation with ferric chloride or alum and a polyelectrolyte indicated a 99.8% removal of asbestos fibers from drinking water (Gr. Lakes Res. Advis. Board, 1975; Lawrence and Zimmerman, 1976).

This is not to say that there will be no hazard from asbestos fibers in cooling-tower blowdown, nor does the absence of detectable asbestos imply the absence of asbestos. Rather, these observations, taken in relation to current information regarding the health effects of ingested asbestos, imply that there is little health risk posed by cooling-tower discharges containing quantities of asbestos similar to those found in this study. This conclusion may need to be revised if future epidemiological studies so indicate.

Additional studies needed for a more confident assessment of the health effects from asbestos in cooling-tower discharges to air and water include:

1. Verification of the observations made in this study, by additional sampling and analysis at these and other cooling-tower sites. The variability among replicates in this study indicates that a larger number of replicate water samples at each sampling location is needed if accuracy greater than order of magnitude is desired.
2. Sampling and analysis of fish populations in waters receiving asbestos discharges from cooling towers, to determine asbestos concentrations in fish and the magnitude of human ingestion of asbestos via consumption of these fish.
3. Improvement in analytical methods for asbestos in water, such that reasonably low limits of detection can be achieved in raw water samples using procedures adapted to routine analysis.
4. Additional studies of asbestos fibers in raw and treated water at municipal water-treatment plants, to ascertain the effectiveness of the treatment in terms of asbestos-fiber removal.
5. Validation of models for cooling-tower plume dispersion and drift deposition, with specific application to transport of asbestos fibers.
6. Epidemiological studies to ascertain the human health effects of inhaled and ingested asbestos in relation to fiber size and quantity.

In view of the time and expense required for such studies (particularly item 6), it is doubtful that much additional information will become available in the immediate future. Reliance must therefore be placed on cooling-tower suppliers, vendors, users, and regulatory agencies to strive for a minimum discharge of asbestos from cooling towers.

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Cooling-Tower Vendors and Suppliers	Cooling-Tower Users
Baltimore Aircoil Company Baltimore, Maryland 21227	Brookhaven National Laboratory Upton, New York 11973
Binks Manufacturing Company Franklin Park, Illinois 60131	Duquesne Light Company Pittsburgh, Pennsylvania 15219
Ceramic Cooling Tower Company Fort Worth, Texas 76101	Goodyear Atomic Corporation Piketon, Ohio 45661
Ecodyne Cooling Products Houston, Texas 77027	Metropolitan Edison Company Reading, Pennsylvania 19603
GAF New York, New York 10020	Northern Indiana Public Service Co. Hammond, Indiana 46325
Hudson Products Corporation Houston, Texas 77063	Pennsylvania Electric Company Johnstown, Pennsylvania 15907
Johns-Manville Corporation Denver, Colorado 80217	Pennsylvania Power and Light Co. Allentown, Pennsylvania 18101
Lillie-Hoffman Cooling Towers, Inc. St. Louis, Missouri	Pennsylvania Power Co. Shippingport, Pennsylvania 15077
The Marley Company (now the Marley Cooling Tower Co.) Mission, Kansas 66202	Philadelphia Electric Co. Philadelphia, Pennsylvania 19101
Munters Corporation Fort Myers, Florida 33901	Potomac Electric Company Washington, D. C. 20006
Fritchard Products Houston, Texas 77027	Sacramento Municipal Utility District Sacramento, California 95813
Research-Cottrell Hamon Cooling Tower Division Bound Brook, New Jersey 08805	Toledo Edison Toledo, Ohio 43652
Robert Burger Associates New York, New York 10010	Union Carbide, Nuclear Division Paducah, Kentucky 42001
Tower Performance, Inc. Fairfield, New Jersey 07006	U. S. Central Intelligence Agency McLean, Virginia
United Tower Maintenance, Inc. Brooklyn, New York 11211	U. S. Energy Research and Development Administration (now Department of Energy) Germantown, Maryland



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## APPENDIX A. EXCERPTS OF FEDERAL REGULATIONS AND STANDARDS FOR ASBESTOS

The following excerpts of federal regulations and standards for asbestos are taken from the U. S. Code of Federal Regulations (1976):

### 1. National Emission Standard (From 40 CFR 60-99, Protection of Environment)

#### Subpart B--National Emission Standard for Asbestos

##### §61.20 Applicability.

The provisions of this subpart are applicable to those sources specified in §61.22.

##### §61.21 Definitions.

Terms used in this subpart are defined in the act, in Subpart A of this part, or in this section as follows:

(a) "Asbestos" means actinolite, amosite, anthophyllite, chrysotile, crocidolite, tremolite.

(b) "Asbestos material" means asbestos or any material containing asbestos.

(c) "Particulate asbestos material" means finely divided particles of asbestos material.

(d) "Asbestos tailings" means any solid waste product of asbestos mining or milling operations which contains asbestos.

(e) "Outside air" means the air outside buildings and structures.

(f) "Visible emissions" means any emissions which are visually detectable without the aid of instruments and which contain particulate asbestos material.

(g) "Asbestos mill" means any facility engaged in the conversion or any intermediate step in the conversion of asbestos ore into commercial asbestos. Outside storage of asbestos materials is not considered a part of such facility.

(h) "Commercial asbestos" means any variety of asbestos which is produced by extracting asbestos from asbestos ore.

(i) "Manufacturing" means the combining of commercial asbestos, or in the case of woven friction products the combining of textiles containing commercial asbestos, with any other material(s), including commercial asbestos, and the processing of this combination into a product as specified in §61.22(c).

(j) "Demolition" means the wrecking or taking out of any load-supporting structural member and any related removing or stripping of friable asbestos materials.

(k) "Friable asbestos material" means any material that contains more than 1 percent asbestos by weight and that can be crumbled, pulverized, or reduced to powder, when dry, by hand pressure.

(l) "Control device asbestos waste" means any asbestos-containing waste material that is collected in a pollution control device.

(m) "Renovation" means the removing or stripping of friable asbestos material used to insulate or fireproof any pipe, duct, boiler, tank, reactor, turbine, furnace, or structural member. Operations in which load-supporting structural members are wrecked or taken out are excluded.



(n) "Planned renovation" means a renovation operation, or a number of such operations, in which the amount of friable asbestos material that will be removed or stripped within a given period of time can be predicted. Operations that are individually non-scheduled are included, provided a number of such operations can be predicted to occur during a given period of time based on operating experience.

(o) "Emergency renovation" means a renovation operation that results from a sudden, unexpected event, and is not a planned renovation. Operations necessitated by non-routine failures of equipment are included.

(p) "Adequately wetted" means sufficiently mixed or coated with water or an aqueous solution to prevent dust emissions.

(q) "Removing" means taking out friable asbestos materials used to insulate or fireproof any pipe, duct, boiler, tank, reactor, turbine, furnace, or structural member from any building, structure, facility, or installation.

#### §61.22 Emission standard.

(a) Asbestos mills: There shall be no visible emissions to the outside air from any asbestos mill except as provided in paragraph (f) of this section.

(b) Roadways: The surfacing of roadways with asbestos tailings or with asbestos-containing waste that is generated by any source subject to paragraphs (c), (d), (e) or (h) of this section is prohibited, except for temporary roadways on an area of asbestos ore deposits. The deposition of asbestos tailings or asbestos-containing waste on roadways covered with snow or ice is considered "surfacing."

(c) Manufacturing: There shall be no visible emissions to the outside air, except as provided in paragraph (f) of this section, from any of the following operations if they use commercial asbestos or from any building or structure in which such operations are conducted.

## 2. Permissible Exposure (From 29 CFR 1900-1919, Labor)

### §1910.1001 Asbestos.

(a) *Definitions.* For the purpose of this section, (1) "Asbestos" includes chrysotile, amosite, crocidolite, tremolite, anthophyllite, and actinolite.

(2) "Asbestos fibers" means asbestos fibers longer than 5 micrometers.

(b) *Permissible exposure to airborne concentrations of asbestos fibers--*(1) *Standard effective July 7, 1972.* The 8-hour time-weighted average airborne concentrations of asbestos fibers to which any employee may be exposed shall not exceed five fibers, longer than 5 micrometers, per cubic centimeter of air, as determined by the method prescribed in paragraph (e) of this section.

(2) *Standard effective July 1, 1976.* The 8-hour time-weighted average airborne concentrations of asbestos fibers to which any employee may be exposed shall not exceed two fibers, longer than 5 micrometers, per cubic centimeter of air, as determined by the method prescribed in paragraph (e) of this section.

(3) *Ceiling concentration.* No employee shall be exposed at any time to airborne concentrations of asbestos fibers in excess of 10 fibers, longer than 5 micrometers, per cubic centimeter of air, as determined by the method prescribed in paragraph (e) of this section.

3. Effluent Limitation Guidelines (40 CFR 427, Protection of Environment)

Under the Federal Water Pollution Control Act (PL 92-500), the U. S. Environmental Protection Agency promulgated effluent limitation guidelines to be met by the asbestos industry. In general, the law requires that guidelines reflecting the "*best practicable control technology currently available*" be implemented by July 1, 1977, and effluent guidelines reflecting the application of the "*best available technology economically achievable*" be implemented by July 1, 1983. In addition, *new source performance standards* (zero discharge) have been established for most of the domestic industrial activity involving asbestos (Ill. Inst. Environ. Qual., 1976).



## APPENDIX B. QUESTIONNAIRE TO COOLING-TOWER VENDORS AND SUPPLIERS



## ARGONNE NATIONAL LABORATORY

Dear Sir:

We are presently collecting information on materials containing asbestos and/or asbestos cement that are used in cooling tower construction, and would greatly appreciate information on the following:

1. Source of the asbestos material (if any) used in your cooling tower or cooling tower products; i.e., from whom purchased, where the raw materials are mined.
2. Your operating experiences with asbestos material in cooling towers; e.g., erodibility, frequency of replacement and/or repair, organic and inorganic incrustations (if any) on asbestos surfaces, effect of water quality such as pH and hardness on erodibility.
3. General mineralogical composition of the asbestos material; i.e., percentage of chrysotile, identity and percentage of other minerals and materials. If proprietary information is involved, simply indicating the type of asbestos mineral, e.g., chrysotile, crocidolite, amosite, etc; and type of binder, e.g., Portland cement, would be sufficient.
4. Specific location of asbestos material in mechanical and natural draft towers; e.g., in drift eliminators? fill? casing?
5. Geographical location (city and state) of at least 5 of your cooling towers or cooling towers using your products, the source of makeup water, and length of time each tower has been in operation.
6. The name and phone number of a contact person in your company with whom we can communicate further regarding this matter.

The information we receive from you will be used in the preparation of a report on the use of asbestos materials in cooling towers. The report is intended to provide generic information on the contribution to receiving waters of asbestos particles (if any) in cooling tower blowdown. Such information is urgently needed by cooling tower users and regulatory agencies for cooling tower environmental impact assessment. We believe that the report will also be of benefit to your company, in terms of providing you with a reference document for answers to questions that may be raised by your customers regarding blowdown water quality. The data in the report will not be identified with any particular company, but your company's help will be acknowledged in the acknowledgement section of the report.

If you have any questions regarding this request or the nature of the report, please call Dr. Barbara-Ann Lewis, (312) 739-7711, Ext. 2389. Similarly, please send the information requested to Dr. Lewis. Thank you.

Sincerely,

P. F. Cuatafoón, Director  
Division of Environmental Impact Studies

APPENDIX C. DESCRIPTIVE STATISTICS FOR ASBESTOS-FIBER ENUMERATION  
IN SAMPLES OF COOLING-TOWER WATER AND SEDIMENTS

Site No.	Sample	Source	No. Obs.	Variable*	Mean	Variance	Maximum	Minimum
1	c, sed	Basin	53	Length	0.87314	1.3308	6.8587	0.16140
				Width	0.030662	0.00018	0.08070	0.02020
				Aspect ratio	26.034	398.48	113.33	8.0000
				Mass	0.00390	0.00011	0.05780	0.00020
3	b, sup	Blowdown	11	Length	1.9696	0.61750	3.7118	1.1297
				Width	0.03042	0.000154	0.06050	0.02020
				Aspect ratio	71.922	1774.2	184.0	40.000
				Mass	0.00532	0.000042	0.02340	0.00110
3	c, sup	Blowdown	43	Length	1.4782	6.7708	14.928	0.20170
				Width	0.04698	0.00935	0.64550	0.02020
				Aspect ratio	37.015	2222.7	280.00	4.8889
				Mass	0.33790	4.7570	14.307	0.00020
4	b, sed	Basin	60	Length	0.90408	0.82841	4.8414	0.08070
				Width	0.03691	0.000769	0.12100	0.02020
				Aspect ratio	27.404	639.90	120.00	4.000
				Mass	0.00733	0.000327	0.10200	0.00010
4	c, sup	Basin	23	Length	3.1241	2.5464	7.2622	0.6859
				Width	0.03628	0.000278	0.08070	0.02020
				Aspect ratio	86.248	1019.2	140.00	34.000
				Mass	0.01605	0.00073	0.10880	0.00060
4	c, sed	Basin	54	Length	2.1454	37.122	45.590	0.16140
				Width	0.04818	0.00258	0.30260	0.02020
				Aspect ratio	42.684	1346.5	150.67	5.200
				Mass	0.19172	1.7030	9.6008	0.00020
4	a	Blowdown	15	Length	1.7429	0.97505	3.4697	0.48410
				Width	0.03601	0.00020	0.06050	0.02020
				Aspect ratio	49.781	925.66	122.86	22.857
				Mass	0.00700	0.00005	0.02410	0.00050
4	b	Blowdown	47	Length	8.7258	66.570	29.049	1.0490
				Width	0.04257	0.00142	0.20170	0.02020
				Aspect ratio	241.08	63981.0	1440.0	44.286
				Mass	0.10984	0.06001	0.93800	0.00100
9	a	Blowdown	22	Length	8.7403	39.726	22.593	0.76660
				Width	0.06068	0.00162	0.16140	0.02020
				Aspect ratio	227.68	52839.	800.00	7.6000
				Mass	0.08537	0.01886	0.48940	0.00200
11	a <sub>1</sub>	Basin	58	Length	1.8500	16.919	30.662	0.10090
				Width	0.02817	0.00020	0.10090	0.02020
				Aspect ratio	61.557	6246.4	300.00	3.5714
				Mass	0.01474	0.00882	0.71750	0.00020
11	b <sub>1</sub>	Basin	52	Length	6.7811	100.02	43.169	0.16140
				Width	0.03685	0.00093	0.16140	0.02020
				Aspect ratio	224.57	114260.	1700.0	5.333
				Mass	0.09518	0.18022	2.3926	0.00020
11	c <sub>2</sub>	Basin	33	Length	2.4537	10.791	16.945	0.16140
				Width	0.02592	0.00017	0.06030	0.02020
				Aspect ratio	94.215	10776.	420.00	8.8000
				Mass	0.00726	0.00060	0.14270	0.00020



## APPENDIX C. CONTINUED

Site No.	Sample	Source	No. Obs.	Variable*	Mean	Variance	Maximum	Minimum
12	c	Basin	47	Length	1.7735	2.0506	5.6484	0.24210
				Width	0.03698	0.00031	0.08070	0.02020
				Aspect ratio	52.357	1843.0	192.86	8.5714
				Mass	0.00770	0.00010	0.05800	0.00030
13	a <sub>1</sub>	Basin	17	Length	3.3629	21.608	17.348	0.16140
				Width	0.05123	0.00112	0.12100	0.02820
				Aspect ratio	54.672	3057.6	215.00	5.7143
				Mass	0.05662	0.01339	0.42140	0.00030
13	a <sub>2</sub>	Basin	10	Length	2.0657	3.1383	6.4553	0.28240
				Width	0.04515	0.00170	0.16140	0.02820
				Aspect ratio	54.243	1967.8	160.00	10.000
				Mass	0.02339	0.00322	0.18370	0.00050
13	a <sub>1</sub>	Riser	6	Length	3.0999	21.113	11.700	0.16140
				Width	0.04568	0.00138	0.12100	0.02820
				Aspect ratio	47.968	2508.3	174.00	5.7143
				Mass	0.06940	0.02337	0.39420	0.00030
					Individual Fiber Data			
Site No.	Sample	Source	No. Obs.	Variable*	1	2	3	4
5**	a	Makeup		Length	18.9623	2.5418	2.2593	0.7666
				Width	0.1412	0.1009	0.0605	0.0403
				Aspect ratio	134.2857	25.2000	37.3333	19.0000
				Mass	0.8696	0.0595	0.0190	0.0029

\*Units: length =  $\mu\text{m}$ ; width =  $\mu\text{m}$ ; mass =  $10^{-12}$  g.

\*\*Individual fiber data listed--data too few for statistical treatment.

# APPENDIX D. ESTIMATE OF ASBESTOS IN COOLING-TOWER WATER DUE TO AIR WASHING

Depending on the assumptions that are made, asbestos concentrations in cooling-tower water--due to washing of the incoming air that may contain asbestos--can be shown to be a small fraction of the total asbestos in cooling-tower water, or can account for the bulk of the asbestos in the water. An example calculation is shown below.

Given a natural-draft cooling tower with the following design characteristics (based on an actual tower):

Air flow rate =  $79.3 \times 10^6$  lb of dry air/hr

Blowdown = 2000 gal/min

Assume: Air temperature =  $22^\circ\text{C}$

Density of dry air = 0.001 g/ml

The volume of air flowing through the tower will thus be approximately equal to:

$$\frac{79.3 \times 10^6 \text{ lb/hr} \times 10^3 \text{ g/kg} \times 10^{-3} \text{ liter/ml} \times 10^{-3} \text{ m}^3/\text{liter}}{2.2 \text{ lb/kg} \times 1.2 \times 10^{-3} \text{ g/ml} \times 60 \text{ min/hr}} = 0.5 \times 10^6 \text{ m}^3/\text{min} .$$

Assume also that the asbestos concentration in ambient air is  $1 \times 10^{-9}$  g/m<sup>3</sup> (1 ng/m<sup>3</sup>), and that all the asbestos in the incoming air is washed out into the circulating water. The rate at which asbestos is coming into the tower is thus:

$$1 \text{ ng/m}^3 \times 0.5 \times 10^6 \text{ m}^3/\text{min} = 0.5 \times 10^6 \text{ ng/min} .$$

At equilibrium, assume that the rate of the incoming asbestos is equal to the rate at which asbestos leaves the tower in blowdown, i.e., in 2000 gal/min (ignore cycles of concentration). Also assume that the asbestos concentration in the blowdown is equal to the asbestos concentration in the circulating water. Therefore,

$$\text{asbestos in blowdown} = \frac{0.5 \times 10^6 \text{ ng/min} \times 10^{-3} \text{ } \mu\text{g/ng}}{2000 \text{ gal/min} \times 3.78 \text{ liter/gal}} = 0.066 \text{ } \mu\text{g/liter} .$$

If it is assumed that 1  $\mu\text{g}$  asbestos =  $10^6$  fibers, then the concentration of fiber in the blowdown will be  $6.6 \times 10^4$  fibers/liter, a concentration that would be on the order of the lower limit of detection using electron microscopy. If a fiber content of  $60 \times 10^6$  fibers/ $\mu\text{g}$  is assumed (see footnote on page 53), then the concentration in the blowdown will be  $3.96 \times 10^6$  fibers/liter and would probably be detectable.

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