Asbestos in Drinking Water Supplied Through Grossly Deteriorated A-C Pipe

James S. Webber, James R. Covey, and Murray Vernon King

High concentrations of asbestos were found in the water supply system of Woodstock, N.Y., following a routine pipe-tapping operation in the fall of 1985. Analysis of a water sample collected 10 days after tapping showed asbestos concentrations in excess of 10^4 million fibers per litre (MFL). The source of this asbestos was asbestos–cement (AC) pipe, which was so deteriorated that sections of pipe could be easily broken by hand. Although asbestos concentrations decreased rapidly as AC pipe was removed from the system, concentrations as high as 49 MFL were measured during the summer of 1986. Throughout the sampling period, even when concentrations fell below 1 MFL, Woodstock water samples were characterized by fibers with much larger lengths, widths, and masses than those collected in nonproblem areas across New York state.

A serious asbestos contamination problem in the Woodstock, N.Y., water supply became dramatically evident in late 1985.[1] Even with prompt remedial action that significantly reduced asbestos concentrations, the problem was chronic until 1987. This article provides a brief chronology of events in the Woodstock water district and a detailed presentation of analytical results.

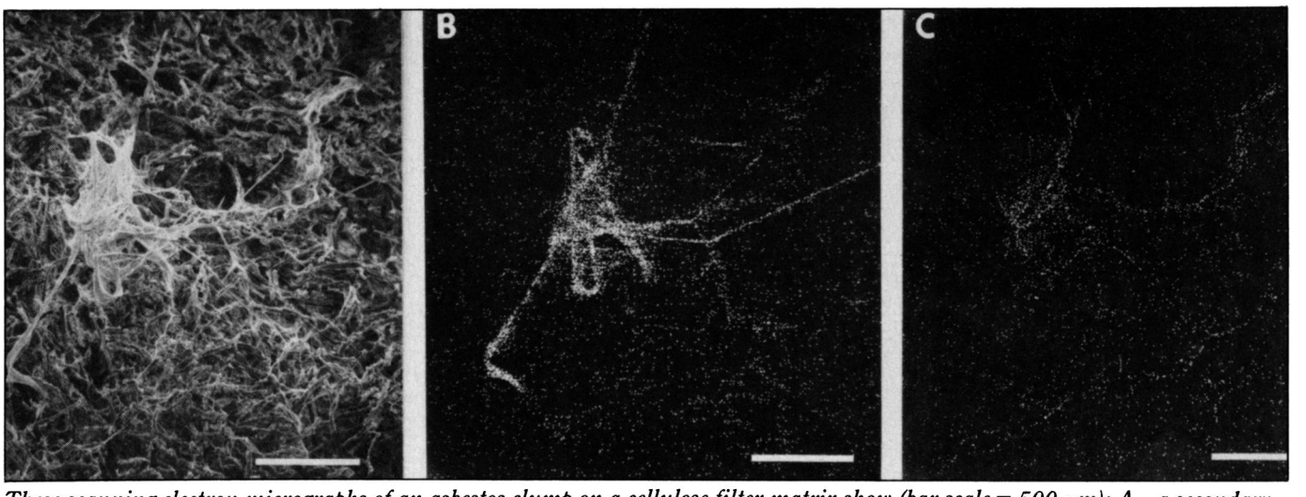
Methods

Water samples were analyzed for asbestos with a transmission electron microscope (TEM) using the interim US Environmental Protection Agency (USEPA) methodology.[2] Water samples were filtered through 0.1-μm-pore polycarbonate filters, and the filter surfaces were then carbon-coated in a vacuum evaporator. Sections were cut from the filters and placed on TEM grids in a chloroform atmosphere so that the filter dissolved, leaving a carbon film with trapped particles on the grid. These were examined at 20,000× and asbestos fibers positively identified by electron

TABLE 1

Asbestos in water samples collected in Woodstock, N.Y., from November 1985 to September 1986

Collection		Total		Chrysotile		Amphibole		Pooled Fiber Geometric Means			
Site	Date	*MFL*	*ng/L*	*MFL*	*ng/L*	*MFL*	*ng/L*	Length *μm*	Width *μm*	Mass *fg*	Aspect Ratio
A	11/25/85	305	11,300	302	9,880	2.90	1,430	0.980	0.0796	15.6	12.3
B		116	12,000	106	11,700	9.67	265	2.76	0.0705	35.1	39.2
F		3.19	483	2.32	175	0.870	307	2.06	0.0709	27.7	29.0
X		19.4	1,190	18.0	1,150	1.45	41.2	2.15	0.0657	23.7	32.8
V		78.3	9,670	74.7	7,070	3.63	2,600	2.63	0.0717	34.2	36.7
F	12/26/85	31.0	1,360	29.3	936	1.74	419	1.01	0.0641	10.5	15.8
A	12/27/85	17.2	1,020	15.6	567	1.63	453	1.24	0.0737	17.2	16.8
V	11/20/86	2.03	12.0	2.03	12.0	0.000	0.00	0.656	0.0502	4.13	13.1
F		1.74	110	1.74	110	0.000	0.00	2.15	0.0657	23.2	32.8
Z		5.80	178	5.51	102	0.290	76.1	1.34	0.0629	13.4	21.3
U		6.67	303	5.80	92.0	0.870	211	1.50	0.0604	14.1	24.8
W		4.35	242	3.77	236	0.580	6.74	1.02	0.0633	10.6	16.1
A		148	1,800	146	1,790	1.45	9.62	0.542	0.0585	4.65	9.26
E		129	9,400	122	9,130	7.25	271	0.674	0.0611	6.37	11.0
D		1,850	18,600	1,700	14,800	148	3,810	0.601	0.0592	5.37	10.2
V	1/24/86	0.725	16.1	0.725	16.1	0.000	0.00	2.68	0.0465	14.5	57.7
F		1.31	10.0	1.31	10.0	0.000	0.00	0.940	0.0462	5.02	20.4



These scanning electron micrographs of an asbestos clump on a cellulose filter matrix show (bar scale = 500 μm): A—a secondary electron image, B—a dot map of iron X-rays of crocidolite, and C—a dot map of magnesium X-rays of chrysotile. The filter was on line from September to November 1986.

diffraction were counted and measured. Individual fiber masses were calculated by multiplying the length times the width squared times the density (2.5 g/cm^3 for chrysotile or 3.25 g/cm^3 for amphiboles) and are reported as femtograms (fg = 10^{-15}g). Aspect ratios are simply length divided by width. Bulk samples were analyzed by polarized-light microscopy with dispersion staining (PLM-DS).[3] Because of the log-normal distribution of most measurements taken in this investigation, mean values, unless otherwise noted, are given as geometric means.

Sequence of events

Drastic changes were noticed in Woodstock's water supply following a routine main-tapping operation Oct. 26, 1985. Water pressure in houses near the worksite dropped to a trickle. Elsewhere, water was clouded with a suspension of threadlike white and blue fibers. In one instance, a person taking a shower was covered with fibers. Accumulations of fibers in faucet screens were quickly identified as the cause of the water-pressure drop.

A whole-water sample collected November 1 was so cloudy with fibers that clumps could be easily removed with forceps. These fibers were identified by PLM-DS as chrysotile (white asbestos) and crocidolite (blue asbestos). A water sample collected November 4 was not cloudy but did contain some small visible fibers. The water distribution system was flushed in an effort to remove asbestos fibers, and samples were collected in late November when fibers were no longer visible. When analyses revealed asbestos concentrations in the hundreds of million fibers per litre (MFL), a water-use advisory was put into effect to minimize possible health risks. Sections of asbestos-cement (AC) pipe in the western part of Woodstock were so deteriorated that they could be crumbled by hand. There were no records to indicate whether or not the pipe had been autoclaved during manufacture. The asbestos types in the AC pipes were confirmed as chrysotile and crocidolite by PLM-DS analysis. Consequently, the town initiated an emergency program to replace all known sections of AC pipe in the distribution system with cement-lined ductile iron pipe, a process that was completed June 3, 1986. Although overall asbestos concentrations in the system did decline during this period, intermittently high concentrations were measured at various sites (Table 1). Throughout the spring and summer of 1986, a series of flushings was performed

TABLE 1, continued

Asbestos in water samples collected in Woodstock, N.Y., from November 1985 to September 1986

Collection		Total		Chrysotile		Amphibole		Pooled Fiber Geometric Means			
Site	Date	*MFL*	*ng/L*	*MFL*	*ng/L*	*MFL*	*ng/L*	Length *μm*	Width *μm*	Mass *fg*	Aspect Ratio
Z	1/24/86	8.41	389	8.27	367	0.145	21.6	2.22	0.0609	20.6	36.4
U		0.580	7.32	0.435	4.37	0.145	2.95	0.880	0.0618	8.98	14.2
Y	3/10/86	3.05	159	3.05	159	0.000	0.00	1.74	0.0549	13.1	31.6
V		3.63	652	2.90	611	0.725	40.8	2.85	0.0646	31.4	44.1
Y	3/18/86	1.60	46.1	1.60	46.1	0.000	0.00	2.63	0.0613	24.7	42.9
V		2.90	149	2.76	137	0.145	11.5	2.17	0.0605	20.1	35.9
C	6/9/86	0.638	54.9	0.580	37.2	0.0580	17.7	3.91	0.0564	31.8	69.2
Y		3.19	84.6	3.09	84.4	0.0970	0.280	3.34	0.0393	13.0	85.0
V		0.387	10.8	0.387	10.8	0.000	0.00	2.32	0.0384	8.55	60.6
V	7/7/86	8.12	37.8	7.83	29.4	0.290	8.41	0.771	0.0365	2.59	21.2
C		49.3	4,090	45.0	1,840	4.35	2,250	1.38	0.0599	12.6	23.0
Y	9/15/86	1.19	33.6	1.19	33.6	0.000	0.00	2.49	0.0374	8.71	66.4
V		0.395	20.6	0.395	20.6	0.000	0.00	1.71	0.0409	7.15	41.8
C		1.19	27.8	1.05	24.8	0.132	3.02	1.43	0.0472	8.17	30.3
1	1/10/86	0.290	2.11	0.290	2.11	0.000	0.00	0.699	0.0645	7.27	10.8
2		0.290	1.50	0.290	1.50	0.000	0.00	1.25	0.0406	5.16	30.8

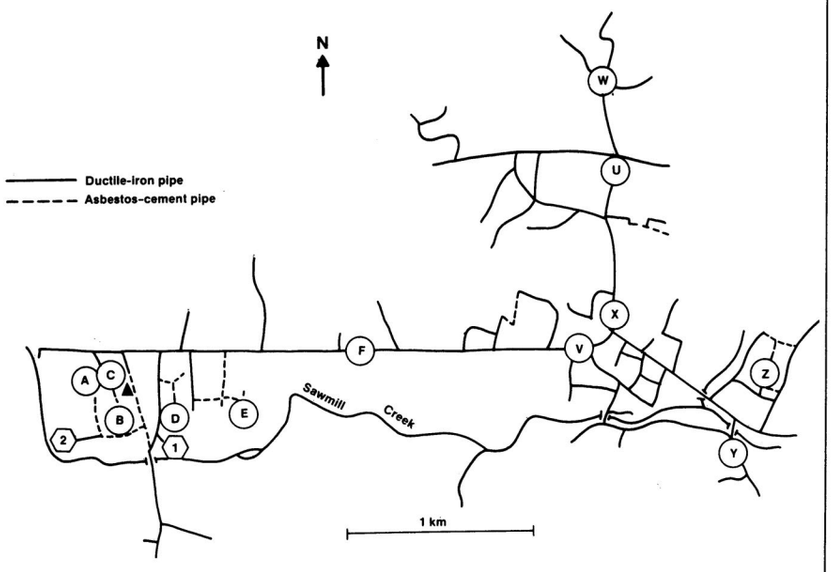


Figure 1. Map of Woodstock water distribution system showing sampling locations *(letters and numbers indicate sampling sites; dark triangle is site of October 1985 tapping)*

TABLE 2
Geometric means of groups of water samples from Woodstock, N.Y., categorized by sampling period

Sampling Period	Asbestos Concentration		Length	Width	Mass	Aspect Ratio
	MFL	*ng/L*	*μm*	*μm*	*fg*	
1985	36.8	2,700	1.64	0.0709	21.0	23.2
Early 1986	6.37	181	0.966	0.0596	8.70	16.2
Mid-1986	1.91	59.5	1.45	0.0495	9.02	29.3

TABLE 3
Geometric means of groups of water samples from Woodstock, N.Y., categorized by geographic location

Sampling Period	Asbestos Concentration		Length	Width	Mass	Aspect Ratio
	MFL	*ng/L*	*μm*	*μm*	*fg*	
East	2.96	96.9	1.92	0.0575	16.1	33.4
West	21.3	692	1.08	0.0649	11.5	16.6

TABLE 4
Geometric mean fiber measurements in Woodstock and non-Woodstock (within New York state) water samples

Sampling Category	Length *μm*	Width *μm*	Mass *fg*	Aspect Ratio
Non-Woodstock	0.858	0.0426	3.93	20.2
Woodstock (total)	1.32	0.0622	13.0	21.2
Woodstock (<5 MFL)	2.07	0.0536	15.2	38.6
Woodstock (>100 MFL)	0.946	0.0657	10.3	14.4

and large sections of water mains were mechanically scrubbed.

Cellulose cartridge filters were installed during early 1986 in houses in the western part of town where most of the deteriorated AC pipe was located. Selected cartridges were removed on a periodic basis and sent to the New York State Department of Health (NYSDOH) laboratory for surface analysis by PLM-DS. Disturbingly, large (>5 mm) asbestos fibers were identified even after all known AC pipe had been removed from the system. In fact, such fibers were identified on filters that had been in service for only 10 days in January 1987, six months after the last AC pipe section had been bypassed. After extensive investigation, in February 1987 mats of residual asbestos were found on coarse screens inside individual water service meters. After these screens and water meters were replaced, asbestos concentrations consistently fell below 1 MFL and all aspects of the water-use advisory were lifted in 1988.

Results

Sample collection dates were divided into three periods: 1985 (November and December); early 1986 (January through March); and mid-1986 (June through September). Sampling locations, as identified in Figure 1, were designated as west (sites A through F) and east (sites U through Z). Two samples (sites 1 and 2) collected at groundwater source pumping stations were not included in either category in this study because water at neither of these sites had passed through AC pipe.

The most striking temporal change was the decrease in fiber concentrations during the 10-month sampling period. The sharpest drop was recorded during the first four months of the investigation when mean fiber concentrations dropped from 36.8 to 6.37 MFL (Table 2). Mass concentrations also declined abruptly, from 2,700 to 181 ng/L. This decrease indicated that the major sources of fibers had been removed or flushed from the system by early 1986. The decrease from early 1986 to mid-1986 was not as pronounced, showing that the drinking water supply was nearing a steady state, with contributions from smaller contamination sources. Continued detection of large asbestos fiber clumps on cartridge filters as late as early 1987 revealed that fugitive fibers were still in the system. These clumps were probably the source of the spike collected at site C July 7, 1986 (Table 1).

Temporal changes in individual fiber dimensions were almost as obvious. Mean fiber length did not consistently decrease but mean fiber width did decrease during the sampling period (Table 2). The thicker fibers seen early in the study were primarily multifibril

chrysotile, and these were gradually replaced by single-strand chrysotile. This caused a noticeable drop in mean fiber mass from 21.0 fg in 1985 to 9.02 fg by mid-1986. The shearing effect on fibers impinged on meter screens may have contributed to this size reduction.

Mean fiber and mass concentrations were greater in western Woodstock than in the eastern portion of the system (Table 3). The greatest difference occurred in early 1986 when concentrations were 38.1 MFL in the west and 2.60 MFL in the east. This was not surprising because most of the deteriorated AC pipe was located in the west. Because the wells providing the corrosive groundwater were located at the western end of the system, AC pipes at that end may have been more severely eroded in a corrosivity gradient suggested by McCabe and Millette.[4] During early 1986 while the deteriorated AC pipe in the west was being replaced, a water-main shunt was installed to bypass the western segment of the system so that water from the wells could be sent directly to the eastern segment. The high concentrations in the west during this period probably resulted from this localization of deteriorated AC pipe and from physical disturbances caused by workers who were replacing AC pipe in the west. Earlier in 1985 concentrations had been similar (36.0 MFL in the west versus 39.0 MFL in the east). This was probably attributable to the uninterrupted dispersion of asbestos from the deteriorated AC pipe throughout the system. The difference was small again in mid-1986 (3.35 MFL in the west versus 1.36 MFL in the east). This reflected the removal of the gross contamination sources and the uniformity of lessened contamination from water meter screens.

Fiber dimensions also showed an east-west gradient. Shorter but wider fibers in the west resulted in much smaller aspect ratios than in the east. Aspect ratios were inversely correlated to fiber concentrations.

During approximately the same period that Woodstock water was being analyzed for asbestos, other drinking water samples from across the state were also being analyzed. The non-Woodstock samples came from a variety of sources and ranged from very clear to very cluttered with particulate matter, especially those from surface water sources. Fiber concentrations were generally much lower in the non-Woodstock samples, as expected, with a maximum concentration of 35 MFL. The lengths and widths of Woodstock fibers were slightly larger (Figure 2) than those of the non-Woodstock fibers. Fibers longer than 50 μm were detected only in 1985. Fibers longer than 10 μm were detected in 21 of 30 Woodstock samples but in only 1 of 23 non-Woodstock samples, and

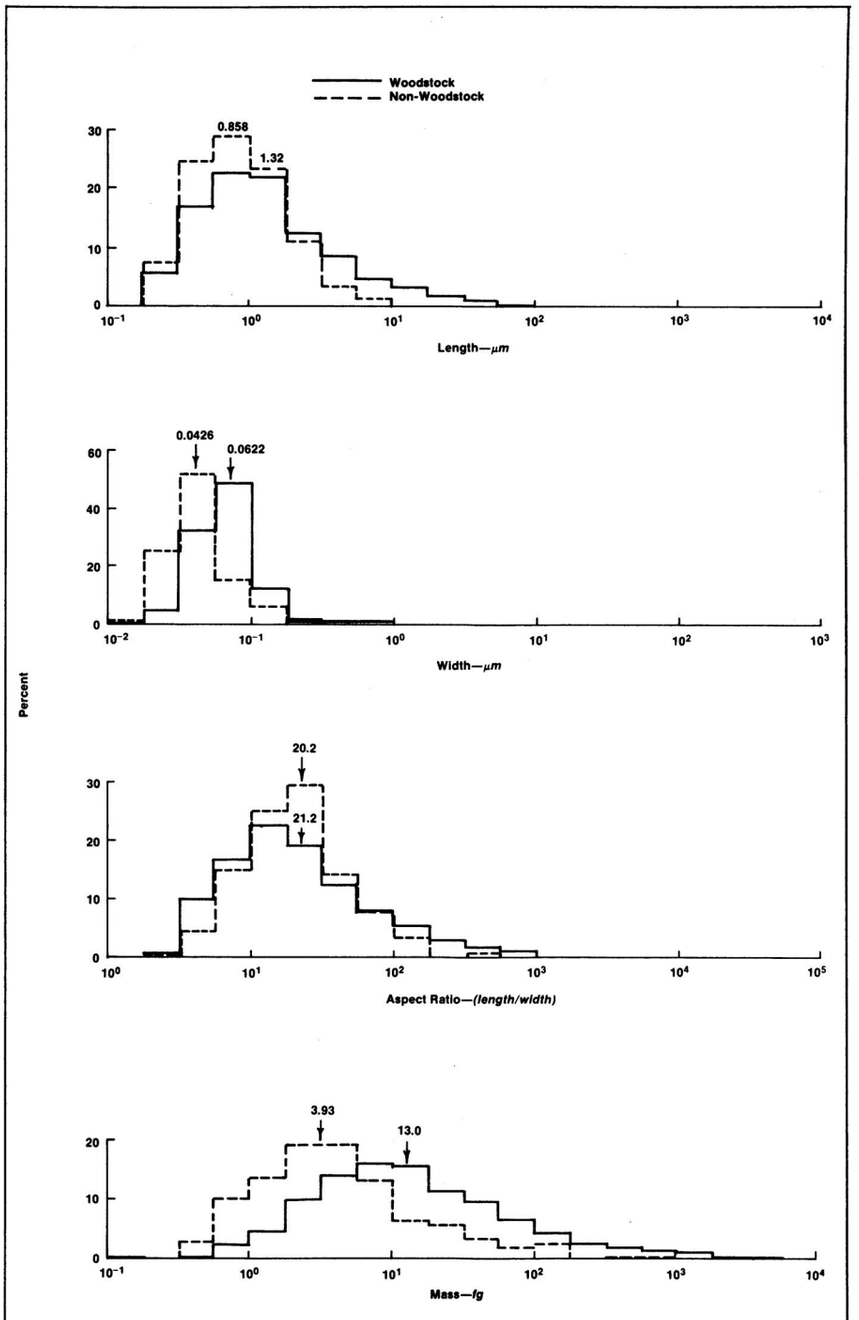


Figure 2. Distribution of individual asbestos fiber measurements collected in water samples from Woodstock and non-Woodstock sources in New York state *(numbers with arrows indicate geometric mean dimension)*

TABLE 5

Amphibole composition in Woodstock and non-Woodstock (within New York state) water samples

Measurement	Amphibole Composition of Woodstock Samples—*percent*				Amphibole Concentration of Non-Woodstock Samples—*percent*
	1985	Early 1986	Mid-1986	Total	
MFL	9.1	5.6	4.5	6.1	6.2
ng/L	26	13	15	17	20

TABLE 6
Arithmetic mean fiber dimensions of waterborne asbestos collected from Woodstock and other sources

Source	n	Length μm	Width μm	Aspect Ratio	Maximum Length μm
Woodstock	1,383	3.0	0.069	48	68
Non-Woodstock	294	1.3	0.049	30	38
AC pipe systems (Florida, Pennsylvania, and South Carolina)[16]	1,440	4.3	0.044	121	80
Silver Lake (New York)[17]	484	0.55	0.083	6.6	4.4
Lake Superior (Minnesota)[16]		1.7	0.18	8	18
Natural erosion (California)[16]	644	1.3	0.04	39	25
Natural erosion (Washington)[16]	289	0.8	0.034	39	10

that was in a raw water sample. Overall, these long fibers constituted 6.7 percent of the Woodstock fibers but only 0.35 percent of the non-Woodstock fibers. Relative composition of long fibers in Woodstock water did not vary over time, ranging from 5 to 8 percent during all three time spans. There was little correlation between long fibers and total MFL because long fibers were detected in Woodstock samples ranging from 0.395 to 305 MFL. Although long fibers were more abundant in the east (10.9 percent) than in the west (4.44 percent), fibers longer than 50 μm were seen only in the west. Most of the long fibers were chrysotile, but long amphibole fibers were seen intermittently throughout the investigation. The narrower fibers in the non-Woodstock (uncontaminated) samples are consistent with the temporal trend seen in Woodstock; multifibril chrysotile was observed most frequently during the period of gross contamination and was largely absent from later Woodstock samples after contamination sources had been reduced.

There was surprisingly little difference in aspect ratios between Woodstock and non-Woodstock fibers except for the paucity of ratios greater than 100 in the non-Woodstock group. Given the impingement of very long fibers on the Woodstock cartridge filters and the generally high aspect ratios of commercial asbestos used in manufacturing AC pipe, larger aspect ratios were expected in the Woodstock samples. Instead there was a simple cancellation of the larger Woodstock dimensions when length was divided by width.

The most noticeable difference between Woodstock and non-Woodstock asbestos was the much larger mass of the Woodstock fibers. Because mass is a cubic product of fiber dimensions, slightly longer and wider Woodstock fibers produced much larger masses. The size differential was consistent, observable for Woodstock fibers from samples with low (<5 MFL) and high (>100 MFL) asbestos concentrations (Table 4). This distinction may be due to entrainment of entire bundles of asbestos in Woodstock versus the occasional release of single fibers from nondeteriorating pipes in other water systems. Woodstock data in Table 4 also reinforce the trend in aspect ratios previously discussed for east versus west. The difference appears to be closely related to fiber concentration. When fiber concentrations are high, the fibers tend to be shorter but thicker, thus producing much smaller aspect ratios but similar fiber masses.

The percentage of amphibole asbestos in the water samples was greatest in 1985 (Table 5). Amphibole fiber concentrations decreased from 9.1 percent of the total MFL in 1985 to 4.5 percent by mid-1986. Amphibole mass concentrations likewise decreased, from 26 percent of the total nanogram-per-litre concentration in 1985 to 15 percent by mid-1986. Overall, however, the amphibole composition of all Woodstock water samples was similar to non-Woodstock samples. In both cases, amphibole fibers constituted a larger mass percentage than fiber percentage. This reflected the larger size of amphibole fibers, compared with chrysotile fibers. Most of the amphibole fibers were not analyzed by energy-dispersive X-ray spectroscopy but for those that were, Na and Fe X-rays identified them as crocidolite. This was consistent with the composition of the AC pipes.

Discussion

Even though asbestos concentrations in the hundreds and even thousands of MFLs were measured during this survey, it was obvious that concentrations had been even higher immediately following the Oct. 26, 1985, tapping. Two water samples were collected in western Woodstock within 10 days of the tapping operation, but because full documentation was not available for either sample (both were collected in mason jars and were accompanied by handwritten notes), neither one was presented with the formally collected samples summarized in Table 1. Water collected November 1 was so milky with asbestos that filtration would have been impossible and homogeneous dilution would have been difficult because of the large clumps. Because of the visible presence of a few small fibers in the water collected November 4, the sample was put through two different dilutions. Results of analyses of the two dilutions were in agreement at 1.39×10^4 and 1.56×10^4 MFL and 5.32×10^5 and 6.89×10^6 ng/L. But the overall contamination problem may have started earlier than the October 1985 tapping. In December 1985 the authors received a washing-machine strainer that had reportedly been removed from service two years earlier. The strainer was matted with chrysotile and crocidolite. Analysis of water that had been stored in an unused plastic jug in a camping trailer for approximately 10 years yielded chrysotile concentrations in excess of 2 MFL. Given the tendency for chrysotile to settle and become attached to container walls,[5] 2 MFL may be a conservative estimate of the actual contamination.

Millette et al[6] reported that of 406 water supply systems surveyed in the United States, more than 80 percent had asbestos concentrations below 1 MFL and fewer than 10 percent had concentrations exceeding 10 MFL. Waterborne asbestos concentrations that exceed 10^3 MFL, as observed in Woodstock, have been documented in very few instances. Chrysotile concentrations of up to 2.6×10^5 MFL have been reported from California surface waters flowing over serpentine bedrock.[7,8] Amphibole concentrations approaching 10^3 MFL have been measured in Lake Superior near a taconite tailings disposal site during storm periods.[9] In both instances, however, fiber sizes were much smaller than those in Woodstock. The larger size of fibers from deteriorated AC pipe in Woodstock is consistent with the observation that fibers from AC pipe are longer than fibers from erosion.[10] Table 6 summarizes arithmetic-mean fiber-size distributions from a variety of sources. With the exception of aspect ratios, the Woodstock fibers are similar to those from AC-pipe systems in other states, whereas non-Woodstock fibers are closer to erosion-generated fibers. The aspect ratios of the Woodstock fibers were smaller than those from other AC systems because of the wider fibers in Woodstock water.

Millette et al[10] reported that tapping AC pipe may release asbestos into the water. The tapping operation in Woodstock certainly brought the problem to the public's attention. The initial high level of asbestos may not have been directly caused by the actual tapping but rather by the shearing effect of the rushing water filling the emptied AC pipes following the completion of the operation. Accumulated sediments in dead-end areas and unflushed hydrant runs have been reported as sources of asbestos.[4] The authors recently observed

such an occurrence in Red Hook, only 20 km east of Woodstock. Samples collected from a hydrant at a dead-end water main following a tapping operation contained 8 MFL, whereas all other samples in the Red Hook distribution system contained less than 1 MFL. The dead end located northwest of site A in Woodstock (Figure 1) may have contributed to the initial slug of asbestos.

In any case, the tapping operation and associated shearing action would not have created gross contamination if the AC pipe had retained its integrity. As mentioned earlier, the AC pipe in Woodstock was easily crumbled with finger pressure when uncovered during remedial action. Highly aggressive water can speed deterioration of AC pipe,[4] and the corrosivity (Langelier Index of −3.1) of Woodstock water probably played a major role in AC pipe degradation. Observation by scanning electron microscopy of AC pipe after exposure to aggressive water showed such badly pitted surfaces that fiber bundles were exposed.[11] Other factors may have contributed to the deterioration because mean asbestos concentrations were less than 1 MFL in water samples carried by AC pipes in Fallsburg (60 km southwest of Woodstock), where the water was even more aggressive, with a Langelier Index as low as −4.0. Possible reasons why corrosivity may not be directly correlated to AC-pipe degradation are discussed by Schock and Buelow.[12] In the case of Fallsburg, a sequestering agent had been routinely added to the water to minimize iron discoloration. Sections of AC pipe that were taken from Fallsburg were checked for integrity, and, although the interiors were somewhat soft, a coat of slime, probably from the sequestering agent, covered the interior surface. Serious contamination episodes of asbestos in drinking water, as have occurred in the past,[6] will undoubtedly occur in the future. There were some 200 million mi of AC pipe in use in the United States as of 1972,[13] and as many as 68 percent of water supply systems may have water sufficiently aggressive to corrode AC pipe.[4]

The health effects of ingested asbestos are still unclear.[14] Based on laboratory investigations with animals, the USEPA has recently published a recommended maximum contaminant level of 7.1 MFL of long asbestos (>10 μm) in drinking water. The sample collected Nov. 4, 1985, contained 3,000 MFL long fibers but once the main flushing and replacement program was initiated, only two more samples contained more than 7.1 MFL long fibers. Both were in the batch collected Nov. 25, 1985 (16.4 MFL at site B and 10.9 MFL at site V). In general, long fibers constituted less than 10 percent of the total fibers and were at low levels (<3 MFL) throughout 1986, even in the Jan. 10, 1986, samples that contained 129 and 1,850 MFL.

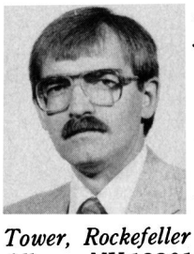
It should be mentioned that results generated by the USEPA procedure are biased in favor of short fibers because fibers intersecting grid bars cannot be counted. In 15 of the 31 samples analyzed from Woodstock, from 1 to as many as 18 fibers intersected grid bars. When visible portions of the fibers inside the grid square were measured, the mean length of these 64 fibers was 14.6 μm. When these results were added to the pool of the other 1,383 fibers, the arithmetic mean length increased from 3.00 to 3.52 μm, and the fiber-length range was extended to 72.6 μm.

Pulmonary exposure to asbestos, an unequivocally carcinogenic combination, cannot be overlooked in cases in which drinking water is grossly contaminated. Increased levels of airborne asbestos were found in Woodstock homes,[15] but fortunately the increase in these levels did not raise the fiber count above background levels as measured in urban environments. Furthermore, most of the increase was composed of fibers shorter than 1 μm.

The Woodstock data show that the fiber concentration in a single water sample is not always a reliable indicator of a contamination problem. For example, even though two samples (E and F) were collected less than 1 km apart Jan. 10, 1986, waterborne asbestos concentrations differed by more than three orders of magnitude. This investigation did, however, show individual fiber characteristics that distinguished asbestos from systems with deteriorated AC pipe. The most obvious difference was the presence of large fibers. Multifibril chrysotile was most abundant in the 1985 Woodstock samples when water was still passing through deteriorated AC pipe but multifibril chrysotile decreased as the system was repaired. This was consistent with the paucity of multifibril chrysotile in the non-Woodstock samples. Extremely long fibers were also more common in Woodstock samples. Thus, there is reason to be suspicious when long fibers are observed or when fiber-mass distributions are similar to those of Woodstock, even if fiber concentrations are low. Surprisingly, large aspect ratios and the presence of amphibole asbestos were not unique to Woodstock samples.

References

1. COVEY, J.R. Asbestos in New York State Drinking Water: the Town of Woodstock Asbestos Problem. Proc. 1986 AWWA Ann. Conf., Denver, Colo.
2. ANDERSON, C.H. & LONG, M. Interim Method for Determining Asbestos in Water. EPA-600/4-80-005 (1980).
3. WEBBER, J.S.; PUPONS, A.; & FLESER, J.M. Quality-Control Testing for Asbestos Analysis With Synthetic Bulk Samples. *Amer. Industrial Hygiene Assn. Jour.*, 43:427 (1982).
4. MCCABE, L.J. & MILLETTE, J.R. Health Effects and Prevalence of Asbestos Fibers in Drinking Water. Proc. 1979 AWWA Ann. Conf., San Francisco, Calif.
5. CHATFIELD, E.J. ET AL. Asbestos Fiber Determination in Water Samples: Preparation Techniques, Improved Analytical Method, and Rapid Screening. EPA-600/S4-83-004 (1983).
6. MILLETTE, J.R. ET AL. Asbestos in Water Supplies of the United States. *Environ. Health Perspectives*, 53:45 (1983).
7. HAYWARD, S.B. Field Monitoring of Chrysotile Asbestos in California Waters. *Jour. AWWA*, 76:3:66 (Mar. 1984).
8. MCGUIRE, M.J.; BOWERS, A.E.; & BOWERS, D.A. Asbestos Analysis Case History: Surface Water Supplies in Southern California. *Jour. AWWA*, 74:9:470 (Sept. 1982).
9. COOK, P.M.; GLASS, G.E.; & TUCKER, J.H. Asbestiform Amphibole Minerals: Detection and Measurement of High Concentrations in Municipal Water Supplies. *Sci.*, 185:853 (1974).
10. MILLETTE, J.R.; CLARK, P.J.; & PANSING, M.F. Exposure to Asbestos From Drinking Water in the United States. EPA-600/1-79-028 (1979).
11. CLARK, P.J.; MILLETTE, J.R.; & BOONE, R.L. Asbestos-Cement Products in Contact With Drinking Water: SEM Observations. *SEM*, I:341 (1980).
12. SCHOCK, M.R. & BUELOW, R.W. The Behavior of Asbestos-Cement Pipe Under Various Water Quality Conditions: Part 2—Theoretical Considerations. *Jour. AWWA*, 73:12:44 (Dec. 1981).
13. OLSON, H.L. Asbestos in Potable Water Supplies. *Jour. AWWA*, 66:9:515 (Sept. 1974).
14. *Fed. Reg.*, 50(210):46961 (Nov. 13, 1985).
15. WEBBER, J.S.; SYROTYNSKI, S.; & KING, M.V. Asbestos-Contaminated Drinking Water: Its Impact on Household Air. *Envir. Res.*, 46:153 (1988).
16. MILLETTE, J.R. ET AL. Concentration and Size Distribution of Asbestos in Water Supplies. *Envir. Health Perspectives*, 34:13 (1980).
17. MARESCA, G.P.; PUFFER, J.H.; & GERMINE, M. Asbestos in Lake and Reservoir Waters of Staten Island, New York: Source, Concentration, Mineralogy, and Size Distribution. *Envir. Geol. Water Sci.*, 6:201 (1984).



About the authors: *James S. Webber is a research scientist in the Wadsworth Center for Laboratories and Research of the New York State Department of Health (NYSDOH), Corning Tower, Rockefeller Empire State Plaza, Albany, NY 12201. Webber has spent the last nine years characterizing microparticles in the environment by electron microscopy. James R. Covey is an associate civil engineer in the Bureau of Public Water Supply Protection with the NYSDOH, and Murray Vernon King is a research scientist, also at the Wadsworth Center.*