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PLAINTIFF'S EXHIBIT

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Chrysotile Asbestos Fibers in Drinking Water from Asbestos–Cement Pipe

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■ Chrysotile asbestos fiber counts were compared in drinking water samples taken before and after flow through asbestos–cement pipes in the San Francisco Bay area. The drinking water supplies in that area are chemically nonaggressive by the standard measures. In one major distribution system, mean chrysotile counts were 115 times greater in drinking water after flow through the pipe. This demonstration of substantial increases in asbestos fiber counts in nonaggressive drinking water raises questions as to the validity of aggressiveness indexes for prediction of fiber release from asbestos–cement pipes.

Many issues have been raised as to the possible health risks to the general population from exposure to asbestos in the environment (*1*). A key question is whether fibers are released to drinking water passing through asbestos–cement (A–C) pipe (*2*). At least 1.5×10^6 mi of such pipe are in use worldwide, with more than 200 000 mi in U.S. drinking water systems (*3*). The need to answer this question is now more important because of the results of our recent epidemiological investigation in the San Francisco Bay area which revealed statistical associations between the presence of chrysotile asbestos fibers in drinking water systems and the incidence of digestive and other cancers (*4*, *5*).

Thirty-nine drinking water samples paired before and after passing through asbestos–cement pipe were taken for asbestos fiber counting as part of the 372 drinking water samples collected during the effort to assess levels within the water distribution systems of the San Francisco Bay area for the epidemiology study. Undoubtedly, the primary sources of asbestos fibers in some of the drinking water supplies in this area are watersheds and reservoirs consisting largely of serpentine rock, the parent material for chrysotile asbestos. Mean chrysotile asbestos fiber counts (in fibers/L) for the major water systems were 2.7×10^5 for Pardee, 2.5×10^5 for Contra Costa Canal, 2.6×10^6 for Hetch Hetchy, 4.1×10^7 for Crystal Springs, 5.1×10^6 for San Andreas, and 1.9×10^6 for San Geronimo/Bon Tempe. This report describes the field data relating to the possible additional release of fibers from asbestos–cement pipe.

There are limited data on the question of release of fibers from asbestos–cement pipe. A 1974 study revealed that asbestos fibers can be transferred from the pipe wall to water circulating through a closed A–C pipe loop, not buried in the soil. Field samples from Malvern, PA, and Glendale, AZ, showed possible release of fibers from pipe walls, and the amount of release appeared not to be significantly influenced by the existing fiber level in the water before flow through the pipes (*6*). Studies of private wells and municipal waters in Rio Grande Valley, NM, and Illinois showed no evidence of significant increases in fiber counts attributable to pipe (*7*, *8*).

It has been assumed that there is a positive correlation between fiber release from the walls of A–C pipe and the "aggressiveness" or corrosiveness of water. An index of aggressiveness has been formulated as follows (*9*):

$$\text{aggressiveness index} = \text{pH} + \log (AH)$$

where A = total alkalinity in mg/L $CaCO_3$ and H = calcium hardness in mg/L $CaCO_3$. The definitions for the degrees of aggressiveness for the index are as follows: highly aggressive, $\text{pH} + \log (AH) \leq 10.0$; moderately aggressive, $\text{pH} + \log (AH) = 10.0\text{–}11.9$; nonaggressive, $\text{pH} + \log (AH) \geq 12.0$.

A 1979 paper by EPA personnel detailed the results of their pipe study in 10 public water supplies in the U.S. (*10*). There appeared to be significant releases of fibers from A–C pipes in only the five systems with highly aggressive water. A 1978 epidemiologic study in the state of Connecticut of the use of A–C pipe in public water supplies and the incidence of gastrointestinal cancers showed no obvious correlations (*11*). The supplies were not exposed to significant amounts of naturally occurring asbestos. Asbestos fiber counts in water systems in Connecticut were rarely over 1×10^5 fibers/L. In comparison to West Coast water supplies exposed to asbestos-bearing rock, or the drinking water of Duluth, these values are relatively low. A 1980 reanalysis (*12*) of the Connecticut data utilizing more sophisticated statistical techniques also showed no consistent associations between asbestos fiber content of town drinking water and cancer incidence. It must be remembered that asbestos–cement pipe was not installed in any parts of Connecticut until 1955, and the possible maximum

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latent period for asbestos-related tumors is up to 40–50 yr. Thus it may be too soon for definitive conclusions in Connecticut.

Experimental Section

The water sampling program for the San Francisco Bay epidemiology study was designed to assess the levels of asbestos in the drinking water of the area's different water distribution systems. The collection of water samples before and after flow through varying lengths of A–C pipe was only one of several factors involved in this overall assessment of asbestos in drinking water supplies. Most "before" A–C pipe samples were collected from treatment-plant effluents or at the main turnout going into a community. Samples were then taken on the same day from various taps within the distribution system to determine continuity of values throughout the area. Since the primary concern of the study was to determine asbestos fibers per liter of drinking water received by the population, the "after" A–C pipe samples were often taken from a tap near the extremity of a system.

The sampling period for the pipe data was July 1974 to March 1978, with most of the data gathered after August 1976. Turbidity and pH were measured on all samples collected after August 1976. Total alkalinity and total hardness (both recorded in mg/L $CaCO_3$) were measured on all samples taken after March 1977. Aggressiveness indexes were derived for all samples. Calcium-hardness values were calculated from average calcium hardness to total hardness ratios for each system. Samples taken before March 1977 were assigned aggressiveness values calculated from measured pH and from estimated alkalinity and hardness averages from each district's historical water quality records. The length, the diameter, and the age of A–C pipe involved in the before–after samples were determined by reviewing maps of districts and consulting with water purveyors. The characteristics of the A–C pipe and the drinking water sampled are presented in Table I. All of the drinking waters of the Bay area rate as nonaggressive or moderately aggressive according to the standard scale. Even the moderately aggressive waters tend toward nonaggressiveness on the scale.

Water samples were collected in 0.5-gal glass bottles cleaned with hot detergent water and rinsed with glass-distilled water. The asbestos content of the distilled water was below detectable limits of the analysis. Before each water sample was collected, the glass bottle was rinsed several times at the sample site with the water to be analyzed. Water samples were filtered through 0.45-μm size Millipore filters. The Millipore filter material, which is a cellulose ester, was removed from the residue by acetone vapor in a cold-finger Soxhlet extractor. This was accomplished by first covering collodion-coated 200-mesh nickel grids with a thin layer of carbon in a high-vacuum optical coater and then placing the grids on the cold finger. Disks of the Millipore filter, 3.3 mm in diameter, were placed particulate side down on the prepared grids. The cold finger was then placed into the extractor cold and the acetone reservoir heated to just below the boiling point of acetone, a temperature sufficient to produce a very slight tremor. The Millipore filter was dissolved in 6–12 h, leaving any particulate matter from the filtered water sample on the grid.

The grids were examined and fibers counted by using a Sieman Elmiskop electron microscope at 10 000× optical magnification. One grid opening of the 200-mesh grid is considered one field. Twenty fields were counted in grids which had a moderate or small number of fibers or where there were no fibers detected. In cases of samples heavily loaded with asbestos fibers, a sufficient number of fields were counted to get a total of 100 fibers. The number of fibers counted were related to the grid area counted, to the whole grid, to the filter area, and to the volume of sample filtered. This count was recorded as the number of fibers of either chrysotile or unidentified fibers per liter of water. The lowest detectable limit of asbestos concentrations in tap water was between 1×10^4 and 1×10^5 fibers/L, depending on the turbidity and the subsequent amount of water sample filtered. The diameter and the length of each fiber were measured and recorded per field. Chrysotile asbestos fibers were identified and distinguished from other fibers by a combination of morphology and selected area diffraction patterns using the transmission electron microscope. Several split samples were analyzed by another laboratory with almost identical results. In many of the water samples, unidentified fibers were observed. Unidentified fibers could have been amphibole asbestos fibers, fibrous talc, or halloysite (a type of fibrous clay).

Results

Table II presents the mean chrysotile fiber counts before and after sections of A–C pipe for each system. When the sample result was below the detectable limit of the analysis (BDL), the lowest detectable limit (LDL) value of the analysis was used as the sample count in taking the mean. The nonparametric Sign test was used for an overall view of increase or decrease in chrysotile counts on the 39 pairs of before–after observations (*13*). There were 19 pairs in which increases were observed; 9 pairs showed decreases; and 11 pairs exhibited no change in fiber count between before and after observations. The Sign test included a correction for continuity and treated each no-change observation (tie) as ½ increase and ½ decrease. The Sign test yielded a p value of 0.039. This indicates a moderate statistical significance, falling between the usual α levels of 0.05 and 0.01. Each system was then analyzed separately, yielding p values of 0.79 for system A, 0.50 for system B, and 0.01 for system C. The number of pairs recorded on

Table I. General Characteristics of Asbestos–Cement Pipes and the Drinking Waters Sampled

	water system			
	A	B	C	others
pipe				
median age (yr)	18.5	20.25	22	9
median length (m)	541	1986	1951	2050
median diameter (cm)	20.32	30.48	20.32	25.4
water				
mean pH	8.96	8.03	9.20	7.79
mean total alkalinity (mg/L Ca CO_3)	82.37	83.20	53.20	129.98
mean calcium hardness (mg/L Ca CO_3)	42.6	79.18	23.05	82.35
mean *before* aggressiveness index	12.28	11.83	11.93	11.30
mean *after* aggressiveness index	12.52	12.05	12.54	12.07
mean aggressiveness index of all samples	12.4	11.94	12.24	11.95
overall aggressiveness	none	moderate	none	moderate

Table II. Mean Chrysotile Asbestos Fiber Counts before and after Asbestos–Cement Pipe

system	no. of before–after pairs	chrysotile fibers/L	
		before	after
A	14	2.25×10^5	1.26×10^5
B	12	1.88×10^5	3.11×10^5
C	9	7.50×10^4	8.63×10^5
others	4	2.88×10^4	5.35×10^5

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other systems was insufficient to carry out the Sign test. Since the Sign test does not account for the amount of increase or decrease in fiber count, a paired Student's t test for the difference in number of fibers counted between each of the 39 before and after sample pairs was used. Again, the increase in fibers after transport through A–C pipe was moderately significant, $p = 0.02$, with a t statistic of 2.04 and 38 degrees of freedom.

Discussion

Eight of the nine system C before–after pairs showed an increase after flow through A–C pipe. These are listed in Table III. The mean of the before samples was 7.500×10^4 fibers/L and the mean of the after samples was 8.628×10^6 fibers/L. This is an increase of 115 times the number of fibers, or apparently, on the average, 8.553×10^6 fibers/L were released from the pipe into the drinking water. To our knowledge, this is the first documentation of such a large release of asbestos fibers from A–C pipe in a system of nonaggressive drinking water.

A possible explanation of the increase in fiber counts after flow through A–C pipes is that fibers already present in the water from natural sources break up, thus yielding higher counts. Analyses of fiber size distributions have been carried out on data generated in the overall sampling program for the San Francisco Bay area (*14*). These analyses pooled system A and system C data to obtain sample sizes large enough to produce statistically reliable conclusions. The after A–C pipe samples have a larger proportion of longer fibers than the before A–C pipe samples. Thus, the theory of fiber breakup seems to be invalidated in that the naturally occurring fibers were generally shorter than those from segments of A–C pipe. Other factors that might affect the release of fibers from A–C pipe include size of pipe, flow rate of water, alternate wetting and drying of surfaces, quality of joint materials used, corrosive cleaners in use to flush sections of pipe, and tapping of pipe. Hydrants and other "dead ends" in a water distribution system often act as a reservoir for fibers released by tapping at other places in the system. None of these factors accounts for the releases recorded in system C.

The chemistry of system C water seems unusual as compared to the other systems. Even though the aggressiveness index is high, indicating nonaggressive water, the calcium content of the water is low. It appears that the aggressiveness index may be unduly weighted in this case by the high pH of these waters, which results from lime addition by the water utility for this system. As was found in the study by Buelow et al. (*10*), the aggressiveness index appeared to rise after flow in the pipes in system C. However, as can be seen from Table I, the aggressiveness indexes rose after flow through the pipes in all of the systems, even though there appeared to be only substantial release of fibers in system C. Thus, it appears that the aggressiveness index cannot be relied on as a sole predictor of release, and further research is needed on water chemistry factors and fiber release. Further sampling is recommended to examine the consistency of release in those areas with A–C pipe and to give insight into the mechanisms and predictors of such release.

Table III. Individual Chrysotile Asbestos Fiber Counts before and after Asbestos–Cement Pipe in System C

system C location	before	LDL[a]	after	LDL[a]
1	5.0×10^4	5.0×10^4	6.2×10^6	1.0×10^5
2	5.0×10^4	5.0×10^4	3.4×10^7	2.5×10^5
3	5.0×10^4	5.0×10^4	2.5×10^6	6.7×10^4
4	5.0×10^4	5.0×10^4	BDL[b]	1.0×10^6
5	2.0×10^5	1.0×10^5	6.0×10^6	1.0×10^5
6	2.0×10^5	1.0×10^5	6.4×10^6	8.4×10^4
7	BDL[b]	2.5×10^4	2.0×10^7	2.0×10^5
8	BDL[b]	2.5×10^4	1.5×10^6	5.0×10^4
9	2.5×10^4	2.5×10^4	5.0×10^4	2.5×10^4

[a] Lowest detectable limit of the analysis. [b] Below detectable limits of the analysis.

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