Tetrachloroethylene Contamination of Drinking Water by Vinyl-Coated Asbestos-Cement Pipe

Stuart G. Wakeham[1], Alan C. Davis[1], Richard T. Witt[2], Bruce W. Tripp[1], and Nelson M. Frew[1]

[1]Department of Chemistry, Woods Hole Oceanographic Institution, Woods Hole, MA 02543. [2]Department of Public Works, Falmouth, MA 02540

Tetrachloroethylene (perchloroethylene; 1,1,2,2-tetrachloro-ethene) is a common solvent used in dry cleaning, metal degreasing, and chemical manufacture. Substantial quantities are produced annually (7 x 10^8 tons in the U.S. in 1973 (U.S. I.T.C. 1975)). Due to the relatively high volatility (b.p. 121^0C), solubility in water (150 mg/L), and dispersive use of this chemical, losses to the environment are inevitable. Tetrachloro-ethylene has been found as a predominant volatile trace organic constituent in rivers (ZURCHER & GIGER 1976, STEIGLITZ et al. 1976, DOWTY et al. 1975), lakes (GROB & GROB 1974, GIGER et al. 1978, SCHWARZENBACH et al. 1979a), and seawater (PEARSON & McCONNEL 1975, MURRAY & RILEY 1975, SCHWARZENBACH et al. 1979b). Traces of tetrachloroethylene have also been found in finished drinking waters (DOWTY et al. 1975, GIGER & MOLNAR-KUBICA 1978, REPORT TO CONGRESS 1975, SYMONDS et al. 1975). Effects on human health of exposure to tetrachloroethylene are poorly documented. However, the NATIONAL CANCER INSTITUTE (1977) has determined that ingestion may cause cancers in mice, but not in rats. In the absence of a formal drinking water standard for tetrachloro-ethylene, the U.S. EPA has suggested a no adverse response level (SNARL) of 40 ppb over a lifetime of exposure, but this level is currently under review.

Recently it has been discovered that drinking water transported in vinyl-coated asbestos-cement (A-C) pipes often contains elevated concentrations of tetrachloroethylene. Vinyl-coated A-C pipe has been used in parts of the northeastern U.S. over the past decade in response to concern that waters carried in un-coated A-C pipes could contain potentially hazardous asbestos fibers. Tetrachloroethylene is used as solvent during applica-tion of the vinyl coating to the asbestos-cement pipe during manufacture, and residual solvent leaches into water carried in these pipes.

We report here results of a preliminary study to assess tetra-chloroethylene contamination of drinking waters flowing in vinyl-coated A-C pipes in the Town of Falmouth, Massachusetts. Data obtained from a brief survey of the Town's water distribution system and in a pipe flushing and recovery experiment are

presented to describe the problems encountered in trying to re-
duce this potential health hazard.

MATERIALS AND METHODS

Water samples were collected from dead-end (a worst case situa-
tion since the water is replaced either only slowly or not at
all) vinyl-coated A-C pipes of different dimensions, time of in-
stallation, and degree of usage (Table 1). Samples were obtained
via bleeder valves at the downstream ends of the vinyl-coated
pipes after flushing the bleeder for 1 min. One-L glass-stoppered
bottles were thoroughly rinsed with the water being sampled and
were completely filled and closed without leaving a headspace
volume. Samples were returned to the laboratory for analysis
within 24 h; any storage was at $4^{o}C$.

Tetrachloroethylene (and other volatile organic compounds) was
purged from 50 or 100 mL of water using the closed-loop gas
stripping method of GROB & ZURCHER (1976). The procedure is
similar to the purge-and-trap methodology (BELLAR & LICHTENBERG
1974) recommended by the U.S. EPA for routine drinking water
analyses, except that our system uses recycled headspace air as
the purging gas and a micro-charcoal trap instead of Tenax.
Prior to stripping, 1-10 µg of 1-chlorohexane (in acetone) was
added as an internal standard. Samples were stripped for 30 min
at $40^{o}C$, after which the charcoal trap was extracted with 20 µL
of distilled CS_2. Stripping for an additional 30 min recovered
no more tetrachloroethylene and 1-chlorohexane.

CS_2 extracts were analyzed by glass capillary gas chromatography
using a flame ionization detector. Injections were made with
the splitter open and the column at ambient temperature. A 40 m x
0.3 mm i.d. column coated with Pluronics 121 (GROB & GROB 1977)
was used with hydrogen carrier gas. Concentrations of tetra-
chloroethylene were determined by measurement of peak heights
compared to 1-chlorohexane and applying the appropriate detector
response factor. Tetrachloroethylene was confirmed by GC/MS.

Analytical precision determined by analysis of replicate samples
and subsamples at levels of 400 and 10,000 ppb was better than
± 10%.

RESULTS AND DISCUSSION

Tetrachloroethylene was the most abundant volatile organic com-
pound detected in the water samples examined. Concentrations
in waters from vinyl-coated A-C pipes at various locations in
Falmouth are given in Table 1. Levels of this compound range
from 140 to 18,000 ppb (µg/L) in unflushed vinyl A-C pipes. For
comparison, tetrachloroethylene concentrations in other parts of
the Falmouth distribution system were less than 2 ppb. Initial
tetrachloroethylene levels appear to be lower in older pipes.
Location 6 was a major distribution line leading from a ground

TABLE 1. Tetrachloroethylene Concentrations (ppb) in Water Samples from Various Vinyl A-C Pipes.

Sample Location (installation date)	Pipe Length, m/ Pipe Diameter, cm (number of services)*	Unflushed	Following 24 h Flushing	Following 72 h Recovery (no flow)	Following 96 h Flushing	Following 168 h Recovery (no flow)
		Tetrachloroethylene, ppb				
1 (1977)	240/20 (9 services)	560	190	265	58	na+
2 (1972)	340/15 (8 services)	170	5	na	na	na
3 (1976)	670/20 (no services)	2,180	19	na	na	na
4 (1972)	300/20 (4 services)	140	2	na	na	na
5 (1975)	520/20 (10 services)	2,860	8	na	na	na
6 (1975)**	250/30 (no services)	1,570	4	na	na	200
7 (1977)	500/20 (no services)	150	na	na	na	na
8 (1979)†	400/20 (no services)	1,510	56	na	na	na
9 (1979)	364/20 (no services)	18,000	na	na	na	na
10 (1923)‡	15 cm cast iron	106	na	na	na	na

* Number of active services (houses) on each line; average usage estimated at 200 gal/day/service.

** 1.1×10^6 m^3 flow over 5 yr period followed by no flow for 9 months.

† Location of flushing/recovery study (Table 2).

‡ Distribution line feeding to location 1.

+ n.a. = Not analyzed.

water well and had a flow of about 1.1×10^6 m^3 (3×10^8 gal) over a 5-year period following installation. Nine months prior to this sampling, the well was closed because of ground water contamination by detergents. Despite the extensive usage, tetrachloroethylene levels had built up to 1570 ppb in the nine months after the well was closed. Leaching of tetrachloroethylene continued even after additional flushing (Table 1).

In general, flushing of a vinyl A-C pipe in lengths varying from 240-670 m for 24 h through a bleeder valve at rates of about 5-10 m^3/h (25-45 gal/min) leads to a reduction of the level of tetrachloroethylene (Table 1). Data from location 1, however, show that flushing, even for 96 h, does not always lower the level of contamination. The reason for this anomalous behavior became apparent after a closer examination of the pipe network leading to location 1, a schematic of which is shown in Figure 1A. After four samples from location 1 repeatedly showed high amounts
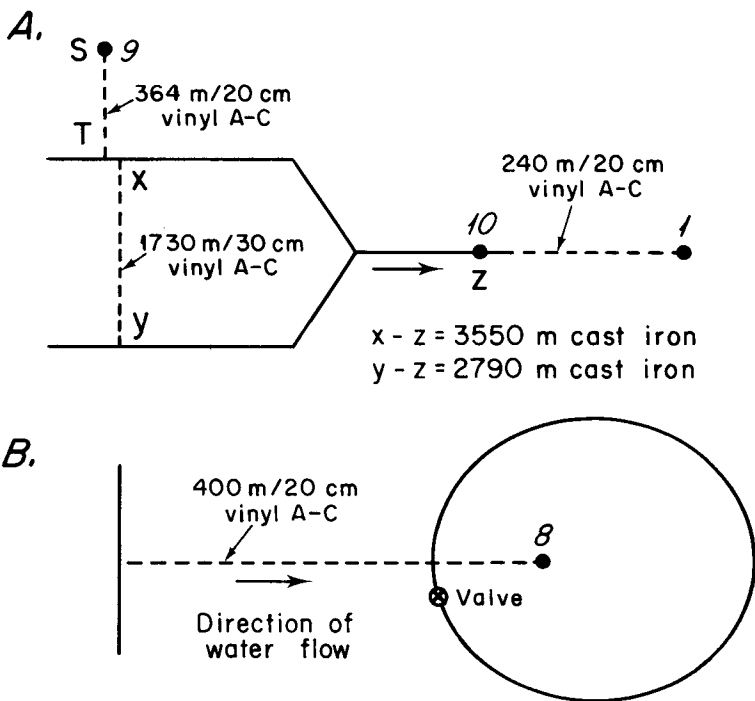

FIGURE 1. Schematic diagram (not to scale) showing pipe networks leading to sampling locations 1, 9, and 10 (A) and location 8 (B).   ---- Vinyl-coated A-C; ——— cast iron.

of tetrachloroethylene, we analyzed a sample of water (location
10) flowing through 65-year-old cast iron pipe leading to the
vinyl A-C section and obtained a concentration of 106 ppb. An
investigation of pipes upstream of location 1 showed two new
sections (sections X-Y and S-T in Figure 1A; 1979 installation)
of vinyl A-C pipe that are apparently the source of these
anomalous levels. Analysis of water at location 9 (Figure 1A)
revealed a tetrachloroethylene concentration of 18,000 ppb (high
enough to be detectable by odor). Even though water flowing
towards locations 1 and 10 probably does not flow through either
of these new installations of vinyl A-C pipe, a sufficient quan-
tity of contaminated water from these pipes apparently mixes into
the mainstream flow. Clearly then, no amount of flushing at
location 1 could ever reduce the contamination as long as tetra-
chloroethylene was mixing in from the contaminated connecting
pipes located approximately 3 km upstream in the network.

Since Falmouth contains some 250 sections ($\sim$ 60 km) of vinyl-
coated A-C pipe which would require flushing to reduce potential
human health hazard, it was quickly realized that insufficient
water supplies were available for 24-h flushings. Therefore,
we undertook a simple flushing and recovery experiment to de-
termine the length of time (or volume of water) required to re-
duce levels to an acceptable level ($\sim$ 40 ppb) and the rate at
which concentrations return to elevated levels. Results for the
flushing and recovery series at location 8 are given in Table 2.

TABLE 2. Tetrachloroethylene in a Flushing and
Recovery Series; Location 8[*].

	Tetrachloroethylene, ppb
Unflushed	1,510
1 h flushing[†]	1,620
2 h flushing	130
6 h flushing	67
16 h flushing	68
24 h flushing	56
24 h recovery	3,500
48 h recovery	2,700

[*]400 m Vinyl-coated A-C pipe; 20 cm diameter.

[†]Flushing at $\sim$ 9.8 m^3/h ($\sim$ 40 gal/min); 0.77 pipe volumes/h).

After 1 h flushing at about 9.8 m^3/h (about 45 gal/min) no
significant concentration change was observed. This is consis-
tent with the fact that the volume of the pipe (400 m x 0.2 m
diameter = 12.6 m^3) was such that a minimum of 1.3 h would be
needed to completely replace the initial, contaminated water in

the pipe. Thus by hour 2 (1.5 pipe volumes), the concentration of tetrachloroethylene had been significantly reduced. Flushing for more than 6 h did not greatly change the level, suggesting additional contamination from some source upstream.

After a 24 h recovery (no water flow) period, the contamination level jumped to 3,500 ppb, twice as high as the initial concentration. We believe that the loop (Figure 1B), which was not sampled, must contain contaminated water from the vinyl A-C lead-in line. During the flushing, one end of the loop was isolated (valve in Figure 1B closed), but the entire loop was not flushed. Only the 400 m length of vinyl A-C pipe was flushed. During the subsequent 24 h recovery, contaminated water from the loop could have mixed with "cleaner" water in the flushed section, although we cannot account for the higher levels after recovery compared to before flushing. These results demonstrate the complexity of flushing processes. It would be necessary to flush all vinyl pipes upstream of a given vinyl section, not simply a single vinyl section, in order to eliminate the contaminant.

This case study shows that vinyl-coated asbestos-cement pipe is apparently a source of widespread contamination of drinking water by tetrachloroethylene. In some cases, flushing of a vinyl-coated pipe leads to a reduction of the tetrachloroethylene level in that pipe, but after flushing is terminated the level of contamination will gradually increase. However, flushing is not a simple process merely involving replacement of water in a vinyl pipe section since mixing with contaminated water from other sections of the distribution system can lead to contamination of water in non-vinyl-coated pipes. Furthermore, the measurements at location 6 suggest that even after five years of heavy use (1.1×10^6 m^3 of water), tetrachloroethylene may continue to leach out of the vinyl lining. Elevated concentrations of tetrachloroethylene were found in pipe sections installed for over eight years.

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