SPECIAL REPORT 96-3

Sampling Trace-Level Organics with Polymeric Tubings

Louise V. Parker and Thomas A. Ranney

February 1996
(revised October 1996)

Abstract

There is concern whether tubings used to sample groundwater can affect contaminant concentrations. Tubings might sorb contaminants, thereby giving falsely low values, or they might leach contaminants, thereby giving falsely high values. There also is concern that a tubing used previously in a well with high concentrations of contaminants might subsequently desorb contaminants into samples taken from other wells if decontamination is insufficient. Our review of the literature indicated that these concerns are valid, although a comprehensive study of this subject does not exist. In our laboratory study, we looked for sorption of a suite of organic solutes by 20 polymeric tubings under static conditions. Seven of these tubings were flexible and the others were rigid. We found that among the rigid tubings tested, the three fluoropolymers (fluorinated ethylene propylene [FEP], FEP-lined polyethylene, and polyvinylidene fluoride [PVDF]) were the least sorptive tubings. However, even these tubings readily sorbed some of the analytes. Among the flexible tubings tested, a fluoroelastomer tubing and a tubing made of a copolymer of vinylidene fluoride and hexafluoropropylene (P[VDF-HFP]) were the least sorptive. We also found that several of the 20 tubings appeared to leach constituents into the test solution. We were unable to detect any evidence that constituents leached from the polyethylene tubings, the rigid fluoropolymer tubings, and one of the plasticized polypropylene tubings. Currently, we are conducting studies to see whether the effects we observed in this study increase, decrease, or remain the same under dynamic conditions.

For conversion of SI units to non-SI units of measurement consult *Standard Practice for Use of the International System of Units (SI),* ASTM Standard E380-93, published by the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.

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Cold Regions Research & Engineering Laboratory

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PREFACE

This report was prepared by Louise V. Parker, Research Physical Scientist, Applied Research Division, Research and Engineering Directorate, U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) and Thomas A. Ranney, Staff Scientist, Science and Technology Corporation, Hanover, New Hampshire. Funding for this work was provided by the U.S. Army Environmental Center (USAEC), Aberdeen Proving Ground, Maryland, Martin H. Stutz, Project Monitor.

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Sampling Trace-Level Organics with Polymeric Tubings

LOUISE V. PARKER AND THOMAS A. RANNEY

INTRODUCTION

It is important that the reported concentrations of contaminants in samples taken from groundwater monitoring wells accurately reflect in-situ values. Recent studies suggest that, among currently used sampling methods, low-flow-rate (~100 mL/min) purging and sampling may cause the least disturbance to the well during the sampling process. Samples taken using this method have lower turbidity (Kearl et al. 1992, Puls et al. 1992, Puls and Powell 1992, Backhus et al. 1993) and yield perhaps the most accurate values for inorganic contaminants (Puls and Powell 1992, Puls et al. 1992). There is some evidence that indicates that low-flow-rate purging and sampling may also produce samples that reflect the true in-situ values of at least some organic contaminants, such as polycyclic aromatic hydrocarbons (Backhus et al. 1993).

One concern about the slow-rate pumping methods for sampling groundwater is that there may be interactions between the sampling tubing (which can be several hundred feet in length) and the sample as it is pumped to the surface. The tubing could either leach inorganic or organic contaminants, thereby giving inaccurate high values, or sorb these contaminants from the sample, thus giving inaccurate low values. Also, if pump tubing is not dedicated to a particular well, it is possible that tubing that was used previously to sample a well with high concentrations of contaminants would release sorbed contaminants into the next sample, thereby giving inaccurate high values. The diffusion of gases, especially oxygen, through the tubing may also affect the sample as it is pumped to the surface (Holm et al. 1988, Kjeldsen 1993). In this paper we will focus on the biases caused by sorption of organic analytes by polymeric tubings and leaching of organic constituents from these tubings.

LITERATURE REVIEW

When assessing these studies it is important to differentiate between flexible and rigid formulations of the same polymer, and to note whether the material that was tested was actually sampling tubing. This is because the formulations can vary between different products made of the same polymer and between flexible and rigid formulations of the same polymer, especially polyvinyl chloride (PVC). It is also useful to note whether a biocide was used. This is especially true for sorption studies that last several days or longer, because losses of analytes could be due to biodegradation rather than by sorption by the polymer.

For the purpose of clarity in this review, we will discuss separately those studies that were conducted using polymeric products other than tubings.

Leaching of organic constituents

With respect to leaching, the importance of discerning between rigid and flexible formulations is most clearly shown with PVC. Several studies (Jaeger and Rubin 1970 and 1972, Junk et al. 1974, Christensen et al. 1976, Fayz et al. 1977, Barcelona et al. 1985) have shown that flexible PVC (FPVC) products leach considerable quantities of phthalate ester plasticizers into a variety of fluids (blood, plasma, saline, water). However, this has not been observed with rigid PVC (RPVC) (Miller 1982, Curran and Tomson 1983, Ranney and Parker

1994). Much of the reason for this difference is that the plasticizer content of FPVC ranges from 30 to 50% by weight (Junk et al. 1974, Aller et al. 1989), while RPVC contains virtually no plasticizers (<0.01%) (Barcelona et al. 1984).

Leaching studies that tested tubings

Junk et al. (1974) tested several plastic tubings to determine if they leached organic constituents when water was pumped through them. The materials they tested included rigid polyethylene (PE), rigid polypropylene (PP), black latex, and six formulations of FPVC tubing. They found that all the tubings leached constituents even though they had been prerinsed. Leached concentrations were the highest from a food- and beverage-grade FPVC and were much lower (three orders of magnitude) from laboratory-grade FPVC, PP, and PE tubings. They noted that most (50–90%) of the total contamination was due to the leaching of only a few (4–6) constituents. Many of the contaminants that leached from the PVC and black latex tubing were identified as plasticizers and other additives. However, they were unable to identify the major contaminants that leached from the PE and PP tubing. They also found that the amount of contamination leached from the PVC tubing was related to the linear velocity of the water flowing through the tubing, with more contamination occurring at the higher flow rates. They suggested that this was due to an erosion mechanism occurring at the polymer/water interface at the higher flow rates. They found that although an initial flushing of PVC tubing with water had a salutary effect in lowering contaminant leaching, extensive washing served no useful purpose. They concluded that FPVC tubing contained a nearly inexhaustible supply of contaminants because of its high concentration of plasticizers, but that this would not be the case for PE and PP tubings.

Curran and Tomson (1983) compared the leachates from PP, PE, polytetrafluoroethylene (PTFE, a type of Teflon), and FPVC (Tygon) tubings and RPVC (pipe). They found that PTFE did not leach any detectable organic contaminants. Leachate concentrations were highest from the FPVC tubing. They noted that the total amount of contaminants leaching from the PE and PP tubings was less than Junk et al. (1974) had observed. They felt that this may have been because of differences in flow rate, tubing conditioning, or manufacturing.

Barcelona et al. (1985) looked at a variety of tubings: silicone rubber, linear polyethylene (which, according to Charrier [1990], is high-density PE [HDPE]), PP, FPVC, and PTFE. They found that all but the PTFE leached significant amounts of organic carbon in 30 minutes. The FPVC and silicone rubber tubings leached the most.

Devlin (1987) was unable to detect any constituents leaching into water pumped through an unspecified type of fluoropolymer (Teflon) tubing or PE tubing.

Leaching studies of polymeric products other than tubing

Miller (1982) was unable to detect any organic constituents leaching from two rigid materials: low-density PE (LDPE) and PP (purchased directly from the plastics manufacturer).

In a static study conducted by this laboratory (Ranney and Parker 1994), no organic constituents were detected leaching into water from either PTFE (well casings) or fluorinated ethylene propylene (FEP) (sampling pipe). (These test solutions were analyzed using reversed-phase high-performance liquid chromatography (RP-HPLC) analyses. In most of the previous studies, samples were concentrated and analyzed by gas chromatography-flame ionization detection [GC-FID], or GC-FID and gas chromatography-mass spectrometry [GC-MS].)

Summary of the leaching studies

These studies show that FPVC and rubber tubings leach substantial quantities of organic constituents, and that leaching tends to be less from the more rigid formulation (e.g., PE and PP). The fluoropolymers tested (PTFE, FEP) do not appear to leach any constituents. For at least one polymer (FPVC), higher flow rates increase leaching, possibly due to erosion of the polymer matrix.

Sorption of organic contaminants

With respect to sorption, again the importance of differentiating between flexible products and rigid products has been demonstrated with PVC. Gillham and O'Hannesin (1990) found FPVC tubing was much more highly sorptive of organic solutes than RPVC (pipe). As an example, there was no loss of benzene after one hour in samples exposed to RPVC, but there was approximately a 55% loss in samples exposed to FPVC tubing.

Sorption studies that tested tubings

A field study by Pearsall and Eckhardt (1987) documented that concentrations of two volatile

organic compounds (VOCs) (1,2-dichloroethylene and trichloroethylene [TCE]) were substantially lower in samples pumped through silicone rubber tubing than those pumped through a type of fluoropolymer tubing. (Flow rates were ~0.7 to 1.0 L/min.)

Several laboratory studies have also documented that sampling tubings can sorb organic solutes. Curran and Tomson (1983) found that 50-ft lengths of PP, PE, and a fluoropolymer sorbed very little naphthalene or *p*-dichlorobenzene from low-ppb-level aqueous solutions pumped through them. In contrast, the FPVC tubing (Tygon) sorbed ~50% of these analytes from solutions pumped through it.

Ho (1983) found that the recovery of nine halogenated VOCs (alkanes and alkenes) from an aqueous test solution was always lower in samples taken using medical-grade silicone rubber than in samples taken using PTFE tubing. (Flow rates varied from 2.6 L/min to 4.0 L/min.)

In a static study, Barcelona et al. (1985) exposed five common tubings (PP, PE, FPVC, PTFE, and silicone rubber) to a solution containing ppb levels of chloroform and to an aqueous solution containing a mixture of four organics (chloroform, trichloroethane, TCE, and tetrachloroethylene [perchloroethylene or PCE]), each at ppb levels. In both experiments, they found that PTFE was the least sorptive material and that the FPVC and silicone rubber tubings were the most sorptive. For example, these tubings sorbed 80% of the chloroform within one hour.

Barcelona et al. (1985) also tested the effect of additional organic carbon (low ppm levels of polyethylene glycol) on sorption. They found that additional organic carbon affected sorption differently depending on the polymer. For example, significant decreases in the sorption of chloroform were observed for PP and PE, but sorption was greater for FPVC and silicone rubber.

Barcelona et al. (1985) noted that sorption by the FPVC and PP tubings was at least two orders of magnitude greater than Miller (1982) had observed for RPVC and PP materials. They felt that the higher density and greater crystallinity of PTFE, PP, and PE may explain why these materials were generally more inert in their study. They concluded that sorption of chlorinated organic solvents from aqueous solutions by flexible tubing materials occurs by absorption into the polymer matrix. They concluded that flexible materials, such as silicone rubber and FPVC tubing, represent a virtual sink for chlorinated solvent sorbates.

In a laboratory study, Devlin (1987) found that when a test solution containing a suite of ppb-level VOCs was pumped through PE and Teflon (fluoropolymer) tubings, PE tubing was more sorptive. Devlin also noted that after flushing the two systems with 2 L of the test solution, concentrations of the analytes in samples taken from either type of tubing were equivalent. However, Devlin noted that a larger amount of test solution was required to "equilibrate" the tubings for two of the analytes (tetrachloroethane [both tubings] and chlorobenzene [PE tubing]).

The results from Devlin's field studies, however, do not show a consistent trend. At one site, concentrations of contaminants in the samples taken using the fluoropolymer tubing were virtually identical to those taken with PE tubing, while at other sites concentrations of contaminants were ~30 to 50% higher in samples collected using the PE tubing.

Sorption studies of polymeric products other than tubing

Miller (1982) compared sorption of low ppb levels of six volatile organics (bromoform, PCE, TCE, trichlorofluoromethane, 1,1,1-trichloroethane, and 1,1,2-trichloroethane) by three polymeric materials: RPVC, LDPE, and PP. These products were purchased directly from the plastics manufacturer. RPVC was by far the least sorptive of these three materials and LDPE was the most sorptive polymer tested.

Reynolds and Gillham (1985) compared sorption of ppb levels of five halogenated aliphatic organic compounds (1,1,1-trichloroethane, 1,1,2,2-tetrachloroethane, hexachloroethane, bromoform, and PCE) by six polymeric materials. The polymers they tested included RPVC rod and a polyamide (nylon) plate, and four types of tubing: PTFE, LDPE, PP, and latex rubber. They found that LDPE and latex rubber were the most sorptive polymers tested. A 10% loss of all five analytes was seen within the first five minutes for samples exposed to rubber and for four of the analytes exposed to the LDPE. RPVC and PTFE were the least sorptive materials; it generally took days to weeks to see a 10% loss with these materials.

For all these polymers, Reynolds and Gillham (1985) attributed losses to absorption within the polymer matrix. They were able to successfully model loss as a function of the partition coefficient of the organic compound between the aqueous solution and the polymer (K), the diffusion coefficient in the polymer (D), time, and surface area.

Gillham and O'Hannesin (1990) compared sorption of low ppm levels of six monoaromatic hydrocarbons (benzene, toluene, ethylbenzene, and m-, o-, and p-xylene) by seven materials used in sampling groundwater wells. The materials included stainless steel (SS) tubing, RPVC pipe, FPVC tubing, PTFE tubing, polyvinylidene fluoride (PVDF) rectangular wire, epoxy-impregnated fiberglass (FG) tubing, and flexible PE tubing. They found that flexible tubings, PE and FPVC, showed the highest rates of uptake, with significant losses (10% or more) of all six compounds within the first five minutes. They found the more rigid polymeric products were much less sorptive, and SS did not sorb any of the analytes. They ranked the materials from most sorptive to least sorptive as follows: FPVC > PE > PTFE > PVDF > FG > RPVC > SS. For the rigid polymeric products, they found that sorption agreed well with their diffusion model (described previously by Reynolds and Gillham [1985]).

Studies by our laboratory (Parker et al. 1990, Parker and Ranney 1994) have also shown that RPVC well casings were less sorptive of a suite of organic solutes than PTFE well casings and that SS well casings did not sorb any of the analytes tested. These studies also showed that the relative rate of sorption by PTFE and RPVC was not affected by concentration, i.e., ppb vs. ppm levels.

Summary of sorption studies

From these studies, it appears that rigid tubings are much less sorptive of organic solutes than flexible tubings. Two of the most sorptive tubings were FPVC and silicone rubber. PTFE was among the least sorptive polymeric tubings tested, although SS products have been shown to be nonsorptive of organic solutes.

RESEARCH STUDY

Purpose of study

The previous studies show that flexible tubing materials can affect analyte concentrations by sorbing organic contaminants and by leaching organic constituents. This is especially true for FPVC. The fluoropolymers were among the least sorptive tubings tested but were still highly sorptive of some organic solutes. A comprehensive comparison of the many tubings that are commercially available, especially for the various types of fluoropolymers that are now available, does not exist.

The purpose of this study was to compare sorption of organic solutes by twenty of the sampling tubings that are commercially available and to look for leaching of contaminants from these materials. The tubings we selected are given in Table 1, where they are categorized by their flexibility. Thirteen tubings were very flexible and thus nonrigid (i.e., easy to collapse with only finger pressure), and seven tubings were slightly flexible (coilable) but rigid (i.e, a person could stand on the tubing without collapsing the tubing). Table 1 also gives the abbreviations for the polymers tested, and the tubings' dimensions and cost. Cost of the tubings used in this study ranged from $19 (LDPE) to $870 (fluoroelastomer) per 100 ft.

Materials and methods

Initial sorption study

The test solution for this study consisted of mg/L concentrations of eight organic compounds: nitrobenzene (NB), *trans*–1,2-dichloroethylene (TDCE), *m*-nitrotoluene (MNT), trichloroethylene (TCE), chlorobenzene (CLB), *o*-dichlorobenzene (ODCB), *p*-dichlorobenzene (PDCB), and tetrachloroethylene (PCE). The test solution was prepared by using a microliter syringe to add a volume of neat organic solvent directly to well water (taken from a deep water well in Hartland, Vermont) contained in a 2-L glass bottle. Mercuric chloride was added to the solution (40 mg/L) to prevent any losses due to biological activity. After adding all of the analytes, the bottle was filled to capacity with well water to eliminate any headspace, capped with a glass stopper, tightly wrapped with parafilm, and stirred for two days using a magnetic stirring device. Prior to pouring the solution into the tubings, we examined the solution using a magnifying glass to make certain that there were not any undissolved droplets of organic solvents in the mixed test solution. The initial concentrations of the organic solutes varied from 10 to 16 mg/L (Table A1).

The twenty tubings were cut into different lengths so that they would all have the same internal surface area, 40 cm^2 (Table 1). This was necessary because three types of tubing (PTFE, ethylene tetrafluoroethylene [ETFE], and polyamide) had different internal diameters than the other tubings (Table 1). The tubing surface-area-to-solution-volume ratios and the solution-volume-to-material-volume ratios differed for these three materials and for one material (FEP-lined PE), which had a different wall thickness (Table 1).

The cut tubing sections were rinsed with sev-

Table 1. Polymeric tubing used in sampling trace-level organics.

	Cost per foot[a] *($)*	*Dimensions (cm)* *I.D.*	*O.D.*	*wall*	*Length (cm)*	*Surface-area-to-solution-volume ratio (cm^{-1})*
Flexible polymers[b]						
polyproplyene-based material with plasticizer, (formulation 1)	0.58	0.64	0.95	0.16	20	6.3
polypropylene-based material with plasticizer, (formulation 2)	2.48	0.64	0.95	0.16	20	6.3
polyvinylchloride (PVC)	0.89	0.64	0.95	0.16	20	6.3
thermoplastic elastomer[c] (TPE)	0.96	0.64	0.95	0.16	20	6.3
linear copolymer of vinylidene fluoride and hexafluoropropylene P(VDF-HFP)	1.99	0.64	0.80	0.08	20	6.3
polyurethane	0.64	0.64	0.95	0.16	20	6.3
fluoroelastomer	8.70	0.64	0.95	0.16	20	6.3
Rigid polymers[d]						
polyethylene, low density (LDPE)	0.19	0.64	0.95	0.16	20	6.3
polyethylene, cross-linked high density (XLPE)	0.43	0.64	0.95	0.16	20	6.3
polyethylene liner in ethyl vinyl acetate shell	0.57	0.64	0.95	0.16	20	6.3
polyethylene liner cross-linked to ethyl vinyl acetate shell	1.08	0.64	0.95	0.16	20	6.3
co-extruded polyester lining in PVC shell	0.77	0.64	0.95	0.16	20	6.3
polypropylene (PP)	0.27	0.64	0.95	0.16	20	6.3
polyamide (nylon)	0.71	0.71	0.95	0.12	18	5.6
polytetrafluoroethylene (PTFE)	4.27	0.75	0.95	0.10	17	5.3
perfluoroalkoxy (PFA)	5.58	0.64	0.95	0.16	20	6.3
ethylene tetrafluoroethylene (ETFE)	5.50	0.48	0.64	0.08	27	8.4
polyvinylidene fluoride (PVDF)	1.80	0.64	0.95	0.16	20	6.3
fluorinated ethylene-propylene (FEP)	3.90	0.64	0.95	0.16	20	6.3
FEP-lined polyethylene	3.00	0.64	0.80	0.08	20	6.3

a Cost varies with quantity, dimensions, and supplier.
b Finger pressure can collapse tubing.
c Styrene-ethylene-butylene block copolymer modified with silicon oil.
d Can be stepped on without collapsing the tubing.

eral volumes of deionized water and left to air-dry. One end of each of the tubings was plugged with a glass rod whose diameter matched the internal diameter of the tubing. The glass rod was inserted in the tubing to a depth of 1 cm, and then the outside of the tubing was clamped with a plastic tubing clamp. (The length of the glass plugs was taken into account when figuring the surface areas and solution volumes.) For each type of tubing, there were five sampling times (1, 8, 24, 48, and 72 hours) and two replicates for each sampling time (i.e., 10 tubing pieces of each material).

For each sample time, the tubings were filled in random order using a glass re-pipettor. The top of the tubings was sealed immediately after filling by inserting a glass plug, leaving no head space, and then clamped as described previously. The tubings were stored in the dark at room temperature. During this process, three high-performance liquid chromatography (HPLC) autosampler vials (1.8 mL) were filled with the test solution at the beginning and at the end of filling each set of tubings (i.e., for each time period). The vials were filled so there was no headspace, capped with Teflon-lined plastic caps, and stored in the dark in a refrigerator. Because we anticipated there would be some loss of the analytes during the filling process, the solutions in these vials served as controls and thus were used to determine the initial analyte concentrations for each sampling time.

When it was time to sample a tubing, one of the plugged ends of the tubing was cut with a special cutter for rigid tubings and then a Pasteur pipet was used to transfer an aliquot of the test solution to a 1.8-mL HPLC autosampler vial. The control solutions were removed from the refrigerator and allowed to warm before analysis.

Analytical determinations were performed using RP-HPLC. A modular system was employed consisting of a Spectra Physics SP8875 autosampler with a 100-µL injection loop, a Spectra Physics SP8810 isocratic pump, a Spectra Physics SP8490 variable wavelength detector set at 215 nm, and a Hewlett Packard 3396 series II digital integrator. Separations were obtained on a 25-cm × 0.46-cm (5 µm) LC–18 column (Supelco) eluted with 65/35 (V/V) methanol/water at a flow rate of 2.0 mL/min. The detector response was obtained from the digital integrator operating in the peak height mode.

For each analyte, a single compound standard was made by adding the neat (undiluted) com-

Table 2. Method detection limits (MDL) for analytes used in the tubing material study.

Analyte	*MDL (mg/L)*	*Analyte*	*MDL (mg/L)*
nitrobenzene (NB)	0.0017	chlorobenzene (CLB)	0.0017
trans-1,2-dichloroethylene (TDCE)	0.0019	*o*-dichlorobenzene (ODCB)	0.0056
m-nitrotoluene (MNT)	0.0022	*p*-dichlorobenzene (PDCB)	0.0086
trichloroethylene (TCE)	0.0032	tetrachloroethylene (PCE)	0.0035

pound to methanol contained in a 50-mL glass volumetric flask on a balance so that the concentration was approximately 2000 mg/L. A combined standard (~200 mg/L for each analyte) was made by pipeting 10 mL of each single compound standard into a 100-mL glass volumetric flask partially filled with methanol and then bringing to volume with methanol. These standards were kept in a freezer. Working standards (~10 mg/L) were made by pipeting 5 mL of the combined standard (warmed to room temperature) into a 50-mL glass volumetric flask partially filled with deionized water, then bringing to volume with deionized water. This working standard was serially diluted in deionized water, giving standards of approximately 1.00, 0.100, and 0.0100 mg/L for each analyte. These working standard solutions were made fresh each sampling period and run in triplicate. The method detection limits (MDL) for the analytes (Table 2) were obtained according to the EPA protocol described elsewhere (Federal Register 1984).

Second sorption study

Because three of the tubings used in this study (PTFE, ETFE, and polyamide) had different surface-area-to-solution-volume ratios than the other tubings, this study was conducted so that we could compare sorption of organic solutes by these tubings with the other seventeen tubings.

In this study, 5-cm pieces of the three tubing types were placed in three different-sized glass vials (9, 25, and 40 mL). The test solution was made of the same organic compounds and in the same manner as in the previous study. The solution was poured into the vials so there was no headspace, and the vials were capped with Teflon-lined plastic caps. The total surface-area-to-solution-volume ratios for PTFE were 0.70, 1.15, 3.55; for ETFE, 0.45, 0.74, and 2.15; and for nylon, 0.69, 1.14, and 3.59. Samples were taken after one hour, eight hours, and 24 hours. There were duplicates for each sample time and tubing type. The same-sized vials (9, 25, and 40 mL) filled with test solution (without tubing) served as controls. The controls were used to account for any losses due to volatiles leaking through loose caps or sorption by the glass vials, Teflon liners, or plastic caps. There were two controls for each size vial and sampling time. All samples were kept in the dark at room temperature. When it was time to take a sample, an aliquot of each sample was transfered from each of the test vials to an autosampler vial using a Pasteur pipet. Analysis was performed as described previously.

Analysis of leachates

Several of the chromatograms for solutions exposed to the various tubings contained spurious peaks. Thus, leaching of some type of constituents occurred in samples exposed to nine types of tubing. In order to determine what some of these contaminants were, we analyzed one of each of the final (72 hr) samples for each of the twenty tubings for semivolatile organics using GC-MS. Two GC-MS systems were used, each with a different column. The first system consisted of a Hewlett Packard (HP) 5890 series II gas chromatograph and an HP 5970 mass selective detector with an HP–1 capillary column, 25-m×0.2-mm ID (0.33 μm). The second GC-MS system consisted of an HP 5890 series II gas chromatograph, an HP 5972 mass selective detector, and an HP 7673 auto-injector with an HP–5 capillary column, 30-m×0.25-mm ID (0.25 μm). Operating parameters were the same on both instruments: initial column temperature of 60°C (hold 1 min.), then ramp to 300°C at 6°C/min. (hold 19 min.). The injector/detector temperatures were 250°C and 300°C, respectively. Carrier gas was helium with a linear velocity of 20 cm/s set at 60°C. For the first instrument, 3 μL were injected manually, while for the second instrument, 1 μL was injected by auto injection. Both injections had a splitless hold time of 45 sec. Mass scan was from 45 to 550.

RESULTS AND DISCUSSION

Sorption studies

For the first study, the data for all the replicates for each analyte, tubing, and time can be found in

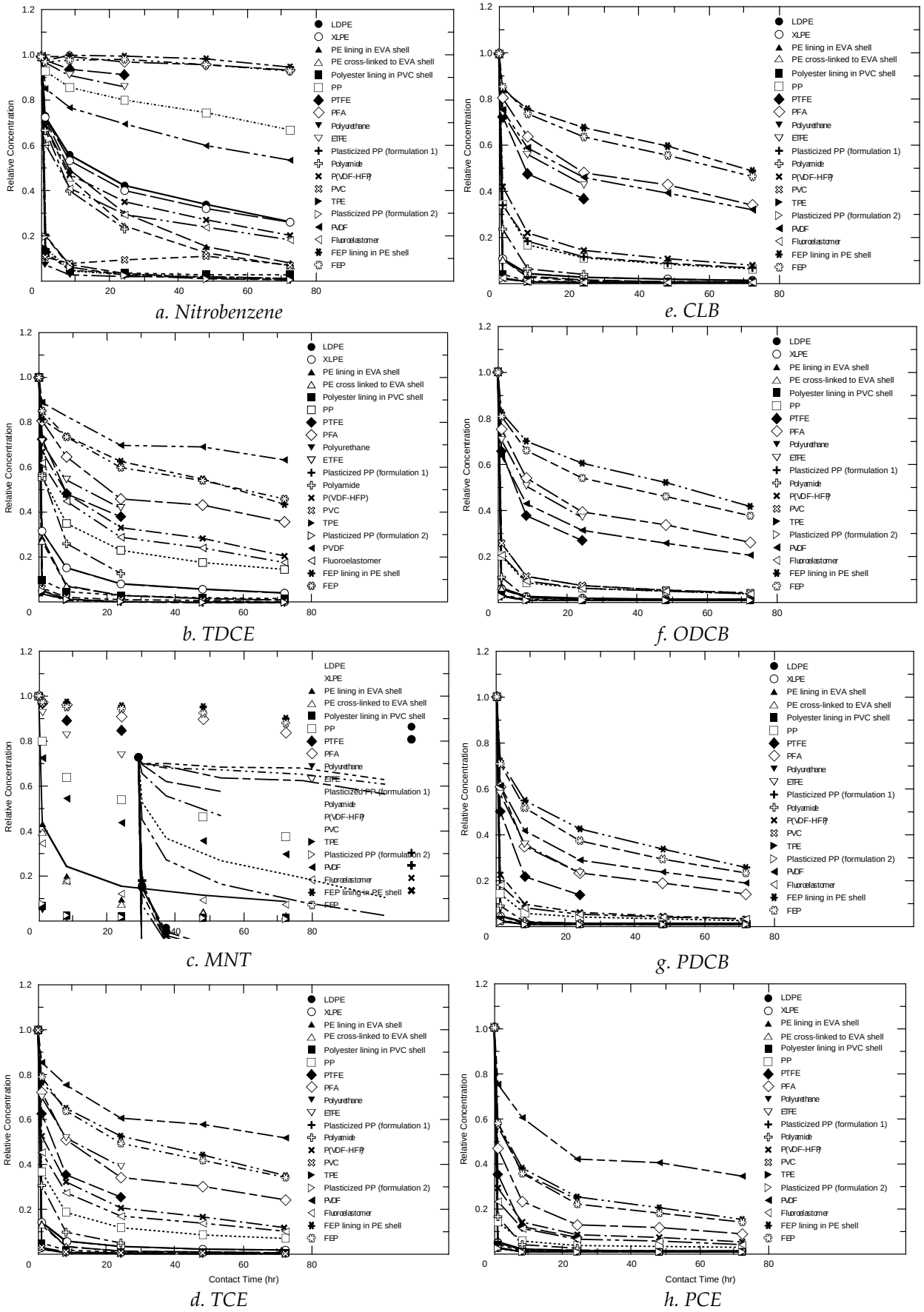

Figure 1. Sorption of analytes by tubing materials. (Values for PTFE, ETFE, and polyamide were adjusted to comparable surface-area-to-solution-volume ratios.)

Table A1. For each analyte and time, analysis of variance (ANOVA) tests were conducted to determine if the tubings had any significant effect (at the 95% confidence level) on the analyte concentrations. When significant differences were found, Fisher's Protected Least Significant Difference Test was performed to determine which tubing materials were significantly different from the controls and each other. The results of these analyses can be seen in Table A2. Because three of the tubing materials (PTFE, ETFE, and the polyamide [nylon]) had different material surface-area-to-solution-volume ratios than the other tubing materials, the data for these tubings were marked with an asterisk.

Mean normalized concentration values were derived (Table A3) by taking the mean concentration of a given analyte exposed to a given tubing at a given sampling time and dividing it by the mean concentration for the control samples for the same analyte and time. Thus a mean normalized value of 1.00 represents no loss of analyte for a given tubing and time.

A second study was conducted so that sorption of the analytes by the three tubings with different surface-area-to-solution-volume ratios could be compared with the other seventeen tubings. This study compared sorption of the same analytes by the three tubings with three different surface-area-to-solution-volume ratios. The results from this study can be found in Table A4. These data show that the material surface-area-to-solution volume does affect sorption and that, as this ratio increases, sorption of the more hydrophobic analytes also increases. Normalized values were derived as described previously and are given in Table A5. (Also included in Table A5 are the normalized values from the previous study for these three materials. This gave us a fourth surface-area-to-solution-volume ratio for comparison.) The best fit equation was obtained for these data for each material, analyte, and time using Cricket Graph software. These equations were then used to determine what the adjusted normalized values would have been for these three materials if the surface-area-to-solution volume had been the same as the other seventeen tubings. This meant that we had to extrapolate values for PTFE and the polyamide and interpolate values for ETFE. These adjusted normalized values can be found in Table A3, in parentheses next to the original mean normalized values. For each analyte, the mean normalized concentrations have been plotted for all 20 materials in Figures 1a-h. These figures show the adjusted mean normalized concentrations for the three materials that had different surface-area-to-volume ratios (PTFE, ETFE, and the polyamide).

As we have found in previous studies that tested PVC and PTFE well casings (Parker et al. 1990, Parker and Ranney 1994), the more hydrophobic analytes—ODCB, PDCB, and PCE—were the most readily sorbed, and NB and MNT were the least sorbed analytes. All the tubings sorbed at least some of the more sorption-prone analytes. For some tubings, sorption of some organic solutes was very rapid; i.e., losses equalled or exceeded 95% after only a one-hour contact time. For polyurethane this was true for seven analytes. For FPVC, the silicone-modified thermoplastic elastomer (TPE), and one of the plasticized PP tubings, it was true for six analytes. For the coextruded polyester lining in a PVC shell and the other plasticized PP, it was true for five analytes. For LDPE, cross-linked high-density polyethylene (XLPE), and PE cross-linked to an ethyl vinyl acetate (EVA) shell, it was true for three analytes. For the PE liner in an EVA shell, it was true for two analytes. These ten materials generally were the most sorptive, and among this group the flexible tubings were the most sorptive. Among all the flexible materials tested, only the two fluorinated products, the fluoroelastomer and P(VDF-HFP), were not highly sorptive.

Using Figures 1a-h and the results from the ANOVAs and the least significant difference tests (Table A2), we compiled a summary table showing the least sorptive materials (Table 3). We see that generally the rigid fluoropolymers (FEP, FEP-lined PE, PVDF, PTFE, perfluoroalkoxy (PFA), and ETFE) were the least sorptive. Specifically, PVDF was the least sorptive material for TDCE, TCE, and PCE. FEP and FEP-lined PE were the least sorptive materials for the other five analytes (NB, MNT, CLB, ODCB, and PDCB). However, even though FEP, FEP-lined PE, and PVDF were generally the least sorptive materials tested, they were still highly sorptive of the more hydrophobic analytes (Fig. 1g and 1h). For example, after 24 hours, losses of PCE and PDCB by these three materials ranged from approximately 60 to 80%. Clearly, long-term storage of aqueous solutions of organic compounds in fluoropolymer containers can be problematic.

With respect to shorter contact times, we see that in the first hour, sorption of PCE and PDCB by FEP, FEP-lined PE, and PVDF tubings ranged from approximately 25 to 40%. However, the con-

Table 3. Summary of sorption study.

Analyte	*Least sorptive tubings*	*Next least sorptive tubings*	*Other less sorptive tubings*
NB nitrobenzene	FEP-lined PE FEP PFA	PTFE	ETFE
TDCE *trans*-dichloroethylene	PVDF	FEP FEP-lined PE	PFA ETFE
MNT *m*-nitrotoluene	FEP-lined PE FEP	PFA	PTFE ETFE
TCE trichloroethylene	PVDF	FEP-lined PE FEP	ETFE PFA
CLB chlorobenzene	FEP-lined PE FEP	PFA	PVDF ETFE
ODCB *o*-dichlorobenzene	FEP-lined PE FEP	PFA	ETFE PVDF
PDCB *p*-dichlorobenzene	FEP-lined PE FEP	PVDF	PFA ETFE
PCE tetrachloroethylene	PVDF	FEP-lined PE ETFE FEP	PFA

ETFE = ethylene tetrafluoroethylene
FEP = fluorinated ethylene propylene
PE = polyethylene
PFA = perfluoroalkoxy
PTFE = polytetrafluoroethylene
PVDF = polyvinylidene fluoride

tact time between a groundwater sample and the tubing used to pump it to the surface would be considerably shorter than one hour. The actual contact time will vary depending on the tubing diameter and flow rate. For the internal diameter tubing used most often in this study (0.64 cm), the contact time for a 50-ft well would be ~5 minutes and for a 100-ft well it would be ~10 minutes if slow flow rate pumping were used (~100 mL/min).

Because there are no data for contact times of less than an hour, we would like to estimate what the losses might be for these four materials for the two most readily sorbed analytes (PCE and PDCB) if the contact time was either five or ten minutes. Because we were unable to model our data in a meaningful way for very short contact times, we used data of Barcelona et al. (1985) to predict what these losses might be. Barcelona and co-workers provide us with data on the sorption of four VOCs by five polymeric tubings (silicone rubber, FPVC, PE, PP, and PTFE) after five, ten, and 60 minutes' contact. We used these data to determine what percent of the analyte was sorbed after five and ten minutes compared with the amount sorbed after 60 minutes for both the sorptive, flexible tubings and the less sorptive, more rigid tubings. (An example of these calculations is given in Table B1.) For example, after ten minutes, losses to the more sorptive tubings they tested (silicone rubber and FPVC) were approximately 75% of that observed after 60 minutes, and for the less sorptive tubings (PE, PP, and PTFE), losses were approximately 60%. These values were then used to estimate what the percent losses of PCE and PDCB by the four materials used in our study (polyurethane, FPVC, FEP, and PVDF) might have been for contact times of five and ten minutes (Table 4).

Table 4. Estimated percent loss of PCE and PDCB after 5 and 10 minutes' contact with selected tubing materials.*

	PCE		*PDCB*	
Material	*5 min.*	*10 min.*	*5 min.*	*10 min.*
FEP	17.0	26.0	12.0	18.0
PVDF	5.6	8.3	16.0	23.0
PUR*	44.0	74.0	44.0	74.0
PVC	44.0	74.0	44.0	74.0

* Values were estimated using the data of Barcelona et al. (1985). An example of these calculations is given in Table B1.
PUR = polyurethane

While these values are only gross estimates, they do indicate that for relatively short contact times (five and ten minutes), sorption of the more sorptive analytes (PDCB and PCE) by the relatively nonsorptive tubings (FEP and PVDF) can still be substantial (~5–25%). For the highly sorptive tubings (polyurethane and FPVC), approximately 45 to 75% of these analytes could be lost in

five to ten minutes. These losses reflect what might be sorbed by a virgin material. However, conditions in the tubing are dynamic and fresh water would be continually replenished as it is pumped through the system. One might anticipate that once equilibrium is reached, little or no more losses of analytes would be expected, unless transfer to the atmosphere through the tubing was significant. The question that then remains is how much time is needed for the tubing to reach equilibrium under dynamic conditions. Currently there are no data available that answer this question.

Leaching study

When we compared the chromatograms of sample solutions exposed to the tubings with the control sample solutions, we saw additional peaks in the solutions exposed to some of the tubings. By the end of the experiment (72 hr), solutions exposed to nine of the tubings had extra or spurious peaks, most likely indicating that some constituents had leached (Table 5). The chromatograms for the solutions exposed to the polyurethane, polyamide, and PVC tubings contained at least eight spurious peaks, with polyurethane having the most (12). The chromatograms for the solutions exposed to the polyester-lined PVC shell and the silicone-modified TPE tubings had four spurious peaks, and chromatograms for the solutions exposed to the PP, one of the plasticized polypropylenes (formulation 1), the P(VDF-HFP), and the fluoroelastomer tubings each contained one spurious peak. The chromatograms for the solutions exposed to the rigid fluoropolymers, the polyethylenes, and one of the plasticized polypropylenes (formulation 2) did not contain any spurious peaks. This plasticized PP tubing was the only flexible tubing that did not appear to leach any contaminants.

One test solution from each of the tubings that was found to leach contaminants was analyzed for semivolatile organics by GC-MS. We reported only those matches where the quality of the match was greater than 75%. Unfortunately, we were unable to identify most of the leachates using this method. The sample solutions exposed to PP and the TPE tubings had one major peak, which was tentatively identified as hexanedioic dioctyl ester (90% match). This compound is commonly used as a plasticizer and lubricant in the manufacture of polymeric materials. The polyamide tubing leached one primary contaminant that we tentatively identified as n-butylbenzene sulfonamide (90% match). The GC chromatogram for the sample solutions exposed to

Table 5. Number of spurious HPLC peaks found during tubing material study and possible identification.

	Contact time (hr)		*Possible identification*
	1	*72*	*(% match)*
Flexible tubings			
Plasticized PP (formulation 1)	1	1	not identified
Plasticized PP (formulation 2)	0	0	
PVC	**3**	**8**	hexacosane (90%)
TPE	**1**	**4**	hexanedioic acid, dioctyl ester (83%)
P(VDF-HFP)	1	1	not identified
Polyurethane	**5**	**12**	hexanoic acid, 2-ethyl (78%)
Fluoroelastomer	1	1	not identified
Rigid tubings			
LDPE	0	0	
XLPE	0	0	
PE in an EVA shell	0	0	
PE cross-linked to EVA shell	0	0	
Polyester lining in a PVC shell	**1**	**4**	not identified
PP	1	1	hexanedioic acid, dioctyl ester (87%)
Polyamide	**2**	**9**	benzenesulfonamide, N-butyl (90%)
PTFE	0	0	
PFA	0	0	
ETFE	0	0	
PVDF	0	0	
FEP	0	0	
FEP-lined PE	0	0	

Boldface = Materials that leached several contaminants during the study.

the polyurethane tubing had a number of peaks, but we were unable to identify any of the compounds that leached. The best match was for the largest peak, which was tentatively identified as 2-ethyl hexanoic acid, with a 78% match. Hexanoic acid (caproic acid) is used in the manufacture of rubber chemicals and resins. The sample solution exposed to the PVC tubing had one major peak; hexacosane (a 26-carbon alkane) was a 90% match. However, we are at a loss to explain its presence unless it was used as a lubricant. The sample solution exposed to the polyester-lined PVC tubing had a number of peaks but no good matches.

Based on these findings, the following tubing materials appear to be least desirable for sampling organics, since each of them appeared to leach several contaminants: polyurethane, polyamide, FPVC, polyester-lined PVC, and silicone-modified TPE. In addition, PP, plasticized PP (formulation 1), P(VDF-HFP), and the fluoroelastomer tubings each appeared to leach one contaminant and thus may be less desirable than those tubings that did not leach any contaminants (i.e., the PE and rigid fluoropolymer tubings).

CONCLUSIONS

Based on the results from these studies, the rigid fluoropolymers appear to be the best materials for sampling groundwater because they were the least sorptive of organic solutes and do not appear to leach any contaminants. Among the fluoropolymers, FEP, FEP-lined PE, and PVDF were the least sorptive materials tested. If one also considers cost, PVDF is the least expensive of these three materials: its price was approximately 50–60% of the FEP and FEP-lined PE tubings. In fact, PVDF was the least expensive of all the rigid fluoropolymers tested.

In some instances, a more flexible tubing may be required—for example, in the head of a peristaltic pump. Among the flexible tubings, the two fluorinated tubings (the fluoroelastomer and P[VDF-HFP]) were much less sorptive of organic solutes than the other flexible tubings. In addition, these two tubings and the two plasticized polypropylenes appeared to leach the fewest constituents. However, if we also consider cost, we see that the fluoroelastomer was the most expensive of all the tubings tested, while the price of the P(VDF-HFP) tubing was less than 25% of the cost of the fluoroelastomer tubing.

Because all the fluoropolymer tubings tend to be expensive, a less expensive material would be desirable if it did not affect sample quality during the relatively short contact time typical of most sampling situations. It is possible that the biases we observed in this study may either increase or decrease under dynamic conditions. With respect to sorption of organic solutes, we expect that losses due to sorption would be reduced, or possibly eliminated, with time as equilibrium is approached. The unanswered question is how much time is required for equilibration to occur. Leaching of constituents, however, may increase or decrease with exposure. Several leaching studies (Packham 1971a,b; Gross et al. 1974, Boettner et al. 1981) have shown that much of the leaching that occurs from RPVC pipe decreases with time and is considered a surface phenomenon. It is possible that leaching of contaminants from other polymers may also be a surface phenomenon. If this is the case, we would expect that leaching would be minimized under dynamic conditions. On the other hand, if higher flow rates increase leaching as Junk et al. (1974) observed with FPVC, then it may be leaching rather than sorption that dictates which types of tubing are acceptable for sampling groundwater. Only a series of studies conducted under dynamic conditions with a suite of organic contaminants will determine whether the biases we observed in this study disappear under dynamic conditions. We are currently conducting studies to address these issues.

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APPENDIX A: TEST RESULTS

Table A1. Concentration (mg/L) of analyte solutions exposed to various tubing materials.

Exposure time (hr)	*Analyte*							
	NB	*TDCE*	*MNT*	*TCE*	*CLB*	*ODCB*	*PDCB*	*PCE*
Controls								
1	11.6	10.9	11.4	15.7	12.6	12.2	11.4	13.1
1	11.6	11.0	11.5	16.0	12.8	12.4	11.6	13.4
1	11.7	11.2	11.6	16.2	12.9	12.5	11.7	13.5
1	11.5	10.9	11.4	15.9	12.7	12.3	11.5	13.3
1	11.5	10.7	11.3	15.7	12.6	12.2	11.4	13.0
1	11.8	11.0	11.6	15.9	12.8	12.4	11.6	13.1
$\overline{X}$	11.61	10.94	11.46	15.91	12.74	12.32	11.53	13.24
8	11.9	12.4	11.8	17.5	13.7	12.8	11.3	14.4
8	10.9	11.0	10.9	16.2	12.3	11.9	11.5	13.4
8	11.2	10.9	11.1	16.0	12.2	11.8	11.4	13.3
8	11.0	11.0	11.0	16.3	12.3	12.0	11.9	14.1
8	11.2	10.9	11.1	16.1	12.3	11.9	11.5	13.7
8	11.2	10.8	11.2	16.0	12.3	12.0	11.4	13.5
$\overline{X}$	11.25	11.17	11.18	16.36	12.51	12.07	11.50	13.75
24*	11.1	10.2	11.1	15.1	12.1	11.8	11.2	12.2
24	11.3	10.1	11.2	15.0	12.2	11.8	11.0	11.7
24	11.3	10.4	11.2	15.5	12.4	12.0	11.4	12.4
24	11.5	10.2	11.3	15.1	12.2	11.8	11.0	11.8
$\overline{X}$	11.32	10.25	11.20	15.16	12.21	11.85	11.18	12.02
48	11.5	9.66	11.5	14.4	12.0	11.9	11.1	11.6
48	11.6	9.93	11.6	14.8	12.3	12.1	11.4	12.0
48	11.4	9.47	11.4	14.2	11.9	11.7	10.8	11.2
48	10.9	9.60	10.8	14.1	11.5	11.3	10.6	11.4
48	11.4	9.87	11.4	14.6	12.1	11.9	11.1	11.8
48	11.2	9.17	11.0	13.6	11.4	11.1	10.1	10.4
$\overline{X}$	11.34	9.616	11.27	14.27	11.89	11.66	10.86	11.39
72	11.3	9.60	11.3	14.3	11.8	11.6	10.9	11.8
72	11.1	9.64	11.1	13.8	11.5	11.3	10.5	11.2
72	11.4	9.59	11.2	14.3	11.8	11.5	10.6	11.5
72	11.3	9.24	11.3	13.8	11.5	11.4	10.6	11.2
72	11.2	9.09	11.2	13.6	11.4	11.3	10.4	11.0
72	11.2	9.24	11.1	13.8	11.6	11.4	10.5	11.2
$\overline{X}$	11.25	9.401	11.20	13.93	11.61	11.41	10.59	11.32
Polyurethane								
1	0.773	0.395	0.431	0.375	0.252	0.241	0.199	0.286
1	0.882	0.406	0.543	0.342	0.231	0.224	0.178	0.228
$\overline{X}$	0.827	0.401	0.487	0.359	0.242	0.232	0.188	0.257
8	0.294	0.137	0.054	0.075	0.032	0.010	D	0.028
8	0.307	0.124	0.053	0.070	0.032	0.012	D	0.023
$\overline{X}$	0.301	0.130	0.053	0.072	0.032	0.011	D	0.025
24	0.245	0.036	0.032	0.039	0.018	0.007	D	0.016
24	0.230	0.046	0.030	0.037	0.018	0.006	D	0.028
$\overline{X}$	0.237	0.041	0.031	0.038	0.018	0.006	D	0.022
48	0.227	D	0.021	0.017	0.013	D	D	0.007
48	0.244	D	0.024	0.018	0.014	D	D	0.008
$\overline{X}$	0.236	D	0.022	0.018	0.013	D	D	0.007

* Analyses of two 24-hr control samples were not recorded by the integrator.
D–Concentration of analyte was below MDL.

Table A1 (cont'd). Concentration (mg/L) of analyte solutions exposed to various tubing materials.

Exposure time (hr)	*NB*	*TDCE*	*MNT*	*TCE*	*CLB*	*ODCB*	*PDCB*	*PCE*
	Analyte							
72	0.158	D	0.018	0.011	0.005	D	D	0.007
72	0.165	D	0.020	0.013	0.009	0.006	D	0.009
$\overline{X}$	0.162	D	0.019	0.012	0.007	<0.006	D	0.008
PVC								
1	1.22	0.676	0.402	0.451	0.258	0.203	0.169	0.242
1	1.28	0.701	0.401	0.450	0.253	0.191	0.158	0.231
$\overline{X}$	1.25	0.689	0.402	0.451	0.255	0.197	0.164	0.236
8	0.874	0.238	0.081	0.115	0.049	0.016	0.013	0.036
8	0.960	0.269	0.090	0.130	0.058	0.020	0.016	0.031
$\overline{X}$	0.917	0.253	0.085	0.122	0.053	0.018	0.015	0.033
24	1.11	0.131	0.054	0.068	0.032	0.011	0.010	0.016
24	1.09	0.129	0.052	0.066	0.031	0.015	0.019	0.019
$\overline{X}$	1.10	0.130	0.053	0.067	0.031	0.013	0.014	0.018
48	1.35	0.072	0.037	0.046	0.024	0.007	D	0.013
48	1.18	0.158	0.037	0.045	0.022	0.006	D	0.012
$\overline{X}$	1.26	0.115	0.037	0.045	0.023	0.007	D	0.013
72	0.862	0.035	0.031	0.032	0.017	0.009	D	0.011
72	0.771	0.033	0.028	0.029	0.017	0.007	D	0.017
$\overline{X}$	0.816	0.034	0.030	0.030	0.017	0.008	D	0.014
TPE								
1	1.72	0.454	0.640	0.351	0.239	0.228	0.188	0.237
1	†	†	†	†	†	†	†	†
$\overline{X}$	1.72	0.454	0.640	0.351	0.239	0.228	0.188	0.237
8	0.545	0.119	0.143	0.062	0.034	0.011	D	0.012
8	0.554	0.114	0.139	0.061	0.033	0.012	D	0.012
$\overline{X}$	0.549	0.116	0.141	0.061	0.034	0.012	D	0.012
24	0.376	0.042	0.080	0.023	0.016	0.007	D	0.006
24	0.373	0.042	0.078	0.021	0.016	0.007	D	0.005
$\overline{X}$	0.374	0.042	0.079	0.022	0.016	0.007	D	0.005
48	0.244	0.048	0.060	0.008	0.007	D	D	D
48	0.260	0.048	0.060	0.005	0.006	D	D	D
$\overline{X}$	0.252	0.048	0.060	0.006	0.006	D	D	D
72	0.123	D	0.058	0.007	0.008	D	D	D
72	0.165	D	0.067	D	0.009	D	D	D
$\overline{X}$	0.144	D	0.062	<0.003	0.009	D	D	D
Plasticized PP (formulation 2)								
1	2.48	0.569	0.861	0.369	0.248	0.204	0.165	0.198
1	2.20	0.537	0.749	0.342	0.221	0.182	0.145	0.186
$\overline{X}$	2.34	0.553	0.805	0.356	0.235	0.193	0.155	0.192
8	0.728	0.164	0.186	0.085	0.045	0.012	0.010	0.009
8	0.760	0.171	0.190	0.083	0.045	0.015	0.009	0.015
$\overline{X}$	0.744	0.168	0.188	0.084	0.045	0.014	0.010	0.012
24	0.318	0.056	0.089	0.045	0.031	0.010	D	0.005
24	0.329	0.040	0.089	0.045	0.028	0.010	0.010	0.009
$\overline{X}$	0.324	0.048	0.089	0.045	0.030	0.010	<0.005	0.007
48	0.145	0.004	0.043	0.011	0.011	0.006	D	0.006
48	0.158	0.004	0.045	0.009	0.009	0.006	D	0.006
$\overline{X}$	0.152	0.004	0.044	0.010	0.010	0.006	D	0.006
72	0.110	D	0.017	0.016	0.010	D	D	D
72	0.089	D	0.020	0.022	0.015	D	D	D
$\overline{X}$	0.100	D	0.019	0.019	0.013	D	D	D

† Sample tubing was found incompletely filled with the test solution.
D–Concentration of analyte was below MDL.

Table A1 (cont'd).

Exposure time (hr)	*NB*	*TDCE*	*MNT*	*TCE*	*CLB*	*ODCB*	*PDCB*	*PCE*
	Analyte							
Plasticized PP (formulation 1)								
1	2.40	0.587	0.831	0.388	0.256	0.207	0.167	0.212
1	2.47	0.614	0.861	0.412	0.272	0.230	0.188	0.243
$\overline{X}$	2.44	0.600	0.846	0.400	0.264	0.218	0.177	0.227
8	0.837	0.178	0.220	0.084	0.049	0.016	0.010	0.013
8	0.861	0.185	0.219	0.088	0.049	0.018	0.011	0.015
$\overline{X}$	0.849	0.181	0.219	0.086	0.049	0.017	0.010	0.014
24	0.426	0.048	0.115	0.043	0.030	0.010	D	0.007
24	0.426	0.045	0.113	0.037	0.026	0.009	D	0.007
$\overline{X}$	0.426	0.046	0.114	0.040	0.028	0.010	D	0.007
48	0.182	0.008	0.060	0.012	0.011	0.006	D	0.006
48	0.229	0.008	0.068	0.016	0.015	0.007	D	0.005
$\overline{X}$	0.206	0.008	0.064	0.014	0.013	0.006	D	0.006
72	0.108	D	0.039	0.007	0.011	D	D	0.006
72	0.087	D	0.030	D	0.009	D	D	D
$\overline{X}$	0.098	D	0.034	<0.003	0.010	D	D	<0.002
Polyester lining in PVC shell								
1	1.54	1.08	0.730	0.837	0.488	0.357	0.293	0.463
1	1.44	1.06	0.618	0.719	0.396	0.251	0.203	0.360
$\overline{X}$	1.49	1.07	0.674	0.778	0.442	0.304	0.248	0.411
8	0.547	0.547	0.168	0.257	0.109	0.032	0.023	0.068
8	0.518	0.487	0.165	0.234	0.099	0.030	0.022	0.063
$\overline{X}$	0.533	0.517	0.166	0.246	0.104	0.031	0.023	0.066
24	0.434	0.340	0.125	0.168	0.076	0.026	0.016	0.044
24	0.425	0.319	0.118	0.160	0.072	0.026	0.016	0.039
$\overline{X}$	0.429	0.329	0.122	0.164	0.074	0.026	0.016	0.041
48	0.338	0.244	0.087	0.116	0.054	0.029	0.013	0.029
48	0.339	0.215	0.091	0.111	0.052	0.029	0.011	0.028
$\overline{X}$	0.339	0.229	0.089	0.114	0.053	0.029	0.012	0.028
72	0.319	0.166	0.083	0.087	0.042	0.024	0.009	0.026
72	0.307	0.153	0.085	0.084	0.042	0.025	0.010	0.027
$\overline{X}$	0.313	0.160	0.084	0.085	0.042	0.025	0.010	0.026
LDPE								
1	8.37	3.41	4.87	2.22	1.33	0.627	0.430	0.563
1	8.67	3.43	4.97	2.26	1.37	0.655	0.449	0.584
$\overline{X}$	8.52	3.42	4.92	2.24	1.35	0.641	0.440	0.573
8	6.39	1.71	2.72	0.947	0.523	0.192	0.120	0.170
8	6.14	1.71	2.56	0.922	0.491	0.174	0.110	0.159
$\overline{X}$	6.26	1.71	2.64	0.934	0.507	0.183	0.115	0.165
24	4.82	0.939	1.705	0.513	0.296	0.109	0.066	0.087
24	4.63	0.924	1.643	0.507	0.291	0.109	0.067	0.084
$\overline{X}$	4.73	0.931	1.674	0.510	0.294	0.109	0.067	0.086
48	3.82	0.609	1.224	0.332	0.195	0.074	0.045	0.066
48	3.83	0.594	1.215	0.327	0.195	0.072	0.043	0.057
$\overline{X}$	3.83	0.602	1.220	0.329	0.195	0.073	0.044	0.061
72	3.01	0.385	0.918	0.231	0.143	0.056	0.031	0.041
72	2.89	0.360	0.886	0.218	0.135	0.053	0.032	0.033
$\overline{X}$	2.95	0.373	0.902	0.225	0.139	0.054	0.031	0.037
XLPE								
1	8.55	3.66	5.02	2.47	1.49	0.711	0.494	0.657
1	8.39	3.18	4.59	2.02	1.20	0.508	0.334	0.447
$\overline{X}$	8.47	3.42	4.80	2.24	1.34	0.609	0.414	0.552

D–Concentration of analyte was below MDL.

Table A1 (cont'd). Concentration (mg/L) of analyte solutions exposed to various tubing materials.

Exposure time (hr)	*Analyte*							
	NB	*TDCE*	*MNT*	*TCE*	*CLB*	*ODCB*	*PDCB*	*PCE*
8	5.84	1.60	2.33	0.857	0.463	0.164	0.102	0.142
8	6.16	1.80	2.51	0.963	0.533	0.190	0.109	0.177
$\overline{X}$	6.00	1.70	2.42	0.910	0.498	0.177	0.106	0.160
24	4.57	0.932	1.62	0.511	0.295	0.110	0.066	0.089
24	4.49	0.924	1.58	0.505	0.289	0.105	0.065	0.092
$\overline{X}$	4.53	0.928	1.60	0.508	0.292	0.108	0.065	0.090
48	3.67	0.585	1.20	0.327	0.198	0.076	0.047	0.059
48	3.63	0.583	1.19	0.328	0.198	0.076	0.048	0.058
$\overline{X}$	3.65	0.584	1.19	0.327	0.198	0.076	0.048	0.059
72	2.90	0.400	0.908	0.241	0.146	0.057	0.036	0.044
72	2.99	0.380	0.903	0.229	0.088	0.054	0.033	0.038
$\overline{X}$	2.95	0.390	0.906	0.235	0.117	0.056	0.035	0.041
PE lining in EVA shell								
1	8.30	3.19	4.91	2.26	1.41	0.741	0.526	0.668
1	8.44	3.04	4.91	2.06	1.26	0.624	0.432	0.552
$\overline{X}$	8.37	3.11	4.91	2.16	1.34	0.683	0.479	0.610
8	5.63	0.845	2.23	0.564	0.347	0.142	0.100	0.096
8	5.45	0.819	2.09	0.550	0.327	0.137	0.074	0.118
$\overline{X}$	5.54	0.832	2.16	0.557	0.337	0.139	0.087	0.107
24	3.45	0.347	1.04	0.230	0.144	0.065	0.032	0.056
24	3.31	0.332	0.972	0.212	0.133	0.058	0.029	0.051
$\overline{X}$	3.38	0.340	1.01	0.221	0.138	0.062	0.030	0.054
48	1.84	0.182	0.446	0.115	0.071	0.032	0.019	0.036
48	1.64	0.172	0.395	0.106	0.064	0.038	0.024	0.040
$\overline{X}$	1.74	0.177	0.421	0.110	0.067	0.035	0.021	0.038
72	0.875	0.092	0.206	0.071	0.044	0.027	0.021	0.031
72	0.926	0.089	0.211	0.068	0.042	0.017	0.011	0.021
$\overline{X}$	0.900	0.090	0.209	0.070	0.043	0.022	0.016	0.026
PE cross-linked to EVA shell								
1	8.04	2.95	4.49	2.08	1.29	0.615	0.420	0.556
1	7.92	2.95	4.48	2.06	1.25	0.599	0.407	0.553
$\overline{X}$	7.98	2.95	4.49	2.07	1.27	0.607	0.414	0.554
8	5.06	0.775	1.93	0.526	0.318	0.140	0.076	0.131
8	5.22	0.796	1.97	0.530	0.326	0.143	0.071	0.136
$\overline{X}$	5.14	0.786	1.95	0.528	0.322	0.142	0.073	0.133
24	2.73	0.322	0.749	0.192	0.117	0.053	0.027	0.048
24	2.80	0.332	0.780	0.200	0.122	0.058	0.030	0.054
$\overline{X}$	2.76	0.327	0.765	0.196	0.119	0.055	0.029	0.051
48	1.44	0.191	0.338	0.111	0.065	0.026	0.014	0.033
48	1.41	0.176	0.333	0.107	0.066	0.028	0.019	0.029
$\overline{X}$	1.42	0.183	0.336	0.109	0.065	0.027	0.016	0.031
72	0.754	0.097	0.184	0.070	0.043	0.020	0.014	0.021
72	0.773	0.106	0.187	0.074	0.044	0.018	0.013	0.025
$\overline{X}$	0.764	0.102	0.186	0.072	0.043	0.019	0.014	0.023
P(VDF-HFP)								
1	7.89	6.87	4.66	7.90	5.09	2.99	2.42	3.51
1	8.17	7.72	4.87	8.83	5.52	3.17	2.61	4.07
$\overline{X}$	8.03	7.30	4.76	8.36	5.31	3.08	2.51	3.79
8	5.28	5.40	2.25	5.29	2.74	1.24	0.997	1.83
8	5.34	5.35	2.30	5.26	2.73	1.25	1.01	1.83
$\overline{X}$	5.31	5.37	2.28	5.27	2.73	1.25	1.00	1.83

Table A1 (cont'd).

Exposure time (hr)	*NB*	*TDCE*	*MNT*	*TCE*	*CLB*	*ODCB*	*PDCB*	*PCE*
	Analyte							
24	4.00	3.64	1.51	3.31	1.77	0.792	0.621	1.01
24	3.92	3.83	1.46	3.44	1.78	0.778	0.606	1.07
$\overline{X}$	3.96	3.73	1.48	3.37	1.77	0.785	0.614	1.04
48	3.09	2.87	1.06	2.42	1.25	0.534	0.419	0.731
48	3.09	2.93	1.07	2.53	1.29	0.558	0.433	0.784
$\overline{X}$	3.09	2.90	1.07	2.48	1.27	0.546	0.426	0.758
72	2.32	1.90	0.779	1.60	0.850	0.360	0.275	0.464
72	2.32	2.06	0.776	1.75	0.927	0.387	0.296	0.525
$\overline{X}$	2.32	1.98	0.778	1.68	0.889	0.374	0.285	0.495
Fluoroelastomer								
1	7.09	6.91	3.95	7.43	4.44	2.53	2.08	3.12
1	7.06	6.55	3.82	7.02	4.19	2.32	1.89	2.78
$\overline{X}$	7.08	6.73	3.88	7.23	4.31	2.42	1.99	2.95
8	4.77	5.33	1.94	4.73	2.37	1.07	0.819	1.52
8	4.53	4.68	1.85	4.29	2.15	1.00	0.828	1.38
$\overline{X}$	4.65	5.00	1.89	4.51	2.26	1.04	0.824	1.45
24	3.30	3.14	1.24	2.74	1.41	0.650	0.523	0.797
24	3.36	3.29	1.24	2.82	1.44	0.631	0.502	0.782
$\overline{X}$	3.33	3.21	1.24	2.78	1.42	0.641	0.512	0.790
48	2.72	2.41	0.961	2.06	1.04	0.469	0.368	0.562
48	2.75	2.50	0.974	2.10	1.06	0.487	0.387	0.598
$\overline{X}$	2.73	2.46	0.968	2.08	1.05	0.478	0.377	0.580
72	2.07	1.63	0.714	1.37	0.748	0.330	0.257	0.369
72	2.11	1.77	0.714	1.46	0.760	0.331	0.262	0.410
$\overline{X}$	2.09	1.70	0.714	1.41	0.754	0.331	0.259	0.390
Polyamide								
1	7.45	6.28	4.67	4.71	2.81	1.15	0.924	2.01
1	8.53	6.39	5.93	5.48	3.47	1.53	1.12	2.45
$\overline{X}$	7.99	6.34	5.30	5.10	3.14	1.34	1.02	2.23
8	5.05	3.20	2.33	2.14	1.14	0.307	0.251	0.681
8	4.93	3.02	2.24	2.03	1.08	0.295	0.242	0.650
$\overline{X}$	4.99	3.11	2.29	2.09	1.11	0.301	0.247	0.666
24	3.21	1.79	1.29	1.20	0.729	0.185	0.156	0.373
24	3.33	1.87	1.33	1.22	0.758	0.187	0.154	0.374
$\overline{X}$	3.27	1.83	1.31	1.21	0.744	0.186	0.155	0.374
48	2.48	1.37	0.991	0.891	0.521	0.147	0.123	0.282
48	2.52	1.38	0.989	0.871	0.513	0.135	0.114	0.274
$\overline{X}$	2.50	1.38	0.990	0.881	0.517	0.141	0.118	0.278
72	1.98	0.892	0.764	0.670	0.283	0.110	0.092	0.217
72	1.93	0.771	0.730	0.596	0.267	0.100	0.081	0.187
$\overline{X}$	1.95	0.832	0.747	0.633	0.275	0.105	0.087	0.202
PP								
1	10.8	6.18	9.19	6.04	4.53	2.59	1.70	1.92
1	10.9	5.96	9.14	5.57	4.13	2.19	1.37	1.54
$\overline{X}$	10.8	6.07	9.17	5.81	4.33	2.39	1.53	1.73
8	9.75	3.91	7.20	3.06	2.11	0.958	0.572	0.668
8	9.59	3.90	7.07	3.00	2.05	0.931	0.559	0.662
$\overline{X}$	9.67	3.90	7.13	3.03	2.08	0.944	0.566	0.665
24	9.02	2.49	5.91	1.81	1.30	0.591	0.341	0.369
24	9.09	2.71	6.09	1.99	1.42	0.638	0.372	0.406
$\overline{X}$	9.05	2.60	6.00	1.90	1.36	0.615	0.356	0.388

Table A1 (cont'd). Concentration (mg/L) of analyte solutions exposed to various tubing materials.

Exposure time (hr)	*NB*	*TDCE*	*MNT*	*TCE*	*CLB*	*ODCB*	*PDCB*	*PCE*
	Analyte							
48	8.40	1.71	5.17	1.25	0.951	0.452	0.261	0.286
48	8.49	1.90	5.16	1.35	0.993	0.464	0.265	0.279
$\overline{X}$	8.45	1.81	5.16	1.30	0.972	0.458	0.263	0.283
72	7.75	1.48	4.33	1.06	0.766	0.355	0.203	0.226
72	7.49	1.33	4.09	0.943	0.687	0.320	0.181	0.197
$\overline{X}$	7.62	1.40	4.21	1.00	0.727	0.338	0.192	0.211
ETFE								
1	11.2	6.68	10.4	9.52	8.33	7.57	5.42	5.87
1	11.0	6.97	10.2	9.90	8.53	7.56	5.35	6.00
$\overline{X}$	11.1	6.83	10.3	9.71	8.43	7.56	5.38	5.93
8	9.86	4.66	8.57	6.50	5.68	4.74	2.89	3.21
8	10.1	5.03	8.68	6.99	5.84	4.77	2.82	3.53
$\overline{X}$	9.96	4.84	8.62	6.74	5.76	4.75	2.86	3.37
24	9.24	3.18	7.43	4.29	3.90	3.07	1.59	1.78
24	9.23	3.04	7.41	4.15	3.85	3.02	1.53	1.67
$\overline{X}$	9.24	3.11	7.42	4.22	3.88	3.04	1.56	1.73
48	8.61	2.30	6.43	3.05	2.80	2.12	1.03	1.21
48	8.52	2.45	6.45	3.23	2.97	2.29	1.14	1.32
$\overline{X}$	8.56	2.37	6.44	3.14	2.88	2.21	1.09	1.26
72	7.61	1.89	5.29	2.42	2.20	1.59	0.755	0.901
72	7.67	1.75	5.35	2.24	2.06	1.53	0.719	0.841
$\overline{X}$	7.64	1.82	5.32	2.33	2.13	1.56	0.737	0.871
PTFE								
1	11.8	8.64	11.3	11.1	9.94	8.77	6.46	5.58
1	11.5	7.97	11.0	10.1	9.29	8.16	5.84	4.78
$\overline{X}$	11.6	8.31	11.2	10.6	9.62	8.46	6.15	5.18
8	10.6	6.15	9.60	6.66	6.09	4.92	3.06	2.05
8	10.8	6.14	9.79	6.67	6.19	4.98	3.02	2.05
$\overline{X}$	10.7	6.15	9.69	6.67	6.14	4.95	3.04	2.05
24	10.6	4.48	9.71	4.68	5.13	3.74	1.98	1.23
24	10.7	4.67	9.84	4.87	5.29	3.84	2.05	1.28
$\overline{X}$	10.6	4.57	9.77	4.78	5.21	3.79	2.01	1.25
48	10.5	3.34	9.32	3.33	3.89	2.79	1.39	0.840
48	10.5	3.33	9.29	3.33	3.93	2.76	1.37	0.814
$\overline{X}$	10.5	3.33	9.30	3.33	3.91	2.77	1.38	0.827
72	10.2	2.63	8.82	2.60	3.14	2.19	1.06	0.636
72	10.4	2.84	8.97	2.76	3.28	2.27	1.12	0.694
$\overline{X}$	10.3	2.74	8.90	2.68	3.21	2.23	1.09	0.665
PFA								
1	11.4	9.01	11.2	11.9	10.5	9.48	7.28	6.57
1	11.5	8.47	11.2	11.1	9.97	8.92	6.63	5.65
$\overline{X}$	11.5	8.74	11.2	11.5	10.2	9.20	6.95	6.11
8	11.0	7.01	10.4	8.24	7.68	6.26	3.93	2.97
8	11.5	7.44	11.1	8.56	8.23	6.71	3.96	3.19
$\overline{X}$	11.2	7.22	10.7	8.40	7.96	6.49	3.94	3.08
24	11.0	5.16	10.2	5.67	6.07	4.73	2.60	1.64
24	10.9	5.13	10.1	5.59	5.95	4.64	2.55	1.66
$\overline{X}$	10.9	5.14	10.2	5.63	6.01	4.69	2.57	1.65
48	10.8	4.36	9.97	4.60	5.19	3.91	2.03	1.29
48	11.0	4.39	10.1	4.60	5.21	3.92	2.02	1.28
$\overline{X}$	10.9	4.37	10.0	4.60	5.20	3.92	2.03	1.29

Table A1 (cont'd).

Exposure time (hr)	*NB*	*TDCE*	*MNT*	*TCE*	*CLB*	*ODCB*	*PDCB*	*PCE*
	Analyte							
72	10.5	3.32	9.36	3.37	3.99	2.94	1.44	0.882
72	10.7	3.49	9.49	3.52	4.10	3.04	1.51	0.956
$\overline{X}$	10.6	3.41	9.43	3.45	4.05	2.99	1.48	0.919
PVDF								
1	10.1	9.80	8.35	13.7	9.67	7.78	7.01	9.91
1	9.82	9.49	8.26	13.4	9.52	7.76	7.00	9.81
$\overline{X}$	9.96	9.64	8.31	13.6	9.60	7.77	7.00	9.86
8	8.71	9.53	6.07	12.8	7.53	5.21	4.78	8.45
8	8.63	8.93	6.03	12.0	7.18	5.05	4.66	8.00
$\overline{X}$	8.67	9.23	6.05	12.4	7.35	5.13	4.72	8.22
24	7.93	7.57	4.89	9.69	5.66	3.69	3.22	5.48
24	7.77	8.04	4.75	10.3	5.85	3.70	3.26	5.80
$\overline{X}$	7.85	7.80	4.82	9.97	5.75	3.70	3.24	5.64
48	6.85	6.87	3.92	8.66	4.76	2.90	2.50	4.57
48	6.83	7.15	3.91	8.91	4.80	2.97	2.62	4.95
$\overline{X}$	6.84	7.01	3.92	8.79	4.78	2.93	2.56	4.76
72	6.08	6.07	3.23	7.39	3.80	2.27	1.95	3.74
72	6.13	6.06	3.30	7.41	3.82	2.33	2.03	3.92
$\overline{X}$	6.11	6.07	3.27	7.40	3.81	2.30	1.99	3.83
FEP lining in PE shell								
1	11.5	8.74	11.2	12.1	10.6	9.91	8.05	7.32
1	11.2	8.94	11.1	12.3	10.8	10.3	8.48	7.89
$\overline{X}$	11.3	8.84	11.2	12.2	10.7	10.1	8.27	7.61
8	11.3	8.45	10.9	11.0	9.70	8.59	6.39	5.31
8	11.3	8.02	10.9	10.4	9.31	8.31	6.13	4.95
$\overline{X}$	11.3	8.24	10.9	10.7	9.51	8.45	6.26	5.13
24	11.0	7.07	10.6	8.79	8.57	7.34	4.92	3.47
24	11.3	6.91	10.8	8.46	8.39	7.17	4.70	3.27
$\overline{X}$	11.2	6.99	10.7	8.62	8.48	7.26	4.81	3.37
48	11.1	5.48	10.6	6.62	7.17	6.02	3.64	2.31
48	11.2	5.67	10.7	6.83	7.35	6.16	3.73	2.39
$\overline{X}$	11.1	5.58	10.7	6.73	7.26	6.09	3.68	2.35
72	10.7	4.03	10.1	4.87	5.68	4.73	2.67	1.57
72	10.7	4.28	10.2	5.13	5.90	4.92	2.80	1.68
$\overline{X}$	10.7	4.16	10.1	5.00	5.79	4.82	2.73	1.63
FEP								
1	11.3	9.32	11.2	12.7	10.9	10.1	8.20	7.74
1	11.4	9.19	11.2	12.5	10.8	9.95	8.00	7.37
$\overline{X}$	11.4	9.25	11.2	12.6	10.9	10.0	8.10	7.56
8	11.3	8.54	10.8	10.8	9.49	8.19	5.97	4.96
8	10.9	7.89	10.5	10.1	8.96	7.88	5.81	4.66
$\overline{X}$	11.1	8.21	10.7	10.5	9.22	8.03	5.89	4.81
24	11.1	6.69	10.6	8.04	7.96	6.61	4.19	2.92
24	11.1	6.69	10.6	8.09	8.02	6.62	4.20	2.88
$\overline{X}$	11.1	6.69	10.6	8.07	7.99	6.61	4.20	2.90
48	10.9	5.55	10.3	6.34	6.74	5.44	3.20	2.09
48	10.9	5.45	10.4	6.33	6.82	5.50	3.21	2.06
$\overline{X}$	10.9	5.50	10.3	6.33	6.78	5.47	3.21	2.07
72	10.7	4.40	9.95	4.89	5.53	4.41	2.44	1.50
72	10.6	4.36	9.96	4.87	5.50	4.43	2.47	1.54
$\overline{X}$	10.6	4.38	9.96	4.88	5.52	4.42	2.45	1.52

Table A2. Mean concentrations (mg/L) of analytes used in the tubing material study.

Exposure time (hr)	*Analyte*							
	NB	*TDCE*	*MNT*	*TCE*	*CLB*	*ODCB*	*PDCB*	*PCE*
Controls								
1	11.6	10.9	11.5	15.9	12.7	12.3	11.5	13.2
8	11.2	11.2	11.2	16.4	12.5	12.1	11.5	13.7
24	11.2	11.2	11.2	16.4	12.5	12.1	11.5	13.7
48	11.3	10.2	11.2	15.2	12.2	11.8	11.2	12.0
72	11.3	9.6	11.3	14.3	11.9	11.7	10.9	11.4
Polyurethane								
1	0.827^{j}	0.401^{m}	$0.487^{h,i}$	0.359^{l}	0.242^{j}	$0.232^{j,k}$	0.188^{j}	0.257^{i}
8	0.301^{j}	0.130^{k}	0.053^{k}	0.072^{l}	0.032^{h}	0.011^{g}	D	0.025^{h}
24	0.237^{l}	0.041^{m}	0.031^{n}	0.038^{m}	0.018^{l}	0.006^{k}	D	0.022^{i}
48	0.236^{k}	D	0.022^{l}	0.018^{i}	0.013^{j}	D	D	0.007^{h}
72	0.162^{k}	D	0.019^{n}	0.012^{j}	0.007^{j}	0.006^{h}	D	0.008^{g}
PVC								
1	1.25^{i}	$0.689^{l,m}$	0.402^{i}	0.451^{l}	0.255^{j}	0.197^{k}	0.164^{j}	0.236^{i}
8	0.917^{i}	$0.253^{j,k}$	0.085^{k}	0.122^{l}	0.053^{h}	0.018^{g}	0.015^{j}	0.033^{h}
24	1.10^{k}	$0.130^{l,m}$	0.053^{n}	0.067^{m}	0.031^{l}	$0.013^{j,k}$	0.014^{j}	0.018^{i}
48	1.26^{j}	0.115^{k}	0.037^{l}	0.045^{i}	0.023^{j}	0.007^{i}	D	0.013^{h}
72	0.816^{j}	0.034^{k}	0.030^{n}	0.030^{j}	0.017^{j}	0.008^{h}	D	0.014^{g}
TPE								
1	1.72^{i}	0.454^{m}	$0.640^{h,i}$	0.351^{l}	0.239^{j}	$0.228^{j,k}$	0.188^{j}	0.237^{i}
8	$0.549^{i,j}$	0.116^{k}	0.141^{k}	0.061^{l}	0.034^{h}	0.012^{g}	D	0.012^{h}
24	0.374^{l}	0.042^{m}	0.079^{n}	0.022^{m}	0.016^{l}	$0.007^{j,k}$	D	0.005^{i}
48	0.252^{k}	0.048^{k}	$0.060^{k,l}$	0.006^{i}	0.006^{j}	D	D	D
72	0.144^{k}	D	$0.062^{m,n}$	0.007^{j}	0.009^{j}	D	D	D
Plasticized PP (formulation 2)								
1	2.34^{h}	0.553^{m}	$0.805^{h,i}$	0.356^{l}	0.235^{j}	0.193^{k}	0.155^{j}	0.192^{i}
8	0.744^{i}	$0.168^{j,k}$	0.188^{k}	0.084^{l}	0.045^{h}	0.014^{g}	0.010^{j}	0.012^{h}
24	0.324^{l}	0.048^{m}	0.089^{n}	0.045^{m}	0.030^{l}	$0.010^{j,k}$	0.010^{j}	0.007^{i}
48	0.152^{k}	0.004^{k}	0.044^{l}	0.010^{i}	0.010^{j}	0.006^{i}	D	0.006^{h}
72	0.100^{k}	D	0.019^{n}	0.019^{j}	0.013^{j}	D	D	D
Plasticized PP (formulation 1)								
1	2.43^{h}	0.600^{m}	0.846^{h}	0.400^{l}	0.264^{j}	0.218^{k}	0.177^{j}	0.227^{i}
8	0.849^{i}	$0.181^{j,k}$	0.219^{k}	0.086^{l}	0.049^{h}	0.017^{g}	0.010^{j}	0.014^{h}
24	0.426^{l}	0.046^{m}	0.114^{n}	0.040^{m}	0.028^{l}	$0.010^{j,k}$	D	0.007^{i}
48	0.206^{k}	0.008^{k}	$0.064^{k,l}$	0.014^{i}	0.013^{j}	0.006^{i}	D	0.006^{h}
72	0.098^{k}	D	0.034^{n}	0.007^{j}	0.010^{j}	D	D	0.006^{g}
Polyester lining in PVC shell								
1	1.49^{i}	1.07^{l}	$0.674^{h,i}$	0.778^{l}	0.442^{j}	$0.304^{j,k}$	0.248^{j}	0.411^{i}
8	$0.533^{i,j}$	$0.517^{j,k}$	0.166^{k}	$0.246^{k,l}$	0.104^{h}	0.031^{g}	$0.023^{i,j}$	0.066^{h}
24	0.429^{l}	0.329^{l}	0.122^{n}	0.164^{m}	0.074^{l}	$0.026^{j,k}$	0.016^{j}	0.041^{i}
48	0.339^{k}	0.229^{k}	$0.089^{k,l}$	0.114^{i}	0.053^{j}	0.029^{i}	0.012^{f}	0.028^{h}
72	$0.313^{j,k}$	$0.160^{i,j,k}$	$0.084^{l,m,n}$	0.085^{j}	0.042^{j}	0.025^{h}	0.010^{j}	0.026^{g}
LDPE								
1	8.52^{e}	3.42^{j}	$4.92^{e,f}$	2.24^{k}	1.35^{i}	$0.641^{i,j}$	0.440^{j}	0.573^{i}
8	6.26^{e}	1.71^{i}	2.64^{g}	0.934^{j}	$0.507^{g,h}$	0.183^{g}	$0.115^{i,j}$	0.165^{h}
24	4.73^{g}	0.931^{k}	1.67^{i}	0.510^{l}	0.294^{k}	$0.109^{i,j}$	0.067^{j}	0.086^{i}
48	3.83^{f}	0.602^{j}	1.22^{i}	0.329^{i}	$0.195^{i,j}$	0.073^{i}	0.044^{f}	$0.061^{g,h}$
72	2.95^{f}	$0.373^{i,j}$	$0.902^{i,j}$	0.225^{j}	$0.139^{i,j}$	0.054^{h}	0.031^{j}	0.037^{g}

For each analyte and sampling time, values with the letter "a" are not significantly different from the controls. For values marked with letters other than "a," all values marked with the same letter are not significantly different from each other. For example, there is no significant difference between the concentration of nitrobenzene in samples exposed to either PVC or TPE for 1 hour (both marked "i"). D—Concentration of analyte was below MDL.

Table A2 (cont'd).

Exposure time (hr)	*NB*	*TDCE*	*MNT*	*TCE*	*CLB*	*ODCB*	*PDCB*	*PCE*
	Analyte							
XLPE								
1	8.47^{e}	3.42^{j}	4.80^{f}	2.24^{k}	1.34^{i}	0.609^{i,j}	0.414^{j}	0.552^{i}
8	6.00^{e}	1.70^{i}	2.42^{g,h}	0.910^{j,k}	0.498^{h}	0.177^{g}	0.106^{i,j}	0.160^{h}
24	4.53^{g}	0.928^{k}	1.60^{i,j}	0.508^{l}	0.292^{k}	0.108^{i,j,k}	0.065^{j}	0.090^{i}
48	3.65^{f}	0.584^{j}	1.19^{i}	0.327^{i}	0.198^{i,j}	0.076^{i}	0.048^{f}	0.059^{g,h}
72	2.95^{f}	0.390^{i}	0.906^{i}	0.235^{j}	0.117^{i,j}	0.056^{h}	0.035^{j}	0.041^{g}
PE lining in an EVA shell								
1	8.37^{e,f}	3.11^{j,k}	4.91^{e,f}	2.16^{k}	1.34^{i}	0.683^{i}	0.479^{j}	0.610^{i}
8	5.54^{f}	0.832^{j}	2.16^{h,i,j}	0.557^{j,k,l}	0.337^{h}	0.139^{g}	0.087^{i,j}	0.107^{h}
24	3.38^{i}	0.340^{l}	1.01^{l}	0.221^{m}	0.138^{l}	0.062^{j,k}	0.030^{j}	0.054^{i}
48	1.74^{i}	0.177^{k}	0.421^{j}	0.110^{i}	0.067^{j}	0.035^{i}	0.021^{f}	0.038^{g,h}
72	0.900^{i}	0.090^{j,k}	0.209^{l}	0.070^{j}	0.043^{j}	0.022^{h}	0.016^{j}	0.026^{g}
PE cross-linked to EVA shell								
1	7.98^{f}	2.95^{k}	4.49^{f}	2.07^{k}	1.27^{i}	0.607^{i,j}	0.414^{j}	0.554^{i}
8	5.14^{f,g}	0.786^{j,k}	1.95^{i,j}	0.528^{j,k,l}	0.322^{h}	0.142^{g}	0.073^{i,j}	0.133^{h}
24	2.76^{j}	0.327^{l}	0.765^{m}	0.196^{m}	0.119^{l}	0.055^{j,k}	0.029^{j}	0.051^{i}
48	1.42^{j}	0.183^{k}	0.336^{j,k}	0.109^{i}	0.065^{j}	0.027^{i}	0.016^{f}	0.031^{h}
72	0.764^{i}	0.102^{i,j,k}	0.186^{l,m}	0.072^{j}	0.043^{j}	0.019^{h}	0.014^{j}	0.023^{g}
P(VDF-HFP)								
1	8.03^{f}	7.30^{f}	4.76^{f}	8.36^{g}	5.31^{f}	3.08^{f}	2.51^{f}	3.79^{f}
8	5.31^{f,g}	5.37^{f}	2.28^{g,h,i}	5.27^{f}	2.73^{e}	1.25^{f}	1.00^{g}	1.83^{e,f}
24	3.96^{h}	3.73^{g}	1.48^{j}	3.37^{h}	1.77^{h}	0.785^{g}	0.614^{h}	1.04^{f,g}
48	3.09^{g}	2.90^{f}	1.07^{i}	2.48^{f}	1.27^{h}	0.546^{g}	0.426^{f}	0.758^{d,e,f}
72	2.32^{g}	1.98^{f}	0.778^{j,k}	1.68^{g}	0.889^{h}	0.374^{g}	0.285^{h}	0.495^{e,}
Fluoroelastomer								
1	7.08^{g}	6.73^{g,h}	3.88^{g}	7.23^{h}	4.31^{g}	2.42^{g}	1.99^{g}	2.95^{g}
8	4.65^{h}	5.00^{f}	1.89^{j}	4.51^{g}	2.26^{e,f}	1.04^{f}	0.824^{g}	1.45^{f}
24	3.33^{i}	3.21^{h}	1.24^{k}	2.78^{i}	1.42^{i}	0.641^{h}	0.512^{h,i}	0.790^{g}
48	2.73^{h}	2.46^{g}	0.968^{i}	2.08^{f}	1.05^{h}	0.478^{g,h}	0.377^{f}	0.580^{e,f,g}
72	2.09^{g,h}	1.70^{f}	0.714^{k}	1.41^{g}	0.754^{h}	0.331^{g}	0.259^{h,i}	0.390^{e,f}
Polyamide*								
1	7.99^{f}	6.34^{h,i}	5.30^{e}	5.10^{j}	3.14^{h}	1.34^{h}	1.02^{i}	2.23^{h}
8	4.99^{g,h}	3.11^{h}	2.29^{g,h,i}	2.09^{i}	1.11^{g}	0.301^{g}	0.247^{i}	0.666^{g}
24	3.27^{i}	1.83^{j}	1.31^{k}	1.21^{k}	0.744^{j}	0.186^{i}	0.155^{j}	0.374^{h}
48	2.50^{h}	1.38^{i}	0.990^{i}	0.881^{h}	0.517^{i}	0.141^{h,i}	0.118^{f}	0.278^{f,g,h}
72	1.95^{h}	0.832^{h}	0.747^{k}	0.633^{i}	0.275^{i}	0.105^{h}	0.087^{i,j}	0.202^{f,g}
PP								
1	10.84^{c}	6.07^{i}	9.17^{c}	5.81^{i}	4.33^{g}	2.39^{g}	1.53^{h}	1.73^{h}
8	9.70^{c}	3.90^{g}	7.13^{e}	3.03^{h}	2.08^{f}	0.944^{f}	0.566^{h}	0.665^{g}
24	9.05^{e}	2.60^{i}	6.00^{g}	1.90^{j}	1.36^{i}	0.615^{h}	0.356^{i}	0.388^{h}
48	8.45^{d}	1.81^{h}	5.16^{g}	1.30^{g}	0.972^{h}	0.458^{g,h}	0.263^{f}	0.283^{e,f,g,h}
72	7.62^{d}	1.40^{g}	4.21^{g}	1.00^{h}	0.727^{h}	0.338^{g}	0.192^{h,i,j}	0.211^{f,g}
ETFE*								
1	11.1^{b,c}	6.83^{g}	10.3^{b}	9.71^{f}	8.43^{e}	7.56^{e}	5.38^{e}	5.93^{d}
8	9.96^{c}	4.84^{f}	8.62^{d}	6.74^{e}	5.76^{d}	4.75^{e}	2.86^{f}	3.37^{d}
24	9.24^{e}	3.11^{h}	7.42^{f}	4.22^{g}	3.88^{g}	3.04^{f}	1.56^{g}	1.73^{e}
48	8.56^{d}	2.37^{g}	6.44^{f}	3.14^{e}	2.88^{g}	2.21^{f}	1.09^{e}	1.26^{d}
72	7.64^{d}	1.82^{f}	5.32^{f}	2.33^{f}	2.13^{g}	1.56^{f}	0.737^{g}	0.871^{d}
PTFE*								
1	11.6^{a}	8.31^{e}	11.2^{a}	10.6^{e}	9.62^{d}	8.46^{d}	6.15^{d}	5.18^{e}
8	10.7^{b}	6.15^{e}	9.69^{c}	6.67^{e}	6.14^{d}	4.95^{e}	3.04^{f}	2.05^{e}
24	10.6^{d}	4.57^{f}	9.77^{e}	4.78^{f}	5.21^{f}	3.79^{e}	2.01^{f}	1.25^{f}
48	10.5^{c}	3.33^{e}	9.30^{e}	3.33^{e}	3.91^{f}	2.77^{e}	1.38^{e}	0.827^{d,e}
72	10.3^{c}	2.74^{e}	8.90^{e}	2.68^{e}	3.21^{f}	2.23^{e}	1.09^{f}	0.665^{d,e}

For each analyte and sampling time, values with the letter "a" are not significantly different from the controls. For values marked with letters other than "a," all values marked with the same letter are not significantly different from each other.

* Tubing had a different material surface-area-to-solution-volume ratio than other tubings.

Table A2 (cont'd). Mean concentrations (mg/L) of analytes used in the tubing material study.

Exposure time (hr)	*Analyte*							
	NB	*TDCE*	*MNT*	*TCE*	*CLB*	*ODCB*	*PDCB*	*PCE*
PFA								
1	11.5[a,b]	8.74[d,e]	11.2[a]	11.5[d]	10.2[c]	9.20[c]	6.95[c]	6.11[d]
8	11.2[a]	7.22[d]	10.7[b]	8.40[d]	7.96[c]	6.49[d]	3.94[e]	3.08[d]
24	10.9[c]	5.14[e]	10.2[d]	5.63[e]	6.01[d]	4.69[d]	2.57[e]	1.65[e]
48	10.9[b]	4.37[d]	10.0[d]	4.60[d]	5.20[d]	3.92[d]	2.03[d]	1.29[d]
72	10.6[b]	3.41[d]	9.43[d]	3.45[d]	4.05[d]	2.99[d]	1.48[e]	0.919[d]
PVDF								
1	9.96[d]	9.64[b]	8.31[d]	13.6[b]	9.60[d]	7.77[e]	7.00[c]	9.86[b]
8	8.67[d]	9.23[b]	6.05[f]	12.4[b]	7.35[c]	5.13[e]	4.72[d]	8.22[b]
24	7.85[f]	7.80[b]	4.82[h]	9.97[b]	5.75[e]	3.70[e]	3.24[d]	5.64[b]
48	6.84[e]	7.01[b]	3.92[h]	8.79[b]	4.78[e]	2.93[e]	2.56[c]	4.76[b]
72	6.11[e]	6.07[b]	3.27[h]	7.40[b]	3.81[e]	2.30[e]	1.99[d]	3.83[b]
FEP lining in PE shell								
1	11.3[a,b]	8.84[c,d]	11.2[a]	12.2[c]	10.7[b]	10.1[b]	8.27[b]	7.61[c]
8	11.3[a]	8.24[c]	10.9[a,b]	10.7[c]	9.51[b]	8.45[b]	6.26[b]	5.13[c]
24	11.2[a,b]	6.99[c]	10.7[b]	8.62[c]	8.48[b]	7.26[b]	4.81[b]	3.37[c]
48	11.1[b]	5.58[c]	10.7[b]	6.73[c]	7.26[b]	6.09[b]	3.68[b]	2.35[c]
72	10.7[b]	4.16[c]	10.1[b]	5.00[c]	5.79[b]	4.82[b]	2.73[b]	1.63[c]
FEP								
1	11.4[a,b]	9.25[b,c]	11.2[a]	12.6[c]	10.9[b]	10.0[b]	8.10[b]	7.56[c]
8	11.1[a,b]	8.21[c]	10.7[b]	10.5[c]	9.22[b]	8.03[c]	5.89[c]	4.81[c]
24	11.1[b,c]	6.69[d]	10.6[c]	8.07[d]	7.99[c]	6.61[c]	4.20[c]	2.90[d]
48	10.9[b]	5.50[c]	10.3[c]	6.33[c]	6.78[c]	5.47[c]	3.21[b]	2.07[c]
72	10.6[b]	4.38[c]	9.96[c]	4.88[c]	5.52[c]	4.42[c]	2.45[c]	1.52[c]

For each analyte and sampling time, values with the letter "a" are not significantly different from the controls. For values marked with letters other than "a," all values marked with the same letter are not significantly different from each other.

* Tubing had a different material surface-area-to-solution-volume ratio than other tubings.

Table A3. Means of normalized analyte concentrations for the tubing material study.[1]

Exposure time (hr)	*NB*	*TDCE*	*MNT*	*TCE*	*CLB*	*ODCB*	*PDCB*	*PCE*
	Analyte							
FLEXIBLE TUBINGS								
Polyurethane								
1	0.071	0.037	0.042	0.023	0.019	0.019	0.016	0.019
8	0.027	0.012	0.005	0.004	0.003	0.001	D	0.002
24	0.021	0.004	0.003	0.002	0.001	0.001	D	0.002
48	0.021	D	0.002	0.001	0.001	D	D	0.001
72	0.014	D	0.002	0.001	0.001	0.001	D	0.001
PVC								
1	0.108	0.063	0.035	0.028	0.020	0.016	0.014	0.018
8	0.082	0.023	0.008	0.007	0.004	0.001	0.001	0.002
24	0.098	0.012	0.005	0.004	0.003	0.001	0.001	0.001
48	0.112	0.011	0.003	0.003	0.002	0.001	D	0.001
72	0.073	0.004	0.003	0.002	0.001	0.001	D	0.001
TPE								
1	0.149	0.042	0.056	0.022	0.019	0.019	0.016	0.018
8	0.049	0.010	0.013	0.004	0.003	0.001	D	0.001
24	0.033	0.004	0.007	0.001	0.001	0.001	D	*
48	0.022	0.005	0.005	*	0.001	D	D	D
72	0.013	D	0.006	*	0.001	D	D	D
Plasticized PP (formulation 1)								
1	0.210	0.055	0.074	0.025	0.021	0.018	0.015	0.017
8	0.076	0.016	0.020	0.005	0.004	0.001	0.001	0.001
24	0.038	0.004	0.010	0.002	0.002	0.001	D	*
48	0.018	0.001	0.006	0.001	0.001	0.001	D	*
72	0.009	D	0.003	0.001	0.001	D	D	0.001
Plasticized PP (formulation 2)								
1	0.202	0.051	0.070	0.022	0.018	0.016	0.013	0.015
8	0.066	0.015	0.017	0.005	0.004	0.001	0.001	0.001
24	0.029	0.004	0.008	0.003	0.002	0.001	0.001	0.001
48	0.013	*	0.004	0.001	0.001	*	D	*
72	0.009	D	0.002	0.001	0.001	D	D	D
P(VDF-HFP)								
1	0.692	0.669	0.414	0.526	0.418	0.250	0.218	0.287
8	0.474	0.480	0.203	0.322	0.219	0.103	0.087	0.134
24	0.353	0.333	0.132	0.206	0.142	0.065	0.053	0.076
48	0.274	0.284	0.095	0.163	0.104	0.046	0.038	0.063
72	0.205	0.206	0.069	0.117	0.075	0.032	0.026	0.043
Fluoroelastomer								
1	0.610	0.617	0.338	0.454	0.340	0.197	0.173	0.224
8	0.415	0.447	0.169	0.275	0.181	0.086	0.072	0.106
24	0.297	0.287	0.111	0.169	0.114	0.053	0.045	0.058
48	0.242	0.241	0.086	0.137	0.086	0.040	0.034	0.048
72	0.185	0.177	0.063	0.099	0.063	0.028	0.024	0.034
RIGID TUBINGS								
Polyamide								
1	0.688(.675)	0.581(.563)	0.461(.449)	0.320(.305)	0.247(.232)	0.109(.100)	0.089(.081)	0.169(.155)
8	0.446(.403)	0.278(.262)	0.204(.166)	0.127(.096)	0.089(.062)	0.025(.014)	0.021(.011)	0.049(.032)
24	0.292(.235)	0.163(.130)	0.117(.078)	0.074(.048)	0.059(.037)	0.015(.007)	0.013(.006)	0.027(.016)
48	0.221	0.135	0.088	0.058	0.042	0.012	0.011	0.023
72	0.173	0.087	0.066	0.044	0.024	0.009	0.008	0.018

[1] These values are determined by dividing the mean concentration of a given analyte at a given time and for a particular tubing by the mean concentration (for the same analyte) of the control samples taken at the same time.
D–Analyte concentrations were less than MDL.
* Values less than 0.0005.
Values in parentheses are adjusted to a material surface-area-to-solution-volume ratio equivalent to the other tubing materials.

Table A3 (cont'd).

Exposure time (hr)	*NB*	*TDCE*	*MNT*	*TCE*	*CLB*	*ODCB*	*PDCB*	*PCE*
	Analyte							
PP								
1	0.934	0.557	0.797	0.365	0.341	0.194	0.133	0.131
8	0.863	0.349	0.637	0.185	0.166	0.078	0.049	0.049
24	0.808	0.232	0.536	0.116	0.109	0.051	0.031	0.028
48	0.748	0.177	0.461	0.085	0.080	0.039	0.023	0.024
72	0.674	0.146	0.372	0.070	0.061	0.029	0.018	0.019
Polyester lining in PVC shell								
1	0.129	0.098	0.059	0.049	0.035	0.025	0.022	0.031
8	0.048	0.046	0.015	0.015	0.008	0.003	0.002	0.005
24	0.038	0.029	0.011	0.010	0.006	0.002	0.001	0.003
48	0.030	0.022	0.008	0.007	0.004	0.002	0.001	0.002
72	0.028	0.017	0.007	0.006	0.004	0.002	0.001	0.002
LDPE								
1	0.734	0.314	0.428	0.141	0.106	0.052	0.038	0.043
8	0.559	0.152	0.236	0.057	0.041	0.015	0.010	0.012
24	0.422	0.083	0.149	0.031	0.023	0.009	0.006	0.006
48	0.339	0.059	0.109	0.022	0.016	0.006	0.004	0.005
72	0.261	0.039	0.080	0.016	0.012	0.005	0.003	0.003
XLPE								
1	0.730	0.314	0.418	0.141	0.106	0.050	0.036	0.042
8	0.536	0.151	0.216	0.055	0.040	0.015	0.009	0.012
24	0.405	0.083	0.143	0.031	0.023	0.009	0.006	0.007
48	0.323	0.057	0.107	0.022	0.016	0.006	0.004	0.005
72	0.261	0.041	0.080	0.016	0.010	0.005	0.003	0.004
PE lining in EVA shell								
1	0.721	0.286	0.427	0.136	0.105	0.055	0.042	0.046
8	0.494	0.074	0.193	0.034	0.027	0.012	0.008	0.008
24	0.302	0.030	0.090	0.013	0.011	0.005	0.003	0.004
48	0.154	0.017	0.038	0.007	0.006	0.003	0.002	0.003
72	0.080	0.009	0.018	0.005	0.004	0.002	0.001	0.002
PE cross-linked to EVA shell								
1	0.688	0.270	0.390	0.130	0.100	0.049	0.036	0.042
8	0.459	0.070	0.174	0.032	0.026	0.012	0.006	0.010
24	0.247	0.029	0.068	0.012	0.010	0.005	0.002	0.004
48	0.126	0.018	0.030	0.007	0.005	0.002	0.001	0.003
72	0.068	0.011	0.016	0.005	0.004	0.002	0.001	0.002
ETFE								
1	0.956(.969)	0.626(.708)	0.895(.927)	0.611(.697)	0.664(.741)	0.615(.702)	0.468(.574)	0.449(.557)
8	0.889(.912)	0.432(.539)	0.770(.825)	0.411(.518)	0.461(.562)	0.393(.499)	0.248(.351)	0.246(.352)
24	0.825(.860)	0.278(.413)	0.662(.737)	0.257(.388)	0.310(.429)	0.252(.363)	0.136(.227)	0.126(.234)
48	0.758	0.233	0.575	0.207	0.236	0.187	0.097	0.105
72	0.676	0.189	0.471	0.163	0.179	0.133	0.068	0.076
PTFE								
1	1.00(.985)	0.762(.723)	0.972(.969)	0.666(.626)	0.757(.726)	0.688(.655)	0.535(.496)	0.392(.345)
8	0.956(.944)	0.549(.480)	0.866(.890)	0.406(.354)	0.491(.475)	0.409(.371)	0.264(.211)	0.149(.111)
24	0.950(.921)	0.408(.381)	0.872(.848)	0.291(.252)	0.417(.368)	0.313(.263)	0.175(.131)	0.092(.066)
48	0.925	0.327	0.831	0.219	0.321	0.235	0.123	0.069
72	0.910	0.285	0.787	0.187	0.270	0.190	0.100	0.058
PFA								
1	0.987	0.802	0.971	0.723	0.805	0.748	0.605	0.463
8	1.00	0.645	0.958	0.512	0.636	0.536	0.343	0.225
24	0.974	0.459	0.906	0.343	0.481	0.387	0.224	0.120
48	0.963	0.429	0.894	0.303	0.426	0.332	0.181	0.107
72	0.938	0.355	0.834	0.241	0.340	0.255	0.135	0.081

Values in parentheses are adjusted to a material surface-area-to-solution-volume ratio equivalent to the other tubing materials.

Table A3 (cont'd). Means of normalized analyte concentrations for the tubing material study.

Exposure time	*Analyte*							
(hr)	*NB*	*TDCE*	*MNT*	*TCE*	*CLB*	*ODCB*	*PDCB*	*PCE*
PVDF								
1	0.858	0.885	0.722	0.854	0.756	0.632	0.609	0.747
8	0.774	0.824	0.540	0.756	0.588	0.424	0.410	0.600
24	0.701	0.696	0.430	0.608	0.460	0.305	0.282	0.412
48	0.605	0.687	0.350	0.578	0.392	0.249	0.229	0.397
72	0.540	0.632	0.289	0.517	0.320	0.196	0.183	0.336
FEP lining in PE shell								
1	0.976	0.811	0.971	0.768	0.841	0.821	0.719	0.576
8	1.01	0.735	0.972	0.652	0.760	0.698	0.544	0.375
24	0.997	0.624	0.957	0.526	0.679	0.600	0.418	0.246
48	0.985	0.547	0.952	0.443	0.595	0.516	0.329	0.196
72	0.946	0.433	0.898	0.350	0.486	0.412	0.251	0.143
FEP								
1	0.981	0.849	0.973	0.793	0.856	0.815	0.704	0.573
8	0.989	0.733	0.953	0.640	0.738	0.664	0.512	0.351
24	0.990	0.598	0.944	0.492	0.639	0.546	0.365	0.212
48	0.967	0.539	0.924	0.417	0.555	0.463	0.286	0.173
72	0.941	0.457	0.881	0.341	0.464	0.378	0.225	0.133

Table A4. Concentrations (mg/L) of analytes in surface-area-to-solution-volume study.

Surface-area-to-solution-volume ratio (cm^{-1})	*Analyte*							
	NB	*TDCE*	*MNT*	*TCE*	*CLB*	*ODCB*	*PDCB*	*PCE*
1-hr controls								
	11.5	10.8	11.0	13.4	11.1	11.2	11.5	13.4
	11.3	10.6	10.9	13.1	10.9	10.9	11.2	12.8
	11.9	10.5	11.4	13.0	11.0	11.1	11.3	12.8
	11.5	10.6	11.1	13.2	11.1	11.2	11.5	13.1
	11.3	10.3	10.9	12.8	10.7	10.8	11.1	12.4
	11.3	10.2	11.0	12.8	10.8	10.9	11.2	12.7
PTFE								
3.55	10.9	8.71	10.5	10.3	9.29	8.88	8.04	7.56
3.55	11.6	9.14	11.0	10.7	9.64	9.27	8.45	8.23
1.15	11.4	9.76	10.9	11.9	10.2	10.1	10.1	11.0
1.15	10.8	9.51	10.5	11.6	10.1	10.1	9.91	10.8
0.7	11.5	9.34	11.1	12.9	10.9	10.9	11.1	12.5
0.7	11.4	9.65	11.0	11.9	10.2	10.2	10.2	11.2
ETFE								
2.15	11.6	9.97	11.1	12.4	10.5	10.4	10.3	11.6
2.15	11.5	9.81	11.0	12.1	10.3	10.1	9.8	11.3
0.74	11.3	10.3	10.9	12.8	10.7	10.7	10.9	12.6
0.74	11.2	10.1	10.9	12.7	10.7	10.8	10.9	12.4
0.45	11.2	10.3	10.9	12.9	10.9	11.0	11.1	12.8
0.45	11.4	10.1	11.0	12.6	10.7	10.8	10.9	12.2
Polyamide								
3.59	9.70	8.35	8.09	8.23	6.25	4.70	4.50	6.36
3.59	9.52	8.21	7.68	7.64	5.62	3.76	3.47	5.55
1.14	10.79	9.10	9.64	9.96	8.12	7.11	6.97	8.70
1.14	10.8	9.81	10.0	11.3	9.23	8.52	8.54	10.3
0.69	11.6	10.3	10.6	11.9	9.78	9.06	9.09	10.8
0.69	11.0	9.82	10.3	11.6	9.59	9.15	9.24	11.1
8-hr controls								
	11.6	12.1	11.2	15.2	12.4	12.2	12.6	14.8
	11.7	12.1	11.2	15.1	12.3	12.1	12.5	14.5
	12.0	12.4	11.5	15.4	12.6	12.3	12.8	15.3
	12.1	12.0	11.5	15.0	12.2	12.0	12.5	14.5
	12.1	12.1	11.5	14.9	12.2	12.0	12.5	14.5
	12.2	12.1	11.6	14.9	12.3	12.2	12.6	14.8
PTFE								
3.55	11.5	7.87	10.7	8.32	8.17	7.05	5.24	4.07
3.55	11.2	8.20	10.5	8.71	8.38	7.20	5.43	4.54
1.15	11.8	11.0	11.3	12.8	11.1	10.4	9.51	9.67
1.15	11.6	10.6	11.1	12.5	10.9	10.2	9.40	9.39
0.7	11.4	10.3	11.0	12.5	10.7	10.3	9.89	10.5
0.7	11.3	10.4	10.9	12.7	10.9	10.5	10.1	10.5

Surface-area-to-solution-volume ratio (cm^{-1})	*Analyte*							
	NB	*TDCE*	*MNT*	*TCE*	*CLB*	*ODCB*	*PDCB*	*PCE*
ETFE								
2.15	11.3	10.0	10.6	12.5	10.4	9.71	8.89	10.7
2.15	11.5	10.3	10.8	12.8	10.7	9.87	8.91	11.0
0.74	11.9	11.6	11.3	14.3	11.8	11.4	11.3	13.6
0.74	11.7	11.2	11.2	13.9	11.5	11.1	11.0	13.0
0.45	11.4	10.9	11.0	13.6	11.2	11.0	11.0	13.0
0.45	11.8	11.2	11.2	13.9	11.5	11.3	11.3	13.1
Polyamide								
3.59	6.94	6.74	3.94	3.78	2.21	0.738	0.666	1.69
3.59	6.97	6.49	3.97	3.71	2.24	0.823	0.751	1.72
1.14	10.3	10.1	8.03	9.02	6.20	3.21	2.93	5.79
1.14	9.73	9.51	7.62	8.45	5.75	2.87	2.62	5.20
0.69	10.8	10.2	8.98	10.2	7.41	4.69	4.46	7.25
0.69	10.9	10.9	9.11	10.8	7.88	5.04	4.77	7.90
24-hr controls								
	12.0	11.6	11.4	14.4	11.5	11.3	11.6	14.7
	11.4	11.2	11.1	14.0	11.2	11.0	11.3	14.6
	11.5	11.4	11.1	14.2	11.3	11.2	11.6	15.0
	11.3	11.5	10.9	14.3	11.3	11.3	11.8	15.6
	11.6	11.1	11.2	13.7	11.0	10.8	11.1	14.4
	11.8	10.8	11.3	13.4	10.8	10.8	11.1	13.7
PTFE								
3.55	10.8	6.19	10.0	6.19	6.41	5.33	3.56	2.71
3.55	11.2	6.86	10.3	6.73	6.73	5.47	3.65	3.05
1.15	11.9	10.2	11.1	11.3	9.82	8.85	7.52	7.76
1.15	11.0	9.24	10.6	10.5	9.17	8.39	7.14	7.19
0.7	11.2	9.61	10.8	11.2	9.53	9.05	8.16	8.89
0.7	11.7	9.64	11.1	11.2	9.59	9.10	8.30	8.95
ETFE								
2.15	11.1	8.88	10.3	11.0	9.10	8.29	7.09	9.47
2.15	11.0	8.74	10.1	10.8	8.85	7.97	6.65	9.21
0.74	11.5	10.7	10.9	13.2	10.5	10.0	9.50	12.9
0.74	11.4	10.2	10.8	12.6	10.2	9.64	9.13	11.9
0.45	11.8	10.6	11.1	13.0	10.4	10.0	9.78	12.7
0.45	11.8	10.5	11.2	12.8	10.4	10.1	9.76	12.7
Polyamide								
3.59	4.57	2.88	1.94	1.68	0.976	0.288	0.269	0.710
3.59	4.89	3.18	2.14	1.84	1.05	0.293	0.263	0.777
1.14	8.41	8.03	5.91	6.04	3.72	1.48	1.33	3.46
1.14	8.94	8.46	6.11	6.22	3.80	1.47	1.32	3.49
0.69	9.72	8.72	7.31	7.41	4.82	2.16	1.95	4.54
0.69	9.67	8.42	7.17	6.96	4.50	1.93	1.71	4.15

Table A5. Normalized concentrations of analytes in surface-area-to-solution-volume study.

Surface-area-to-solution-volume ratio (cm^{-1})	*NB*	*TDCE*	*MNT*	*TCE*	*CLB*	*ODCB*	*PDCB*	*PCE*
				1-hour				
PTFE								
5.30*	1.014	0.790	0.989	0.695	0.780	0.712	0.561	0.421
5.30*	0.990	0.729	0.964	0.636	0.729	0.662	0.507	0.361
3.55	0.958	0.815	0.955	0.776	0.841	0.803	0.707	0.576
3.55	1.019	0.855	1.007	0.807	0.873	0.838	0.744	0.628
1.15	0.977	0.922	0.972	0.911	0.923	0.907	0.887	0.853
1.15	0.922	0.899	0.936	0.889	0.914	0.905	0.870	0.832
0.70	1.022	0.911	1.017	1.007	1.013	1.008	0.994	0.994
0.70	1.015	0.941	1.007	0.935	0.948	0.940	0.922	0.889
ETFE								
8.40*	0.966	0.611	0.908	0.598	0.654	0.614	0.470	0.443
8.40*	0.945	0.637	0.888	0.622	0.669	0.614	0.464	0.453
2.15	1.015	0.933	1.009	0.934	0.954	0.944	0.904	0.883
2.15	1.012	0.918	1.003	0.911	0.928	0.915	0.866	0.865
0.74	0.964	0.971	0.969	0.974	0.969	0.962	0.955	0.977
0.74	0.955	0.954	0.966	0.966	0.969	0.972	0.958	0.961
0.45	0.991	1.006	1.001	1.009	1.013	1.011	1.001	1.015
0.45	1.016	0.984	1.011	0.984	0.991	0.993	0.984	0.973
Polyamide								
5.60*	0.642	0.574	0.408	0.296	0.220	0.093	0.080	0.152
5.60*	0.735	0.585	0.518	0.344	0.273	0.124	0.097	0.185
3.59	0.852	0.782	0.738	0.622	0.566	0.425	0.396	0.485
3.59	0.836	0.768	0.700	0.578	0.508	0.340	0.306	0.423
1.14	0.923	0.860	0.858	0.760	0.736	0.638	0.611	0.672
1.14	0.923	0.927	0.890	0.864	0.837	0.765	0.749	0.799
0.69	1.029	1.001	0.973	0.934	0.909	0.835	0.818	0.861
0.69	0.972	0.958	0.947	0.911	0.892	0.843	0.832	0.881
				8-hour				
PTFE								
5.30*	0.931	0.534	0.888	0.412	0.522	0.423	0.268	0.156
5.30*	0.956	0.533	0.906	0.413	0.531	0.428	0.264	0.155
3.55	0.987	0.651	0.952	0.549	0.660	0.581	0.417	0.277
3.55	0.958	0.677	0.938	0.575	0.677	0.593	0.432	0.309
1.15	0.980	0.898	0.978	0.845	0.899	0.855	0.752	0.651
1.15	0.961	0.865	0.964	0.825	0.878	0.840	0.744	0.632
0.70	0.937	0.852	0.950	0.836	0.870	0.852	0.790	0.714
0.70	0.931	0.862	0.943	0.849	0.885	0.865	0.805	0.717
ETFE								
8.40*	0.877	0.417	0.766	0.397	0.454	0.393	0.251	0.234
8.40*	0.894	0.450	0.776	0.427	0.467	0.395	0.245	0.257
2.15	0.969	0.828	0.947	0.824	0.842	0.800	0.707	0.727
2.15	0.990	0.854	0.962	0.842	0.861	0.813	0.709	0.748
0.74	0.988	0.947	0.981	0.941	0.954	0.940	0.896	0.914
0.74	0.973	0.918	0.970	0.919	0.931	0.917	0.871	0.878
0.45	0.940	0.897	0.951	0.913	0.916	0.908	0.882	0.885
0.45	0.974	0.925	0.972	0.928	0.940	0.931	0.900	0.893
Polyamide								
5.60*	0.449	0.286	0.208	0.131	0.091	0.025	0.022	0.050
5.60*	0.439	0.271	0.201	0.124	0.087	0.024	0.021	0.047
3.59	0.596	0.557	0.351	0.250	0.179	0.061	0.053	0.115
3.59	0.599	0.536	0.354	0.245	0.181	0.068	0.060	0.117
1.14	0.853	0.826	0.697	0.594	0.501	0.265	0.232	0.389
1.14	0.806	0.777	0.662	0.557	0.465	0.236	0.207	0.350
0.69	0.892	0.846	0.777	0.682	0.604	0.388	0.356	0.494
0.69	0.896	0.898	0.788	0.724	0.643	0.416	0.381	0.538

* Values from initial study.

Table A5 (cont'd). Normalized concentrations of analytes in surface-area-to-solution-volume study.

Surface-area-to-solution-volume ratio (cm^{-1})	*NB*	*TDCE*	*MNT*	*TCE*	*CLB*	*ODCB*	*PDCB*	*PCE*
				24-hour				
PTFE								
5.30*	0.933	0.437	0.867	0.309	0.420	0.315	0.177	0.102
5.30*	0.948	0.456	0.878	0.321	0.433	0.324	0.183	0.107
3.55	0.923	0.543	0.894	0.436	0.566	0.478	0.311	0.185
3.55	0.957	0.602	0.918	0.474	0.594	0.490	0.318	0.208
1.15	1.045	0.894	1.010	0.795	0.870	0.788	0.643	0.507
1.15	0.963	0.807	0.957	0.738	0.813	0.747	0.611	0.470
0.70	0.958	0.876	0.961	0.827	0.876	0.838	0.737	0.633
0.70	0.999	0.879	0.985	0.828	0.881	0.843	0.749	0.637
ETFE								
8.40*	0.817	0.310	0.663	0.283	0.320	0.259	0.143	0.148
8.40*	0.815	0.297	0.661	0.273	0.315	0.255	0.137	0.139
2.15	0.949	0.779	0.922	0.776	0.803	0.743	0.619	0.645
2.15	0.938	0.766	0.902	0.759	0.781	0.714	0.581	0.628
0.74	1.008	0.935	0.984	0.924	0.934	0.891	0.813	0.843
0.74	1.002	0.893	0.976	0.887	0.900	0.858	0.781	0.777
0.45	1.004	0.966	0.987	0.960	0.958	0.929	0.882	0.906
0.45	1.009	0.954	0.997	0.944	0.952	0.935	0.880	0.907
Polyamide								
5.60*	0.283	0.174	0.116	0.079	0.060	0.016	0.014	0.031
5.60*	0.294	0.183	0.119	0.081	0.062	0.016	0.014	0.031
3.59	0.390	0.252	0.173	0.119	0.086	0.026	0.024	0.048
3.59	0.418	0.279	0.190	0.130	0.092	0.026	0.023	0.053
1.14	0.738	0.701	0.535	0.424	0.329	0.131	0.113	0.226
1.14	0.784	0.739	0.553	0.437	0.337	0.131	0.113	0.228
0.69	0.828	0.795	0.652	0.548	0.443	0.200	0.176	0.323
0.69	0.824	0.767	0.639	0.514	0.413	0.179	0.154	0.296

* Values from initial study.

APPENDIX B: ANALYTE LOSSES

Table B1. An example of the calculations used to determine the losses of analytes after 5 and 10 minutes.

For this example:
Time = 10 minutes
Analyte lost = PCE
Sorptive Material = PVC

1. Determination of the percent sorbed after 10 minutes vs 60 minutes based on the data of Barcelona et al. (1985).

		Analyte sorbed ($\mu g/m^2$)*		
Analyte	*Material*	*after 10 min.*	*after 60 min.*	*Percent sorbed*
TCE	SIL	125	165	76
	PVC	120	160	75
Chloroform	SIL	120	160	75
	PVC	95	145	66
PCE	SIL	120	150	80
	PVC	125	165	76
Trichloro-	SIL	110	143	77
ethane	PVC	90	140	64
				$\bar{x}$ = 74%†

* These values are taken from Figure 2 in Barcelona et al. (1985).
† Rounding to nearest 5% = 75%.
SIL = Silicone rubber tubing.

2. Amount of PCE sorbed by PVC after 60 minutes in our study = 1 – (mean normalized concentration of PCE in solution) = 1 – 0.018= 0.982.

3. (#1) (#2) = (75%) (0.982) = 74% of the PCE in solution would be sorbed by PVC after 10 minutes' contact.

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13. ABSTRACT (*Maximum 200 words*)

There is concern whether tubings used to sample groundwater can affect contaminant concentrations. Tubings might sorb contaminants, thereby giving falsely low values, or they might leach contaminants, thereby giving falsely high values. There also is concern that a tubing used previously in a well with high concentrations of contaminants might subsequently desorb contaminants into samples taken from other wells if decontamination is insufficient. Our review of the literature indicated that these concerns are valid, although a comprehensive study of this subject does not exist. In our laboratory study, we looked for sorption of a suite of organic solutes by 20 polymeric tubings under static conditions. Seven of these tubings were flexible and the others were rigid. We found that among the rigid tubings tested, the three fluoropolymers (fluorinated ethylene propylene [FEP], FEP-lined polyethylene, and polyvinylidene fluoride [PVDF]) were the least sorptive tubings. However, even these tubings readily sorbed some of the analytes. Among the flexible tubings tested, a fluoroelastomer tubing and a tubing made of a copolymer of vinylidene fluoride and hexafluoropropylene (P[VDF-HFP]) were the least sorptive. We also found that several of the 20 tubings appeared to leach constituents into the test solution. We were unable to detect any evidence that constituents leached from the polyethylene tubings, the rigid fluoropolymer tubings, and one of the plasticized polypropylene tubings. Currently, we are conducting studies to see whether the effects we observed in this study increase, decrease, or remain the same under dynamic conditions.

14. SUBJECT TERMS

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14. SUBJECT TERMS

Ethylene tetrafluoroethylene
Fluorinated ethylene-propylene
Hexafluoropropylene
Perfluoroalkoxy
Polyamide
Polyester
Polyethylene
Polymeric tubing
Polypropylene
Polytetrafluoroethylene
Polyurethane
Polyvinyl chloride
Polyvinylidene fluoride
Sampling tubing
Thermoelastic elastomer
Tubing