



Decontaminating Materials Used in Groundwater Sampling Devices

Louise V. Parker and Thomas A. Ranney

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Abstract: In these studies, the efficiency of various decontamination protocols was tested by using small pieces of materials commonly used in groundwater sampling devices. Three types of materials that ranged in their ability to sorb organic solutes were tested: stainless steel, polyvinyl chloride (PVC), and polytetrafluoroethylene (PTFE). These test pieces were exposed to two aqueous test solutions: one solution contained three volatile organic compounds and one nitroaromatic compound, and the other solution contained four pesticides of varying hydrophobicity. Also, three types of polymeric tubing were exposed to pesticide solutions. Generally, contact times for sorption and desorption were 10 minutes and 24 hours. The test

results indicate that, generally, organic contaminants are removed from these materials simply by washing with a hot detergent solution and rinsing with hot water. The exceptions were low-density polyethylene tubing that was exposed to a pesticide test solution for 24 hours and allowed to desorb for 24 hours, and PTFE that was exposed to volatile organics for 24 hours. For these, a hot detergent water wash and rinse followed by oven drying at ~105°C was the most effective treatment. With this treatment, VOCs were not detected desorbing from the PTFE, and pesticide contamination desorbing from LDPE was substantially reduced. Solvent rinsing did not improve removal of VOCs and only marginally improved removal of pesticides from LDPE.

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Louise V. Parker and Thomas A. Ranney

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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), Hanover, New Hampshire, 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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Decontaminating Materials Used in Groundwater Sampling Devices

LOUISE V. PARKER AND THOMAS A. RANNEY

INTRODUCTION

Decontamination is necessary to reduce the possibility of cross contamination when groundwater sampling devices are not dedicated to a particular well. Also, it may be prudent to decontaminate dedicated sampling devices if they are not stored inside the well. Presumably this would eliminate any contamination from the storage area or handling. In addition, there is some debate in the groundwater monitoring industry regarding whether devices that are left installed in the well should also be decontaminated prior to each sampling event to prevent cross contamination from sample to sample.

Currently used decontamination protocols

Mickam et al. (1989) surveyed the various decontamination procedures required by state and other regulatory agencies, and Parker (1995) published a literature review on decontamination methods. Both reported that there is a lot of disparity between the numerous protocols that have been published and that there has been almost no systematic study on the effectiveness of these procedures. Although decontamination procedures vary considerably in their methodology, most utilize some type of aqueous cleaning method and often use solvent cleaning as a final or additional rinse. A typical protocol might be the following: wash with detergent, rinse with tap water, rinse with (high quality) acids and solvents, rinse with some type of high quality water (e.g., distilled, deionized, organic-free reagent water), and air dry (Mickham et al. 1989).

Aqueous cleaning is used to remove gross contamination and particles. Water acts as a solvent for water-soluble contaminants, and as a dispersal medium for insoluble substances that can be car-

ried in suspension. A surface-active agent, or surfactant such as soap or detergent, is commonly added to 1) improve the wetting ability of the cleaning solution once removed from the surface, 2) separate the contaminant from the solid surface, and 3) keep the contaminants in suspension/solution.

Typically, smaller sampling devices, such as bailers, are washed by soaking in a bath containing the cleaning solution, with or without scrubbing. Larger items, such as pumps, are usually cleaned in place by circulating the cleaning solutions and rinse water. In addition, steam cleaners or high-pressure washing systems are sometimes recommended for decontaminating sampling devices, especially to remove gross contamination such as dirt and oils.

With steam cleaning, pressure developed in the steam boiler imparts a high velocity to a mixture of water droplets and steam, which is directed from a nozzle onto the target surface. Detergent and heat from the steam weaken the bonds between the dirt and surface while the high velocity of the water droplets has sufficient power to remove the debris from the surface (Summers 1982). Depending upon the contaminant, steam can also facilitate volatilization and hydrolysis, and may aid in the removal of subsurface contaminants. Problems associated with steam cleaning include workers being burned, corrosion of metal surfaces, and warping of some polymers. From what we have been able to determine, the "steam cleaners" that are typically used to decontaminate groundwater sampling devices are actually hot-water (99°C), high-pressure washing systems.

With pressurized water washing systems, high-pressure pumps produce a stream of water rather than the small droplets produced by steam cleaning. The advantages of this type of cleaning

over steam cleaning are that there is increased force available, the energy requirements are lower because water does not have to be converted to steam, polymeric materials are less likely to be degraded, and there is less likelihood of the operator being burned.

Organic solvent rinses are used to remove any residual contaminants by dissolving them. Generally, like dissolves like; i.e., polar solvents dissolve polar contaminants, and nonpolar solvents dissolve nonpolar contaminants. Because water is a very polar solvent, nonpolar solvents are typically used to remove nonpolar organic contaminants (e.g., oils, tars) that have not been removed by aqueous cleaning. This is usually done either by flushing the surfaces with a stream of solvent, or circulating solvent through larger equipment.

Recommended organic solvents vary with the particular protocol but typically include acetone, hexane, or methanol. In most protocols, these solvents are recommended without any regard to the type of contaminants (Parker 1995), and it should be noted that among the three solvents typically used only hexane is relatively nonpolar. Obviously any organic solvent that is used as a rinsing agent should not be one of the target analytes or interfere with chemical analyses.

There are a number of problems associated with using organic solvents. These can include flammability, toxicity, disposal (although recycling can reduce this problem), and possible spillage, which can cause additional contamination problems on site. In addition, many polymers (e.g., the thermoplastics) are degraded by various organic solvents, and all polymers will sorb some of these organic solvents. Sorbed contaminants may subsequently desorb and thus contaminate water samples. Information on incompatibilities between polymers and organic solvents can be found in chemical resistance tables published by the Plastics Design Library (1994a, b) and in some of the scientific supply catalogs (e.g., Nalgene Co. and Cole-Parmer Co.). A few decontamination protocols (e.g., US EPA Region IV 1991) acknowledge that some materials are degraded by solvent cleaning and eliminate this step for these materials, although most decontamination protocols do not (Parker 1995).

The acid rinse is used to desorb sorbed metal ions from nonmetal (polymeric and glass) surfaces, and thus this step is usually recommended only if inorganics are to be analyzed. Another reason to use an acid rinse is because acid-soluble soils are poorly removed by most mildly alkaline

detergent solutions, but would be removed by an acid rinse (McLaughlin and Levin 1995). Typically dilute (0.1 N) hydrochloric or nitric acid is used. Some protocols recommend not using an acid treatment on metal surfaces (Parker 1995) because it would be ineffective and because acids corrode metal surfaces (Driscoll 1986).

Factors affecting decontamination efficiency

Parker (1995) listed several factors that would affect how readily a sampling device can be decontaminated. These include the type of sampling device (e.g., pump vs. bailer), the materials to be decontaminated, and physical characteristics of the organic contaminant, such as its aqueous solubility, volatility, and propensity to adsorb on or absorb into materials used in the sampling device. Contact time and the degree of initial contamination on the surface are also critical factors. Presumably removing a dilute solution will be easier than removing neat (pure) product. Other types of contaminants, such as grease and oil, may also affect removal.

Several studies (Gillham and O'Hannesin 1990, Parker et al. 1990, Reynolds et al. 1990) have shown that less hydrophobic organic solutes (with log octanol-water partition coefficient [K_{ow}] values less than 4) are not sorbed by non-permeable surfaces, such as glass and stainless steel (SS). However, sorption of more hydrophobic contaminants, such as polychlorinated biphenyls (PCBs), chlorinated pesticides, and polyaromatic hydrocarbons (PAHs), by SS and glass surfaces has been reported by Champion and Olsen (1971), Ogan et al. (1978), Sharom and Solomon (1981), Strachan and Hess (1982), and Jones and Miller (1988). Most likely these losses are due to adsorption by these surfaces (i.e., sorption is a surface phenomenon). Sharom and Solomon (1981) concluded that pesticides with solubilities in the $\mu\text{g/L}$ range have a tendency to be adsorbed by glass while more soluble compounds do not.

There has been relatively little study of desorption of organic contaminants from these surfaces. Sharom and Solomon (1981) noted that the pesticide permethrin was much more readily desorbed from glass than from polyvinyl chloride (PVC), polyethylene (PE), or Teflon. They were able to recover up to 94% of the lost permethrin by shaking with water for one minute. Parker (1995) proposed that decontamination of non-permeable surfaces, such as metals and glass, should involve removing only surface contaminants, such as any residual film (either wet or dry) that

is left on the surface when the sampling device is removed from the well, and any highly hydrophobic contaminants that may have adsorbed to the surface.

In contrast, several studies (Barcelona et al. 1985, Reynolds and Gillham 1985, Gillham and O'Hannesin 1990, Parker et al. 1990, Reynolds et al. 1990, Parker and Ranney 1996a, b) have shown that permeable materials, such as polymeric well casings and the tubings used in groundwater sampling pumps, sorb substantial quantities of some organic contaminants from aqueous solutions. Most of these studies agree that these organic compounds have diffused into the polymer matrix, i.e., absorption has occurred. The rate and extent of sorption varies between analytes for a given material, and varies considerably between polymers for a given analyte. Generally, flexible materials tend to be much more sorptive, i.e., both the rate of sorption and the extent of sorption are greater (Barcelona et al. 1985, Gillham and O'Hannesin 1990, Reynolds et al. 1990, Parker and Ranney 1996a). For example, Gillham and O'Hannesin (1990) found that after only 10 minutes, sorption of low ppm levels of benzene by flexible PVC was approximately 35%, while losses were less than 1% for solutions exposed to rigid PVC.

For polymers that are exposed to very low activities (i.e., trace levels) of organic solutes, diffusion of the organic molecule in the polymer is considered to be concentration independent, and at slightly higher activities diffusion is considered to be concentration dependent (Berens 1985, Jenkins et al. 1986, Holsen 1988). However, when glassy amorphous polymers (e.g., rigid PVC) are subjected to even higher concentrations (i.e., approaching the compound's aqueous solubility) or to the neat chemical, and the chemical is a solvent or swelling agent of the polymer, then diffusion will increase several orders of magnitude (Berens 1985, Jenkins et al. 1986, Holsen 1988).

Parker (1995) proposed that decontaminating permeable materials should involve more than removing surface contaminants if desorption of absorbed contaminants is significant. Unfortunately, there have been only a few studies (Miller 1982, Barcelona et al. 1985, Parker et al. 1990) that have examined desorption of organic contaminants from polymeric materials. Barcelona et al. (1985) followed the kinetics of desorption of chloroform from five tubing materials (polypropylene, polyethylene, PVC, silicone rubber, and PTFE) that had been previously exposed to a 100-

ppb solution of chloroform for one hour. They found that 80–90% of the desorption they observed occurred within the first 5–10 minutes, and that the amount desorbed after one hour constituted less than 10% of the total chloroform sorbed. The results of this study indicate that contaminants at or near the surface desorb rapidly and that release of the remainder of the absorbed contaminants is slower, most likely because it is controlled by diffusion. All three studies found that the compounds present in the greatest concentrations following desorption were not the same compounds that had been sorbed the most rapidly or to the greatest extent. Parker et al. (1990) noted that it was the smaller molecules that were more readily desorbed and attributed this to the fact that diffusion is more rapid for smaller molecules (Berens and Hopfenberg 1982, Reynolds et al. 1990).

Studies that demonstrate the factors that affect decontamination efficiency

While not many studies have examined the efficiency of the various decontamination protocols, three studies that demonstrate the impact the type of contaminants, level of contamination, and materials being decontaminated can have on decontamination effectiveness are summarized below.

Devlin (1987) found that polyethylene tubing was harder to decontaminate than Teflon tubing (the actual type was not specified). These tubings had been exposed to ppb levels of a suite of VOCs and were decontaminated by pumping deionized water through them.

Schuh et al. (1993) compared the effectiveness of distilled water rinses for removing seven pesticides (bromoxynil, diclofop-methyl, dimethoate, 2-methyl-4-chlorophenoxyacetic acid [MCPA], methyl parathion, propiconazole, and trifluralin) from a PVC bailer. They selected a one-minute contact time to represent the time required to take a bailed sample in a shallow well. With one exception (dimethoate), they correlated the number of rinses required with the analyte's solubility in water and its K_{ow} value. They observed that the most hydrophilic contaminants (i.e., with a solubility of >500 mg/L or $\log K_{ow} < 2.3$) were removed from the bailer with no residual carryover with just one rinse, while the most hydrophobic analytes (i.e., with a solubility of <3 mg/L or $\log K_{ow} \sim 4.6, 4.7$) had residual carryover after six rinses.

Fink et al. (1989) decontaminated a stainless

steel bladder pump, with a PTFE bladder and PTFE-lined sample tubing, after it had been used to sample VOCs. The pump was cleaned by steam cleaning the outside of the pump and tubing, and then circulating (15 gal.) a warm (120°F or 49°C) aqueous detergent (1%) solution through the system followed by (5 gal.) ambient temperature rinse water. In each test, the pump was contaminated by pumping at least five sampling pump/tubing assembly volumes of contaminated water. Detectable levels of TCE (1–2 µg/L) were found in the final rinse water when the pump had been used to sample the two wells with the highest TCE concentrations (1600 µg/L and 2215 µg/L, respectively), but not when the pump had been used to sample wells with lower concentrations.

Parker (1995) concluded that decontamination studies that evaluate the various decontamination procedures need to be conducted, and that these studies should consider the type of contaminants, concentration of contaminants, materials being decontaminated, and contact times.

PURPOSE OF THIS STUDY

In these studies we will evaluate the ability of various decontamination methods to remove two types of organic contaminants: volatile organic contaminants (VOCs), which are relatively hydrophilic, and pesticides, which are relatively hydrophobic. We will use one nonpermeable surface (stainless steel) and several polymers. We will evaluate the efficacy of several aqueous cleaning methods, solvent rinsing, and the use of air drying with and without heat. Contact (sorption) time and desorption time will be considered in these studies.

MATERIALS AND METHODS

For these studies, the decontamination efficiency was determined by measuring the amount that was desorbed from contaminated test pieces into fresh deionized (DI) water following the cleaning treatment. We considered a decontamination method effective if we were unable to detect any residual analytes following treatment (i.e., concentrations were below the Method Detection Limit [MDL]).

Three types of 5-cm- (2-in.-) diameter well casings were used in these studies: schedule 40 PVC, PTFE, and 304 stainless steel. Sections were cut to varying lengths (1.1 to 1.4 cm) and then cut into

quarters. The length of the section varied, depending upon the thickness of the casing wall, so that the final surface area of all the sections would be constant.

In addition, three polymeric materials (tubings)—polyvinylidene fluoride (PVDF), low-density polyethylene (LDPE), and a copolymer of vinylidene fluoride and hexafluoropropylene [P(VDF-HFP)]—were used in the pesticide studies. The internal diameter of the tubings was 0.64 cm and the lengths were ~2 cm. Because the wall thickness varied slightly among the tubings, the actual lengths varied slightly so the total surface area would be constant for all three tubing materials.

Special care was taken to eliminate contamination from grease or oil in the cutting process. The cut pieces were washed in a 2% solution of Liqui-Nox detergent for 30 minutes with intermittent stirring, rinsed with several volumes of deionized water, and then air dried on paper towels.

The test pieces were exposed to aqueous test solutions containing either a mixture of volatile organic compounds (VOCs) plus one nitroaromatic compound (called the VOC studies), or a mixture of pesticides (called the pesticide studies).

Three sorption/desorption protocols were used in most of these experiments: 10 minutes/10 minutes, 24 hours/10 minutes, and 24 hours/24 hours. The 10-minute/10-minute time was selected to represent the contact time a bailer and water sample might have in a deep well (i.e., a longer contact time). The 24-hour contact time was selected to represent the time that a pump left in the well overnight would have to sorb analytes. The 10-minute desorption time (i.e., 24 hours/10 minutes) was selected to simulate the time that materials in a cleaned pump might contact a sample while it is pumped to the surface, using slow-flow pumping. The 24-hour desorption time (i.e., 24 hours/24 hours) was selected to simulate the time that a cleaned pump would have to contaminate a well if it was left in the well overnight.

For all our experiments, there were three replicate samples for each material, time, and treatment. New materials were used throughout these experiments, and stainless steel forceps were used to handle the test pieces.

VOC STUDIES

General information

The VOC test solutions contained approximately 2 mg/L of three volatile organic compounds

(trichloroethylene [TCE], *p*-dichlorobenzene [PDCB], and tetrachloroethylene [PCE]); one nitroaromatic compound (*m*-nitrotoluene [MNT]); and 40 mg/L of mercuric chloride, which was added to prevent any losses due to biological activity. The test solutions were prepared by adding the neat organic chemicals directly to deionized water in a volumetric flask. A small headspace was left between the top of the liquid and the glass stopper to prevent any loss of the floaters. The top of the flask was tightly wrapped with parafilm and the solution was stirred with a magnetic stirrer for a minimum of three days.

Two pieces of casing were placed in a 40-mL

borosilicate glass vial that was filled with the test solution so that there was no headspace. The vials were capped with Teflon-lined plastic screw caps. Vials with the test solution but no casing served as controls. The ratio of casing-surface area/solution volume was 0.8 cm²/mL.

The test pieces were left in the vials for a specified time to sorb (Table 1). The two test pieces were then removed from the test solution and given a decontamination treatment (Table 1). Following decontamination, the two test pieces were transferred to a fresh 40-mL borosilicate glass vial containing deionized water, topped off with water, capped, and left to desorb for a specified

Table 1. Summary of experimental design of VOC decontamination experiments.

Exp. no.	Decontamination treatment	Materials tested*	Sorption/desorption times*
1	None.	PTFE PVC SS	10 min/10 min 24 hr/24 hr
2	(a) No treatment.	PTFE PVC SS	10 min/10 min 24 hr/10 min 24 hr/24 hr
	(b) 15-sec DI [†] water rinse with squirt bottle.	PTFE PVC SS	10 min/10 min 24 hr/10 min 24 hr/24 hr
3	(a) Brief DI water rinse with squirt bottle, soak in (100 mL) room-temp. solution of 1% Liqui-Nox detergent with intermittent stirring, brief DI water rinse, soaked in (100 mL) DI water for 5 min, brief DI water rinse.	PTFE PVC SS [†]	10 min/10 min** 24 hr/10 min 24 hr/24 hr
	(b) Same as above except 5 min detergent wash and 5 min DI water rinse at ~100°C.	PTFE PVC	10 min/10 min 24 hr/10 min 24 hr/24 hr
4	(a) Hot water wash with detergent as described in 3(b).	PTFE	24 hr/24 hr
	(b) Same as 4(a), followed by two 10-sec rinses with methanol (from a squirt bottle), and then blotted dry with paper towel.	PTFE	24 hr/24 hr
	(c) Hot water wash with detergent as described in 3(b) followed by two 10-sec rinses with hexane (from a squirt bottle), and then blotted dry with paper towel.	PTFE	24 hr/24 hr
5	(a) Air dried (at room temperature) on paper towel.	PTFE	24 hr/24 hr
	(b) Hot water wash with detergent as described in 3(b), followed by air drying at room temperature for 24 hr.	PTFE	24 hr/24 hr
	(c) Hot water wash with detergent as described in 3(b), followed by oven drying at 105°C for 24 hr.	PTFE	24 hr/24 hr
6	(a) Blotted dry with paper towel.	PTFE	24 hr/24 hr 7 days (168 hr)/24 hr
	(b) Blotted dry with a paper towel and then oven dried at 105°C for 1 hr.	PTFE	24 hr/24 hr 7 days (168 hr)/24 hr
	(c) Blotted dry with paper towel and then oven dried at 105°C for 4 hr.	PTFE	24 hr/24 hr 7 days (168 hr)/24 hr

* All the materials were tested for all sorption/desorption times listed, unless noted otherwise.

† DI = deionized.

** Stainless steel was not exposed to a 10 min/10 min sorption/desorption regime because rinsing had already been found to be sufficient.

time (Table 1). After removing the test pieces from the initial test solution, the test solutions were sampled and analyzed for analyte loss (sorption). After allowing time for desorption, the vials containing the deionized water were also sampled and analyzed. In each instance, an aliquot was removed from each 40-mL vial using a Pasteur pipet and transferred to an autosampler vial (1.8 mL), which was filled to capacity so there was no headspace, and capped.

Analytical determinations were performed using reversed-phase high-performance liquid chromatography (RP-HPLC). A modular system was employed consisting of a Dynatech LC-241 autosampler with a 100- μ L injection loop, a Spectra Physics SP8810 isocratic pump, a Spectra Physics SP100 variable wavelength UV detector set at 210 nm, and a Hewlett Packard 3396 series II digital integrator. Separations were obtained on a 25-cm $\times$ 0.46-cm (5- μ m) LC-18 column (Supelco) by eluting with 65/35 (V/V) methanol/water at 1.5 mL/minute. The detector response was obtained from the digital integrator operating in the peak height mode.

A set of primary standards (each 3000 mg/L) was made in methanol. A combined standard (300 mg/L) was made by pipeting a volume of each primary standard into a volumetric flask containing methanol. These standards were kept in a freezer. Each day, a series of aqueous standards was made by serially diluting the combined standard with deionized water. These working standards ranged in concentration from 3.0 to 0.012 mg/L. The MDLs for the analytes were determined by the protocol described in the Federal Register (1984).

First VOC study—Effect of no treatment

In this study, we wanted to establish what level of contamination would be carried over to DI water blanks if the three materials (PVC, SS, and PTFE) received no decontamination treatment.

Second VOC study—Effect of a water rinse

In this study, untreated samples were compared with test pieces that were briefly rinsed with DI water. This was done to reduce or eliminate any carryover of water droplets clinging to the test pieces (Table 1).

Third VOC study—Effect of a cold water wash and a hot water wash

In this study, we examined the efficiency of a

room-temperature detergent water wash with a DI water rinse vs. a hot water detergent wash with a hot DI water rinse (Table 1). We selected 100°C for the hot wash and rinse to simulate steam cleaners and hot water washing systems.

Fourth VOC study—Effect of solvent rinsing

The purpose of this study was to determine if solvent rinsing enhanced removal following a hot water detergent wash and a hot DI water rinse. Two solvents were selected: methanol, a relatively polar solvent, and hexane, a relatively nonpolar solvent (Table 1).

The protocol differed in this and subsequent VOC experiments in that only the PTFE test pieces that were exposed to the test solution for 24 hours and allowed to desorb for 24 hours were used in this study (Table 1). The reason we did this was because the previous experiment demonstrated that a detergent water wash removed all traces of the contaminants from the other test pieces (i.e., all the PVC and SS pieces, and the PTFE pieces exposed for 10 minutes/10 minutes and 24 hours/10 minutes).

Fifth VOC study—Effect of room temperature and oven drying

The purpose of this experiment was to compare three treatments: 1) air drying at room temperature for 24 hours (with no washing involved), 2) hot water detergent wash with hot DI water rinse followed by air drying for 24 hours, and 3) hot water detergent wash with hot DI water rinse followed by oven drying at 105°C for 24 hours (Table 1).

Sixth VOC study—Effect of only oven drying

The purpose of this study was to determine whether oven drying was effective without using any type of detergent washing or rinsing. After blotting dry the contaminated test pieces, the test pieces received one of the following treatments: 1) no further treatment, 2) oven drying at 105°C for one hour, or 3) oven drying for four hours (Table 1).

The experimental protocol for contaminating the test pieces differed in this study. Two 460-mL wide-mouth glass jars were filled with test solution so there was no headspace. Eighteen pieces of PTFE were placed in each jar, and the jars were closed with Teflon-lined plastic screw caps. The test pieces in one jar were allowed to sorb for 24 hours while those in the other jar sorbed for seven days.

PESTICIDE STUDIES

General information

Four pesticides (lindane [γ -BHC], dieldrin, heptachlor, and aldrin) were chosen for this study. These compounds were selected because they varied in their hydrophobicity (i.e., K_{ow} values and aqueous solubilities) (Table 2).

A weighed amount of each pesticide was added to a 2-liter volumetric flask containing deionized water, and the solution was mixed on a magnetic stirring device for one week. (Mercuric

chloride was not added to this test solution.) The solution was filtered through a 0.45- μ Nylon 66 membrane filter to remove any undissolved pesticides.

Two pieces of a casing material were placed in individual 40-mL borosilicate glass vials. Thirty mL of the pesticide test solution was added to each vial and the vial was capped with Teflon-lined plastic screw caps. The casing-surface area/solution volume ratio was 0.92 cm²/mL. After soaking in the pesticide solution for a specified time (Table 3), the test pieces were removed from

Table 2. Range in reported log octanol-water partition coefficients, aqueous solubilities, melting points, and boiling points of pesticides.*

Pesticide	Log K_{ow}	Aq. solubility (at 25°C) (mg/L)	Melting point	Boiling point
Aldrin	5.2-5.7	0.011-0.180	104-107°C	145°C [†]
Lindane	3.2-3.9	6.8-7.8	112-113°C	323.4°C
Dieldrin	3.7-5.5	0.195-0.200	150-176°C	decomposes
Heptachlor	4.4-5.4	0.056-0.180	46-96°C	135-145°C**, decomposes

* Taken from Montgomery and Welkom (1990).

† Boiling point at 1-1.5 mm.

** Boiling point at 2 mm.

Table 3. Summary of experimental design for pesticide decontamination experiments.

Exp. no.	Decontamination treatment	Materials tested*	Sorption/desorption times*
1	No treatment.	PTFE PVC SS	10 min/10 min 24 hr/10 min 24 hr/24 hr
2	Rinsed with DI [†] water (from a squirt bottle) for 15 sec.	PTFE PVC SS	10 min/10 min 24 hr/10 min 24 hr/24 hr
3	Brief 5-sec rinse with DI water (from squirt bottle), soak in (100 mL) solution of 1% Liqui-Nox detergent at 100°C for 5 min, rinsed 5 sec with DI water (from squirt bottle), soaked in (100 mL) DI water at 100°C for 5 min, then rinsed for 5 sec with DI water (from a squirt bottle).	PTFE PVC SS	10 min/10 min 24 hr/10 min 24 hr/24 hr
4	Same as Experiment 3.	PVDF LDPE P(VDF-HFP)	10 min/10 min 24 hr/10 min 24 hr/24 hr
5	(a) Wash procedure same as Experiment 3 except tubing was kept submerged by placing a glass beaker on top of tubing. (b) Same wash procedure, soak in 20 mL methanol for 30 sec, rinse with DI water for 10 sec (from a squirt bottle). (c) Same wash procedure, soak in 20 mL hexane for 30 sec, rinse with DI water for 10 sec (from a squirt bottle). (d) Same wash procedure, oven dry at ~117°C for 24 hr.	LDPE	24 hr/24 hr

* All the materials were tested for all three sorption/desorption times.

† DI = deionized.

the pesticide solution and given a decontamination treatment (Table 3). Following decontamination, the two test pieces were placed in a 40-mL clean borosilicate glass vial containing 30 mL of DI water, capped, and allowed to desorb for a specified time (Table 3). The test pieces were then removed from the water and the DI water was solvent extracted so that it could be analyzed for pesticides. Vials with the test solution but no casing served as sorption controls. To show that these materials did not leach pesticides or contaminants that interfered with these analyses, one set of well casing materials was placed in DI water for 24 hours and then the water was solvent extracted and analyzed (i.e., blanks or desorption controls).

Extraction of pesticides from the 30 mL of aqueous solution followed a modified EPA method #505 procedure (US EPA 1991) as follows: nine grams of reagent sodium chloride was added to each vial, which was then shaken to dissolve the salt; 3 mL of pesticide-grade hexane was added, and the vial was recapped and shaken horizontally for three hours on a shaking table. The vials were allowed to stand vertically for approximately 10 minutes to allow separation of the two phases. The hexane layer was drawn off with a Pasteur pipet and placed in a 1.8-mL amber autosampler vial. The autosampler vials were stored in the refrigerator (4°C) until analyzed.

Analyses were run on a Hewlett-Packard (HP) 5890 series II gas chromatograph (GC) using an electron capture detector and equipped with an HP 6890 series autosampler injector, all under the control of HP-Chemstation software. The operating parameters are given in Table 4. The MDLs

Table 4. Operating parameters for GC analyses of pesticides.

Mode: Splitless
Column: J & W Scientific DB-5.625, 30-m × 0.255-mm i.d., 0.50-μm film.
Injector temperature: 250°C
Detector temperature: 300°C
Purge time: 1.0 min
Oven parameters:
Initial temperature: 150°C
Initial hold time: 2 min
Ramp rate and final oven temperature: 10°/min to 250°C
Final hold time: 8 min
Carrier gas: nitrogen
Makeup gas: nitrogen
Column flow rate: 1.0 mL/min
Purge rate: 2.5 mL/min
Makeup gas flow rate: 60 mL/min
Injection volume: 1 μL

were determined following the procedure outline in the Federal Register (1984).

Primary certified standards were purchased from Ultra Scientific (100 μg/mL in hexane) and each was diluted to 10 μg/mL with pesticide-grade hexane. A combined standard was made by adding a volume of each of the diluted pesticide standards into a volumetric flask containing hexane (1 μg/mL). Working standards were made each sampling day by serial dilution of the combined standard into hexane (600, 400, 200, 100, 20, and 4 ng/mL). All standards were kept in the dark in the freezer.

First pesticide study—No treatment

The purpose of this study was to determine what concentrations of pesticides would be carried over if the test pieces received no treatment at all (Table 3).

Second pesticide study—Effect of rinsing

The purpose of this study was to eliminate any carryover of pesticides that might be contained in the droplets of test solution that clung to the test pieces. This was done by briefly rinsing the test pieces with DI water (Table 3).

Third pesticide study—Effect of a hot detergent wash and rinse

The purpose of this study was to see how effective a hot detergent water wash and hot DI water rinse would be for removing pesticides (Table 3).

Fourth pesticide study—Effect of a hot detergent wash on other polymers

The purpose of this study was to determine if a hot detergent wash and DI rinse would also be effective for removing pesticides from three polymeric tubing materials (tubings): polyvinylidene fluoride (PVDF), low-density polyethylene (LDPE), and a copolymer of vinylidene fluoride and hexafluoropropylene [P(VDF-HFP)].

The procedure was the same as the previous experiment except that four pieces of the tubing were placed in each of the glass vials containing 30 mL of the pesticide solution (Table 3). The tubing surface area/solution volume ratio was 1.33 cm²/mL. Desorption controls (blanks) consisted of vials that contained 30 mL of deionized water and four test pieces.

Fifth pesticide study—Effect of various decontamination treatments on LDPE

The purpose of this study was to determine

whether 1) keeping LDPE tubing submerged during the wash procedure was required to remove contamination and 2) an additional decontamination treatment following the wash procedure would remove the contaminants. Additional treatments consisted of briefly rinsing with either methanol or hexane, or oven drying (Table 3). In this study, the pesticide solution was stirred for two weeks, rather than the one week used in the previous experiments.

RESULTS AND DISCUSSION

VOC studies

Tables A1–A6 present the raw data from these studies. In these studies, the mean initial concen-

trations ranged from 1.88 to 2.29 mg/L for MNT, from 1.68 to 2.68 mg/L for TCE, from 1.33 to 3.25 mg/L for PDCB, and from 1.44 to 3.04 mg/L for PCE.

First VOC study—Effect of no treatment

Even though sorption of the four analytes (MNT, TCE, PDCB, PCE) by the test materials after 10 minutes' exposure was minimal (2% or less), contaminants were desorbed from these materials into the organic-free DI water (Table 5). This indicates that carryover of these contaminants is a problem, even though the contact time is brief. Mean desorbed concentrations ranged from 7 to 27 µg/L. This low level of contamination may be attributable to droplets of the test solution that clung to the surfaces of the test pieces when they were placed in the organic-free water.

Following 24 hours' exposure, substantial losses due to sorption were observed, especially in the test solutions exposed to the PTFE test pieces (Table 5). Desorbed concentrations were also considerably higher for PTFE and ranged from 16 µg/L for MNT to 205 µg/L for PCE. In contrast, sorption of analytes by the SS and PVC test pieces was much less. However, desorbed concentrations for the SS materials were very similar whether the sorption/desorption protocol was 10 minutes/10 minutes or 24 hours/24 hours. Desorbed concentrations were slightly higher for samples exposed to the PVC test pieces for 24 hours. This would indicate that most of the contaminants have remained at the surface of the SS pieces and the PVC pieces exposed to the test solution for 10 minutes (i.e., little absorption occurred). If this is the case, then it may be possible to remove most or all of the contamination from these surfaces by either rinsing or washing the surface.

Second VOC study—Effect of rinsing

Table 6 shows the effect of rinsing on removal. Rinsing removed almost all of the contamination from the stainless steel surfaces. Rinsing also removed nearly all the contamina-

Table 5. Summary of findings from the first VOC study—Effect of no treatment.

Material	10-min sorption				24-hr sorption			
	MNT	TCE	PDCB	PCE	MNT	TCE	PDCB	PCE
a. Mean percent loss of analyte from test solution due to sorption								
PVC	0.9	0.4	0.4	0.0	0.9	0.8	3.5	1.0
PTFE	0.4	1.9	2.1	1.9	0.9	13.7	22.2	31.7
SS	0.9	0.0	0.0	0.0	0.5	5.5	4.8	7.4
b. Mean desorbed conc. (mg/L)								
Material	10-min sorb/10-min desorb				24-hr sorb/24-hr desorb			
	MNT	TCE	PDCB	PCE	MNT	TCE	PDCB	PCE
PVC	0.015	0.016	0.022	0.027	0.015	0.028	0.058	0.032
PTFE	0.007	0.018	0.023	0.018	0.016	0.151	0.178	0.205
SS	0.012	0.020	0.020	0.016	0.011	0.011	0.017	0.014
MDL	0.004	0.006	0.008	0.008				

Table 6. Summary of findings from the second VOC study—Effect of rinsing.

Material	Mean desorbed concentration (mg/L) after the following treatments							
	No treatment				Rinsed samples			
	10-min sorb/10-min desorb				10-min sorb/10-min desorb			
PVC	0.007	0.009	0.015	0.011	LD	<0.003	LD	<0.007
PTFE	0.002	0.012	0.017	0.020	LD	0.009	0.012	0.015
SS	0.006	0.006	0.010	0.007	LD	LD	LD	<0.005
24-hr sorb/10-min desorb								
PVC	0.006	0.009	0.014	0.012	LD	0.005	LD	<0.006
PTFE	0.003	0.022	0.025	0.039	0.002	0.017	0.024	0.038
SS	0.008	0.007	0.020	0.019	LD	<0.003	LD	<0.005
24-hr sorb/24-hr desorb								
PVC	0.011	0.031	0.045	0.037	0.006	0.026	0.036	0.044
PTFE	0.016	0.167	0.184	0.314	0.013	0.158	0.174	0.308
SS	0.012	0.010	0.027	0.027	LD	LD	LD	<0.005
MDL	0.001	0.002	0.009	0.004				

LD = less than detection limit.

Table 7. Summary of findings from the third VOC study—Effect of cold and hot detergent washes and rinses.

Material	Mean desorbed concentration (mg/L) after the following treatments							
	Cold wash				Hot wash			
	10-min sorb /10-min desorb				10-min sorb /10-min desorb			
	MNT	TCE	PDCB	PCE	MNT	TCE	PDCB	PCE
PVC	LD	LD	LD	LD	LD	LD	LD	LD
PTFE	LD	<0.005	<0.008	0.010	LD	LD	LD	LD
SS	Not done				Not done			
	24-hr sorb/10-min desorb				24-hr sorb/10-min desorb			
	MNT	TCE	PDCB	PCE	MNT	TCE	PDCB	PCE
PVC	LD	LD	LD	LD	LD	LD	LD	LD
PTFE	LD	LD	0.010	0.023	LD	LD	LD	LD
SS	LD	LD	LD	LD	Not done			
	24-hr sorb/24-hr desorb				24-hr sorb/24-hr desorb			
	MNT	TCE	PDCB	PCE	MNT	TCE	PDCB	PCE
PVC	0.004	0.023	0.026	0.019	LD	LD	LD	LD
PTFE	0.013	0.159	0.165	0.334	LD	0.046	0.034	0.068
SS	LD	LD	LD	LD	Not done			
MDL	0.003	0.004	0.005	0.009				

LD = less than detection limit.

tion from the PVC pieces that were exposed to the test solution for 10 minutes. As expected, rinsing was least effective in removing the contamination from the PTFE test pieces.

Third VOC study—Effect of cold and hot detergent washes and rinses

Table 7 shows the effectiveness of detergent washing and rinsing at room temperature (called a cold wash) and at ~100°C (called a hot wash). The room temperature detergent wash and rinse was effective for removing contamination from the stainless steel surfaces. This was also true for the PVC test pieces as long as the desorption time was 10 minutes.

The hot water detergent wash and rinse was effective in removing contamination from all the PVC test pieces, irrespective of the sorption/desorption scheme, and from all the PTFE test pieces except those exposed to a 24-hour/24-hour sorption/desorption regime.

The findings from this study and the previous study agree with what Parker (1995) predicted: the nonpermeable stainless steel surfaces are much more readily decontaminated than the more sorptive polymeric materials; the most sorptive polymeric material, PTFE, is the most difficult to decontaminate; and the longer the contact time, the more difficult it is to decontaminate.

The next three studies focus on trying to remove residual contamination from PTFE pieces that were not effectively decontaminated by

detergent washing (i.e., those exposed to a 24-hour sorption/desorption regime).

Fourth VOC study—Effect of solvent rinsing

Table 8 clearly shows that neither the methanol nor hexane solvent rinses improved removal of any of these analytes from the PTFE test pieces. It is not surprising that a solvent rinse was not effective in removing contamination from this polymer because presumably the bulk of the residual contamination comes from within the polymer matrix.

Fifth VOC study—Effect of room temperature and oven air drying

The hot water detergent wash and rinse fol-

Table 8. Summary of findings from the fourth VOC study—Effect of solvent rinsing on PTFE.

Treatment	Mean desorbed conc. (mg/L) after decontamination treatment			
	MNT	TCE	PDCB	PCE
Hot detergent wash and hot water rinse	LD	0.040	0.052	0.063
Hot detergent wash, hot water rinse, and methanol rinse	LD	0.041	0.051	0.059
Hot detergent wash, hot water rinse, and hexane rinse	LD	0.045	0.055	0.070
MDL	0.002	0.006	0.007	0.006

LD = less than detection limit.

Table 9. Summary of findings from the fifth VOC study—Effect of room temperature and oven drying on PTFE.

Treatment	Mean desorbed conc. (mg/L) after decontamination treatment			
	MNT	TCE	PDCB	PCE
Air dry 24 hr	0.002	0.037	0.034	0.062
Hot detergent wash, hot water rinse, and air dry 24 hr	LD	0.021	0.017	0.031
Hot detergent wash, hot water rinse, and oven dry 24 hr	LD	LD	LD	LD
MDL	0.001	0.004	0.005	0.007

LD = less than detection limit.

lowed by oven drying (105°C) did remove the residual contamination from these test pieces (Table 9). This was not the case for the samples that were air dried at room temperature for 24 hours or the samples that were detergent washed and then air dried for 24 hours (Table 9). Clearly the higher temperature facilitated diffusion of the organic penetrants out of the polymer matrix.

Sixth VOC study—Effect of only oven drying

In this study, the test pieces were oven dried and did not receive any washing. Oven drying for one hour was not sufficient to remove these contaminants. However, oven drying at 105°C for four hours was sufficient (Table 10). This was true even for the samples that had been exposed to the test solution for one week, where losses of TCE, PDCB, and PCE ranged from 52% to 77% (Table 10). Thus, to remove volatile organics, extensive detergent washing and rinsing does not appear to be necessary, even for samples that have been exposed to the test solution for up to one week.

Pesticide studies

Tables A7–A11 present the raw data from these studies. In these studies, the mean initial concentration of analytes ranged from 576 to 5605 µg/L for lindane, from 0 to 96 µg/L for heptachlor, from 160 to 625 µg/L for aldrin, and from 191 to 393 µg/L for dieldrin.

Table 10. Summary of findings from the sixth VOC study—Effect of oven drying on PTFE.

a. Mean percent loss of analytes from test solution due to sorption

	24-hr sorption				7-day sorption			
	MNT	TCE	PDCB	PCE	MNT	TCE	PDCB	PCE
% loss	1.8	17.9	29.3	39.6	3.2	51.8	60.2	76.4

b. Mean desorbed concentration (mg/L) after oven-drying (105°C)

Time in oven (hr)	24-hr sorb/24-hr desorb				7-day sorb/24-hr desorb			
	MNT	TCE	PDCB	PCE	MNT	TCE	PDCB	PCE
0	0.014	0.092	0.101	0.119	0.024	0.101	0.113	0.108
1	LD	0.005	LD	LD	<0.004	0.018	LD	<0.010
4	LD	LD	LD	LD	LD	LD	LD	LD
MDL	0.001	0.003	0.008	0.009				

LD = less than detection limit.

First pesticide study—Effect of no treatment

For all three sorption/desorption times, all three materials sorbed significant quantities of at least some of the analytes (Table 11). Losses following 10 minutes' exposure were less than 10%, while after 24 hours' exposure losses were as high as 69%. Table 11 shows that there will be carry-over of these contaminants if the materials receive no decontamination treatment.

It is interesting that the stainless steel test pieces were the most sorptive material, and PTFE was the least sorptive. Our previous studies (Parker et al. 1990, Parker and Ranney 1994), with

Table 11. Summary of findings from the first pesticide study—Effect of no treatment.

Material	a. Mean percent loss of analyte from test solution due to sorption							
	10-min sorption				24-hr sorption			
	Lindane	Heptachlor	Aldrin	Dieldrin	Lindane	Heptachlor	Aldrin	Dieldrin
PVC	1.9	1.3	7.7	8.3	4.5	52.6	16.3	31.4
PTFE	2.3	0	5.2	7.3	0.3	37.1	15.0	16.5
SS	2.8	3.2	5.7	9.4	3.3	69.2	18.5	47.7

Material	b. Mean desorbed conc. (µg/L)							
	10-min sorb/10-min desorb				24-hr sorb/24-hr desorb			
	Lindane	Heptachlor	Aldrin	Dieldrin	Lindane	Heptachlor	Aldrin	Dieldrin
PVC	7.61	LD	3.91	3.99	9.01	5.31	6.61	31.2
PTFE	2.72	0.68	2.45	5.49	2.86	7.11	6.74	22.8
SS	12.3	LD	4.57	2.62	17.4	4.09	10.4	36.9

Material	24-hr sorb/10-min desorb			
	Lindane	Heptachlor	Aldrin	Dieldrin
PVC	6.79	0.78	4.31	7.98
PTFE	2.46	1.68	2.93	9.57
SS	12.8	LD	6.14	6.94
MDL	0.88	0.62	0.83	0.61

LD = less than detection limit.

**Table 12. Summary of findings from the second pesticide study—
Effect of a water rinse.**

a. Mean percent loss of analyte from test solution due to sorption								
<i>Material</i>	<i>10-min sorption</i>				<i>24-hr sorption</i>			
	<i>Lindane</i>	<i>Heptachlor</i>	<i>Aldrin</i>	<i>Dieldrin</i>	<i>Lindane</i>	<i>Heptachlor</i>	<i>Aldrin</i>	<i>Dieldrin</i>
PVC	4.4	9.6	5.6	11.0	4.4	49.1	21.7	29.7
PTFE	0.8	8.0	3.7	8.5	1.5	37.6	20.1	16.7
SS	2.7	8.7	3.7	10.8	4.0	66.8	27.4	44.2

b. Mean desorbed conc. (µg/L)								
<i>Material</i>	<i>10-min sorb/10-min desorb</i>				<i>24-hr sorb/24-hr desorb</i>			
	<i>Lindane</i>	<i>Heptachlor</i>	<i>Aldrin</i>	<i>Dieldrin</i>	<i>Lindane</i>	<i>Heptachlor</i>	<i>Aldrin</i>	<i>Dieldrin</i>
PVC	2.50	0.45	1.69	5.69	3.77	10.0	6.03	57.7
PTFE	0.70	1.15	1.29	8.28	1.06	12.1	8.57	35.8
SS	6.19	0.29	2.80	3.77	6.95	9.20	7.66	68.1

<i>24-hr sorb/10-min desorb</i>				
<i>Material</i>	<i>Lindane</i>	<i>Heptachlor</i>	<i>Aldrin</i>	<i>Dieldrin</i>
PVC	1.97	1.28	1.81	12.2
PTFE	0.46	2.82	2.25	12.7
SS	5.75	0.89	3.18	11.7
MDL	0.35	0.14	0.53	0.83

**Table 13. Summary of findings
from the third pesticide study—
Effect of a hot water wash and
rinse.**

<i>Mean desorbed conc. (µg/L) after the following treatments*</i>				
<i>Material</i>	<i>10-min sorb/10-min desorb</i>			
	<i>Lindane</i>	<i>Aldrin</i>	<i>Dieldrin</i>	
PVC	LD	LD	LD	
PTFE	LD	LD	LD	
SS	LD	LD	LD	

<i>24-hr sorb/10-min desorb</i>			
<i>Material</i>	<i>Lindane</i>	<i>Aldrin</i>	<i>Dieldrin</i>
PVC	LD	LD	LD
PTFE	LD	LD	LD
SS	LD	LD	LD

<i>24-hr sorb/24-hr desorb</i>			
<i>Material</i>	<i>Lindane</i>	<i>Aldrin</i>	<i>Dieldrin</i>
PVC	LD	LD	LD
PTFE	LD	LD	LD
SS	LD	LD	LD
MDL	0.53	0.41	0.73

LD = less than detection limit.

* Heptachlor was inadvertently left out
of the test solution.

less hydrophobic organic contaminants (i.e., with K_{ow} values of 10^3 or less [munitions, VOCs]), have shown the opposite trend, with virtually no sorption by the stainless steel test pieces. We initially thought that perhaps the samples had been mislabeled, but our next two studies show the same

trend (Tables A8 and A9). These results agree with the findings of Sharom and Solomon (1981), who found that sorption of the pesticide permethrin was much more rapid for the nonpermeable glass surfaces than for the polymeric (PVC, PE, and Teflon) surfaces.

As would be expected, we also noted that desorbed concentrations were highest in DI water exposed to the SS test pieces. This also agrees with Sharom and Solomon's findings for desorption of permethrin from glass vs. polymeric surfaces.

Second pesticide study—Effect of a water rinse

Table 12 shows that rinsing the test pieces for 10 seconds with organic-free water was not effective in removing all the contamination, even for the samples that were exposed to the test solution only briefly (10 minutes). These results indicate that these highly hydrophobic contaminants were sorbed in some way by the surface. Otherwise, we would expect that rinsing would remove most or all of the contamination, and the time for desorption would not have affected desorbed concentrations.

Third pesticide study—Effect of a hot water detergent wash and rinse

Table 13 clearly shows that a hot water detergent wash and hot DI water rinse were effective in removing the pesticides from all three test materials, including samples that were given the longest exposure times.

Table 14. Summary of findings from the fourth pesticide study—Effect of hot water detergent wash and rinse on other polymers.

a. Mean percent loss of analytes from test solution due to sorption				
Material	24-hr sorption*			
	Lindane	Heptachlor	Aldrin	Dieldrin
PVDF	2.1	75.0	5.0	53.4
LDPE	71.4	>91.5	20.5	92.0
P(VDF-HFP)	35.1	>83.8	23.7	82.6

b. Mean desorbed concentration (µg/L)				
Material	10-min sorb/10-min desorb*			
	Lindane	Heptachlor	Aldrin	Dieldrin
PVDF	LD	LD	LD	LD
LDPE	LD	LD	LD	LD
P(VDF-HFP)	LD	LD	LD	LD

Material	24-hr sorb/10-min desorb			
	Lindane	Heptachlor	Aldrin	Dieldrin
PVDF	LD	LD	LD	LD
LDPE	LD	LD	LD	LD
P(VDF-HFP)	LD	LD	LD	LD

Material	24-hr sorb/24-hr desorb			
	Lindane	Heptachlor	Aldrin	Dieldrin
PVDF	LD	LD	LD	LD
LDPE	5.6	LD	1.7	LD
P(VDF-HFP)	LD	LD	LD	LD
MDL	0.98	0.58	0.91	0.96

* No measurements of analyte loss were made for 10 min. See Tables 10 and 11 for analyte losses at 10 min.
LD = less than detection limit.

Fourth pesticide study—Effect of a hot detergent wash on other polymers

After 24 hours' exposure, all three tubings [LDPE, PVDF, P(VDF-HFP)] were highly sorptive of at least two of the pesticides (Table 14). Generally, LDPE was the most highly sorptive tubing tested, and PVDF was the least sorptive. Parker and Ranney (1996a) had similar results with respect to sorption of VOCs and nitroaromatic compounds by these three tubings.

Generally, these three materials were readily decontaminated by a hot detergent water wash and hot DI water rinse. The exception was the highly sorptive LDPE that was exposed to a 24-hour/24-hour sorption/desorption regime. We thought that one reason why this tubing wasn't effectively decontaminated by this procedure may have been because the tubing pieces floated on top of the cleaning solutions while the other materials sank to the bottom.

Table 15. Summary of findings from the fifth pesticide study—Effect of various treatments on LDPE tubing.

Treatment	Mean desorbed concentration (µg/L) after the following treatments			
	Lindane	Heptachlor	Aldrin	Dieldrin
Submerged wash* only	196	LD	2.84	LD
Wash and methanol rinse	133	LD	1.80	LD
Wash and hexane rinse	123	LD	2.64	LD
Wash and oven dry†	11.8	LD	LD	LD
MDL	0.74	0.84	0.55	0.85

LD = less than detection limit.

* Hot water detergent wash and hot water rinse

† ~117°C for 24 hours

Fifth pesticide study—Effect of various decontamination treatments on LDPE

The data from this study (Table 15) show that keeping the pieces of LDPE tubing submerged during the hot detergent wash and hot water rinse was not sufficient to remove these contaminants. In addition, these data show that while none of these procedures removed all the contaminants from this material, the wash procedure followed by oven drying was by far the most effective procedure. In this study, solvent rinsing significantly improved removal efficiency over the washing procedure alone but was not nearly as effective as oven drying (Table A11). It should be noted that, with this method, residual concentrations of the one remaining contaminant, lindane, were approximately one-tenth of those from the solvent treatments.

Apparently even large molecules such as pesticides are absorbed by LDPE, and thus oven drying speeds diffusion of these molecules out of the polymer.

CONCLUSIONS

These studies show that if either permeable or nonpermeable materials are not decontaminated, there will be significant carryover of both hydrophilic and hydrophobic contaminants.

Table 16 summarizes the effectiveness of the various decontamination procedures by listing the minimum treatment required to remove the contaminants. We found that any organic contaminant can be removed from the nonpermeable stainless steel surfaces by using a hot detergent wash and distilled water rinse. The permeable polymeric materials are much less readily decon-

Table 16. Minimum treatment required to remove organic contaminants.

Contaminants	Material	Sorption/desorption times		
		10 min/10 min	24 hr/10 min	24 hr/24 hr
VOCs	SS	Rinse only	Rinse	Cold wash
	Rigid PVC	Cold wash	Cold wash	Hot wash
	PTFE	Hot wash	Hot wash	Hot wash/oven dry (105°C) ¹
Pesticides	SS	Hot wash ²	Hot wash ²	Hot wash ²
	Rigid PVC	Hot wash ²	Hot wash ²	Hot wash ²
	PTFE	Hot wash ²	Hot wash ²	Hot wash ²
	PVDF	Hot wash ³	Hot wash ³	Hot wash ³
	LDPE	Hot wash ³	Hot wash ³	Hot wash, oven dry, plus unspecified additional treatment needed ⁴
	P(VDF-HFP)	Hot wash ³	Hot wash ³	Hot wash ³

"Cold wash" was room temperature water containing 1% detergent.

"Hot wash" was ~100°C water containing 1% detergent.

1 – Oven dry for 4 hours.

2 – Rinsing was not sufficient to remove pesticides, but a room temperature wash was not tested.

3 – Only a hot detergent water wash and rinse was tested.

4 – A hot detergent water wash, hot water rinse, and oven drying (~117°C, 24 hr) removed most (>99.7%), but not all of the contamination.

taminated. For these materials, ease of decontamination is a function of the analyte, the rigidity and sorptive nature of the material, and the contact time for sorption and desorption.

Volatile organics are readily removed from PVC test pieces that have been exposed to low ppm levels for up to 24 hours simply by washing with a hot detergent solution and rinsing with hot DI water. For more sorptive polymers, such as PTFE, additional oven drying is necessary for effective decontamination. Apparently oven drying speeds diffusion of the organic contaminants out of the polymer.

Pesticides are readily removed from most polymeric materials by using a hot detergent wash and hot water rinse. LDPE was found to be the exception to this, and could not be adequately cleaned using this method if the exposure times were 24 hours. This tubing material was also the most sorptive material tested. Washing followed by oven drying did substantially improve removal of these contaminants. Again it appears that oven drying speeds diffusion of the organic out of the polymer.

This study also showed that solvent rinsing did not aid in the removal of VOCs from these surfaces. While solvent rinsing did improve removal of pesticides from LDPE slightly, oven drying was much more effective. These findings are important because this means that a considerably cumbersome, expensive, and hazardous

step (i.e., solvent rinsing) serves no useful purpose and thus could be eliminated from all decontamination protocols.

The data from this study also indicate that washing is not necessary to remove VOCs and nitroaromatic compounds if the materials are oven dried for four hours at 105°C. We did not pursue testing the effectiveness of using only oven drying for removing pesticides, because we felt that detergent washing was essential to remove other contaminants, such as metals, silt, oil, etc.

This study shows the importance of hot air drying for decontaminating the more sorptive materials. While it would be a departure from currently used protocols, there are several ways that equipment could be heated in the field. A gas oven or an electric oven with a generator could be set up in the field. Another possibility would be to place an oven in a small trailer or in any building on site that has either gas or electricity. Perhaps even a hair dryer could be used. Our next study will examine this issue further.

There are two decontamination issues that have not been explored at this time but should be addressed at a later date: the effect of even longer exposure times and the effect of exposure to either neat organic chemicals or to aqueous organic solutions at very high concentrations. Longer exposure times may be significant when decontaminating devices that have been left in a

well for an extended period of time. Polymers that are exposed to a neat chemical that is either a solvent or swelling agent of the polymer will be seriously degraded (softened, swollen, dissolved, etc.), and thus devices made with these materials would not require decontamination because the device would be ruined. The same would be true if these polymers were exposed to very high concentrations of these same chemicals (i.e., approaching the aqueous solubility of the chemical). However, slightly lower concentrations can result in much more rapid diffusion in some polymers because of changes within the polymer (Berens 1985; Vonk 1985, 1986; Jenkins et al. 1986; Holsen 1988). These materials may not appear to be degraded but may be more difficult to decontaminate because of the greater volume of chemical(s) that was sorbed by the material. (As an example, see Berens [1985], Vonk [1985, 1986], and Parker and Ranney [1994, 1995, 1996b] for information on rigid PVC.) Other materials, such as stainless steel and fluoropolymers, are not degraded by neat organic solvents or by aqueous solutions containing organic solvents. However, it still may be more difficult to remove neat chemicals from the porous fluoropolymers.

In the next phase of this study, we will apply the findings from these studies towards developing and testing decontamination methods using actual groundwater sampling devices that have been exposed to low ppm or ppb levels of organic contaminants. This study shows that the decontamination protocols currently being used (i.e., detergent wash, water rinse, and then solvent rinse) most likely will not be effective in removing organic contaminants from groundwater sampling devices. Because of the size and structure of the various sampling devices, we anticipate that decontaminating sampling devices will be more problematic than decontaminating small test pieces has been. The results from this study indicate that hot air is required to remove some organic contaminants from the more sorptive polymers. While it should be relatively easy to wash, rinse, and oven dry a small device such as a bailer, we anticipate that cleaning and hot air drying a pump will be more challenging.

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APPENDIX A: RAW DATA FROM THE VOC AND PESTICIDE STUDIES

Table A1. First VOC study—Effect of no treatment.

	Analyte conc. (mg/L) in 10-min controls				Analyte conc. (mg/L) in 24-hr controls			
	MNT	TCE	PDCB	PCE	MNT	TCE	PDCB	PCE
A	2.17	2.58	2.35	2.11	2.16	2.67	2.37	2.13
B	2.16	2.38	2.20	1.93	2.16	2.53	2.30	1.99
C	2.17	2.84	2.51	2.24	2.15	2.44	2.21	1.95
$\bar{X}$	2.17	2.60	2.35	2.09	2.16	2.55	2.30	2.02
% RSD	0.27	8.9	6.6	7.5	0.27	4.6	3.5	4.7

Material	Solution conc. (mg/L) after 10-min sorption				Desorbed conc. (mg/L) after 10 min			
	MNT	TCE	PDCB	PCE	MNT	TCE	PDCB	PCE
PVC-A	2.17	2.85	2.49	2.34	0.008	0.007	0.014	0.014
PVC-B	2.13	2.33	2.18	1.89	0.018	0.022	0.029	0.036
PVC-C	2.16	2.58	2.34	2.10	0.018	0.018	0.024	0.030
$\bar{X}$	2.15	2.59	2.34	2.11	0.015	0.016	0.022	0.027
% RSD	0.97	10	6.6	11	39	49	35	42
% of initial	99	100	100	101	0.69	0.63	0.96	1.23
PTFE-A	2.15	2.80	2.43	2.27	0.008	0.020	0.024	0.020
PTFE-B	2.16	2.45	2.25	1.97	0.007	0.019	0.027	0.020
PTFE-C	2.17	2.39	2.23	1.92	0.008	0.016	0.018	0.014
$\bar{X}$	2.16	2.55	2.30	2.05	0.008	0.018	0.023	0.018
% RSD	0.46	8.7	4.8	9.2	7.2	12	20	19
% of initial	99.6	98.1	97.9	98.1	0.32	0.62	0.98	0.86
SS-A	2.16	2.86	2.49	2.36	0.012	0.017	0.016	0.010
SS-B	2.15	2.51	2.26	2.04	0.010	0.019	0.026	0.013
SS-C	2.14	2.72	2.38	2.23	0.015	0.023	0.017	0.025
$\bar{X}$	2.15	2.70	2.38	2.21	0.012	0.020	0.020	0.016
% RSD	0.47	6.5	4.8	7.3	21	15	28	50
% of initial	99.1	103	101	106	0.55	0.76	0.85	0.77

Material	Solution conc. (mg/L) after 24-hr sorption				Desorbed conc. (mg/L) after 24 hr			
	MNT	TCE	PDCB	PCE	MNT	TCE	PDCB	PCE
PVC-A	2.15	2.58	2.27	2.07	0.012	0.022	0.042	0.024
PVC-B	2.13	2.50	2.20	1.97	0.018	0.030	0.072	0.033
PVC-C	2.13	2.51	2.20	1.97	0.015	0.031	0.059	0.041
$\bar{X}$	2.14	2.53	2.22	2.00	0.015	0.028	0.058	0.033
% RSD	0.54	1.7	1.8	2.9	20	18	26	26
% of initial	99.1	99.2	96.5	99.0	0.69	1.10	2.51	1.58
PTFE-A	2.15	2.26	1.85	1.46	0.014	0.142	0.169	0.200
PTFE-B	2.13	2.21	1.80	1.39	0.016	0.149	0.174	0.202
PTFE-C	2.13	2.12	1.71	1.30	0.017	0.160	0.192	0.214
$\bar{X}$	2.14	2.20	1.79	1.38	0.016	0.150	0.178	0.205
% RSD	0.54	3.2	4.0	5.8	9.6	6.1	6.8	3.7
% of initial	99.1	86.3	77.8	68.3	0.74	5.92	7.74	10.1
SS-A	2.16	2.58	2.31	2.00	0.010	0.008	0.019	0.015
SS-B	2.15	2.56	2.29	2.02	0.011	0.012	0.015	0.019
SS-C	2.14	2.10	1.96	1.60	0.012	0.014	0.014	0.014
$\bar{X}$	2.15	2.41	2.19	1.87	0.011	0.011	0.016	0.016
% RSD	0.47	11	9.0	13	9.1	28	17	17
% of initial	99.5	94.5	95.2	92.6	0.51	0.43	0.74	0.69
MDL	0.004	0.006	0.008	0.008				

Table A2. Second VOC study—Effect of rinsing.

	Analyte conc. (mg/L) in 10-min controls				Analyte conc. (mg/L) in 24-hr controls			
	MNT	TCE	PDCB	PCE	MNT	TCE	PDCB	PCE
A	2.30	2.12	1.99	2.07	2.29	2.09	1.96	2.11
B	2.28	2.08	1.93	2.05	2.28	2.05	1.97	2.09
C	2.29	2.07	1.90	2.02	2.30	2.09	1.89	2.03
$\bar{X}$	2.29	2.09	1.94	2.05	2.29	2.08	1.94	2.08
% RSD	0.44	1.3	2.4	1.2	0.44	1.1	2.2	2.0

Material	Desorbed concentration (mg/L) after the following treatments No treatment				Rinsed samples			
	10-min sorb /10-min desorb				10-min sorb /10-min desorb			
	MNT	TCE	PDCB	PCE	MNT	TCE	PDCB	PCE
PVC-A	0.007	0.010	0.015	0.010	LD	0.003	LD	LD
PVC-B	0.007	0.007	0.009	0.009	LD	LD	LD	0.012
PVC-C	0.008	0.009	0.019	0.013	LD	0.004	LD	LD
$\bar{X}$	0.007	0.009	0.014	0.011	LD	<0.003	LD	<0.007
% RSD	7.9	18	35	20				
% of initial	0.32	0.4	0.8	0.5				
PTFE-A	0.001	0.012	0.016	0.020	LD	0.007	0.009	0.014
PTFE-B	0.002	0.012	0.014	0.017	0.001	0.008	0.016	0.016
PTFE-C	0.002	0.011	0.020	0.023	LD	0.012	0.010	0.015
$\bar{X}$	0.002	0.012	0.017	0.020	LD	0.009	0.012	0.015
% RSD	35	4.9	18	15		29	32	7
% of initial	0.07	0.56	0.86	0.98		0.43	0.60	0.72
SS-A	0.006	0.005	0.005	0.005	LD	LD	LD	LD
SS-B	0.002	0.004	0.014	0.007	LD	LD	LD	LD
SS-C	0.010	0.008	0.011	0.010	LD	LD	LD	0.006
$\bar{X}$	0.006	0.006	0.010	0.007	LD	LD	LD	<0.005
% RSD	67	37	46	34				
% of initial	0.26	0.27	0.52	0.36				

Material	24-hr sorb /10-min desorb				24-hr sorb /10-min desorb			
	MNT	TCE	PDCB	PCE	MNT	TCE	PDCB	PCE
PVC-A	0.005	0.011	0.011	0.010	LD	0.006	LD	LD
PVC-B	0.008	0.010	0.015	0.017	0.001	0.005	LD	0.008
PVC-C	0.007	0.007	0.015	0.009	0.001	0.005	0.009	0.007
$\bar{X}$	0.007	0.009	0.014	0.012	LD	0.005	LD	<0.006
% RSD	23	22	17	36		11		
% of initial	0.29	0.45	0.70	0.59		0.26		
PTFE-A	0.002	0.020	0.018	0.038	0.001	0.019	0.022	0.035
PTFE-B	0.004	0.024	0.030	0.040	0.002	0.018	0.030	0.049
PTFE-C	0.004	0.022	0.026	0.040	0.002	0.014	0.022	0.031
$\bar{X}$	0.003	0.022	0.025	0.039	0.002	0.017	0.025	0.038
% RSD	35	9.1	25	2.9	35	16	19	25
% of initial	0.15	1.1	1.3	1.9	0.07	0.82	1.3	1.8
SS-A	0.007	0.004	0.018	0.018	LD	LD	LD	LD
SS-B	0.010	0.010	0.018	0.020	LD	0.004	LD	LD
SS-C	0.007	0.005	0.026	0.018	LD	LD	LD	0.006
$\bar{X}$	0.008	0.006	0.021	0.019	LD	<0.003	LD	<0.005
% RSD	22	51	22	6.2				
% of initial	0.35	0.30	1.1	0.91				

Table A2 (cont'd). Second VOC study—Effect of rinsing.

<i>Desorbed concentration (mg/L) after the following treatments</i>								
<i>No treatment</i>					<i>Rinsed samples</i>			
<i>Material</i>	<i>24-hr sorb / 24-hr desorb</i>				<i>24-hr sorb / 24-hr desorb</i>			
	<i>MNT</i>	<i>TCE</i>	<i>PDCB</i>	<i>PCE</i>	<i>MNT</i>	<i>TCE</i>	<i>PDCB</i>	<i>PCE</i>
PVC-A	0.013	0.037	0.040	0.030	0.006	0.026	0.042	0.071
PVC-B	0.010	0.031	0.047	0.051	0.007	0.029	0.040	0.041
PVC-C	0.010	0.026	0.046	0.029	0.005	0.022	0.027	0.020
$\bar{X}$	0.011	0.031	0.044	0.037	0.006	0.026	0.036	0.044
% RSD	16	18	9	34	17	14	22	58
% of initial	0.48	1.5	2.3	1.8	0.26	1.2	1.9	2.1

<i>Material</i>	<i>24-hr sorb / 24-hr desorb</i>				<i>24-hr sorb / 24-hr desorb</i>			
	<i>MNT</i>	<i>TCE</i>	<i>PDCB</i>	<i>PCE</i>	<i>MNT</i>	<i>TCE</i>	<i>PDCB</i>	<i>PCE</i>
PTFE-A	0.015	0.172	0.189	0.325	0.012	0.163	0.177	0.324
PTFE-B	0.018	0.167	0.186	0.313	0.013	0.165	0.179	0.309
PTFE-C	0.016	0.162	0.178	0.303	0.013	0.148	0.165	0.292
$\bar{X}$	0.016	0.167	0.184	0.314	0.013	0.159	0.174	0.308
% RSD	9.4	3.0	3.1	3.5	4.6	5.9	4.4	5.2
% of initial	0.71	8.0	9.5	15	0.55	7.6	9.0	15
SS-A	0.013	0.012	0.028	0.036	LD	LD	LD	0.008
SS-B	0.009	0.007	0.022	0.014	LD	LD	0.009	LD
SS-C	0.014	0.009	0.032	0.032	LD	LD	LD	LD
$\bar{X}$	0.012	0.009	0.027	0.027	LD	LD	LD	<0.005
% RSD	22	27	18	1.20	43			
% of initial	0.52	0.45	1.4	1.3				
MDL	0.001	0.002	0.009	0.004				

LD = less than detection limit.

Table A3. Third VOC Study—Effect of cold and hot detergent washes and rinses.

	<i>Analyte conc. (mg/L) in 10-min controls</i>				<i>Analyte conc. (mg/L) in 24-hr controls</i>			
	<i>MNT</i>	<i>TCE</i>	<i>PDCB</i>	<i>PCE</i>	<i>MNT</i>	<i>TCE</i>	<i>PDCB</i>	<i>PCE</i>
A	2.18	2.37	1.49	2.65	2.21	2.57	1.65	2.85
B	2.18	2.40	1.52	2.64	2.20	2.45	1.73	2.92
C	2.19	2.23	1.42	2.47	2.20	2.81	1.73	3.11
$\bar{X}$	2.18	2.33	1.48	2.59	2.20	2.61	1.70	2.96
% RSD	0.26	3.9	3.5	3.9	0.26	7.0	2.7	4.5
<i>Desorbed concentration (mg/L) after the following treatments</i>								
<i>Cold wash</i>					<i>Hot wash</i>			
<i>Material</i>	<i>10-min sorb /10-min desorb</i>				<i>10-min sorb /10-min desorb</i>			
	<i>MNT</i>	<i>TCE</i>	<i>PDCB</i>	<i>PCE</i>	<i>MNT</i>	<i>TCE</i>	<i>PDCB</i>	<i>PCE</i>
PVC-A	LD	LD	LD	LD	LD	LD	LD	LD
PVC-B	LD	LD	LD	LD	LD	LD	LD	LD
PVC-C	LD	LD	LD	LD	LD	LD	LD	LD
$\bar{X}$	LD	LD	LD	LD	LD	LD	LD	LD
PTFE-A	LD	0.005	0.011	0.010	LD	LD	LD	LD
PTFE-B	LD	LD	LD	0.009	LD	LD	LD	LD
PTFE-C	LD	0.005	0.007	0.010	LD	LD	LD	LD
$\bar{X}$	LD	<0.005	<0.008	0.010	LD	LD	LD	LD
% RSD				6.0				
% of initial				0.4				
SS-A								
SS-B		Not done				Not done		
SS-C								
<i>Material</i>	<i>24-hr sorb /10 min desorb</i>				<i>24-hr sorb /10 min desorb</i>			
	<i>MNT</i>	<i>TCE</i>	<i>PDCB</i>	<i>PCE</i>	<i>MNT</i>	<i>TCE</i>	<i>PDCB</i>	<i>PCE</i>
PVC-A	LD	LD	LD	LD	LD	LD	LD	LD
PVC-B	LD	LD	LD	LD	LD	LD	LD	LD
PVC-C	LD	LD	LD	LD	LD	LD	LD	LD
$\bar{X}$	LD	LD	LD	LD	LD	LD	LD	LD
PTFE-A	LD	0.008	0.008	0.020	LD	LD	LD	LD
PTFE-B	LD	0.009	0.015	0.021	LD	LD	LD	LD
PTFE-C	LD	LD	0.007	0.026	LD	LD	LD	LD
$\bar{X}$	LD	LD	0.010	0.023	LD	LD	LD	LD
% RSD			44	14				
% of initial			0.7	0.9				
SS-A	LD	LD	LD	LD				
SS-B	LD	LD	LD	LD		Not done		
SS-C	LD	LD	LD	LD				
$\bar{X}$	LD	LD	LD	LD				
<i>Material</i>	<i>24-hr sorb / 24-hr desorb</i>				<i>24-hr sorb / 24-hr desorb</i>			
	<i>MNT</i>	<i>TCE</i>	<i>PDCB</i>	<i>PCE</i>	<i>MNT</i>	<i>TCE</i>	<i>PDCB</i>	<i>PCE</i>
PVC	0.004	0.025	0.028	0.020	LD	LD	LD	LD
PVC	0.005	0.021	0.025	0.017	LD	LD	LD	LD
PVC	0.004	0.023	0.024	0.021	LD	LD	LD	LD
$\bar{X}$	0.004	0.023	0.026	0.019	LD	LD	LD	LD
% RSD	73	8.7	8.1	11				
% of initial	0.2	1.0	1.7	0.7				
PTFE	0.013	0.160	0.158	0.328	LD	0.037	0.030	0.047
PTFE	0.013	0.161	0.164	0.333	LD	0.046	0.034	0.071
PTFE	0.013	0.157	0.173	0.342	0.003	0.056	0.038	0.084
$\bar{X}$	0.013	0.159	0.165	0.334	LD	0.046	0.034	0.067
% RSD	0	1.3	4.6	2.1		21	12	28
% of initial	0.6	6.8	11	13		1.8	2.0	2.3
SS	LD	LD	LD	LD				
SS	LD	LD	LD	LD		Not done		
SS	LD	LD	LD	LD				
$\bar{X}$	LD	LD	LD	LD				
MDL	0.003	0.004	0.005	0.009				

LD = less than detection limit.

Table A4. Fourth VOC study—Effect of solvent rinsing.

	<i>Analyte conc. (mg/L) in controls</i>			
	<i>MNT</i>	<i>TCE</i>	<i>PDCB</i>	<i>PCE</i>
A	2.12	2.53	3.29	3.08
B	2.13	2.55	3.27	3.08
C	2.12	2.47	3.19	2.97
$\bar{X}$	2.12	2.52	3.25	3.04
% RSD	0.3	1.7	1.6	2.1

Desorbed conc. (mg/L) after the following treatments:

Material

hot detergent wash and hot water rinse

PTFE-A	LD	0.038	0.044	0.056
PTFE-B	LD	0.046	0.062	0.075
PTFE-C	LD	0.035	0.051	0.058
$\bar{X}$	LD	0.040	0.052	0.063
% RSD		14	17	17
% of initial		1.6	1.6	2.1

hot detergent wash, hot water rinse, and methanol rinse

PTFE-A	LD	0.042	0.053	0.058
PTFE-B	LD	0.041	0.046	0.054
PTFE-C	LD	0.041	0.053	0.064
$\bar{X}$	LD	0.041	0.051	0.059
% RSD		1.4	8.0	8.6
% of initial		1.6	1.6	1.9

hot detergent wash, hot water rinse and hexane rinse

PTFE-A	LD	0.056	0.067	0.089
PTFE-B	LD	0.040	0.049	0.060
PTFE-C	LD	0.039	0.049	0.061
$\bar{X}$	LD	0.045	0.055	0.070
% RSD		21.1	19	24
% of initial		1.8	1.7	2.3
MDL	0.002	0.006	0.007	0.006

LD = less than detection limit.

Table A5. Fifth VOC Study—Effect of room temperature and oven air drying.

	<i>Analyte concentration (mg/L) in controls</i>			
	<i>MNT</i>	<i>TCE</i>	<i>PDCB</i>	<i>PCE</i>
A	1.88	2.71	1.80	2.84
B	1.89	2.66	1.78	2.78
C	1.88	2.68	1.78	2.79
$\bar{X}$	1.88	2.68	1.79	2.80
% RSD	0.31	0.94	0.65	1.1

Desorbed conc. (mg/L) after the following treatments:

Material

air dry 24 hr

PTFE-A	0.002	0.036	0.029	0.062
PTFE-B	0.002	0.034	0.033	0.060
PTFE-C	0.002	0.040	0.038	0.063
$\bar{X}$	0.002	0.037	0.033	0.062
% RSD	0	8.3	14	2.5
% of initial	0.11	1.4	1.9	2.2

hot detergent wash, hot water rinse, and air dry 24 hr

PTFE-A	LD	0.022	0.022	0.035
PTFE-B	LD	0.019	0.011	0.028
PTFE-C	LD	0.020	0.017	0.031
$\bar{X}$	LD	0.020	0.017	0.031
% RSD		7.5	33	11
% of initial		0.76	0.93	1.1

hot detergent wash, hot water rinse, and oven (105°C) dry 24 hr

PTFE-A	LD	LD	LD	LD
PTFE-B	LD	LD	LD	LD
PTFE-C	LD	LD	LD	LD
$\bar{X}$	LD	LD	LD	LD
MDL	0.001	0.004	0.005	0.007

LD = less than detection limit.

Table A6. Sixth VOC study—Effect of oven drying time.

	<i>Analyte conc. (mg/L) in controls</i>							
	<i>MNT</i>	<i>TCE</i>	<i>PDCB</i>	<i>PCE</i>				
A	2.19	1.70	1.34	1.47				
B	2.20	1.66	1.33	1.44				
C	2.19	1.66	1.32	1.41				
$\bar{X}$	2.19	1.67	1.33	1.44				
% RSD	0.26	1.4	0.75	2.1				

	<i>Analyte conc. (mg/L) after PTFE sorbed for 24 hr</i>				<i>Analyte conc. (mg/L) after PTFE sorbed for 7 days</i>			
	<i>MNT</i>	<i>TCE</i>	<i>PDCB</i>	<i>PCE</i>	<i>MNT</i>	<i>TCE</i>	<i>PDCB</i>	<i>PCE</i>
A	2.16	1.38	0.95	0.87	2.10	0.80	0.52	0.33
B	2.16	1.40	0.95	0.88	2.13	0.80	0.55	0.34
C	2.15	1.36	0.94	0.86	2.15	0.81	0.53	0.34
$\bar{X}$	2.16	1.38	0.94	0.87	2.13	0.80	0.53	0.34
% RSD	0.27	1.4	0.61	1.1	1.2	0.72	2.9	1.7
% of initial	98	82	71	60	97	48	40	23

<i>Time in oven (hr)</i>	<i>Desorbed conc. (mg/L) after oven (105°C) drying</i>				<i>Desorbed conc. (mg/L) after oven (105°C) drying</i>			
	<i>MNT</i>	<i>TCE</i>	<i>PDCB</i>	<i>PCE</i>	<i>MNT</i>	<i>TCE</i>	<i>PDCB</i>	<i>PCE</i>
0	0.014	0.093	0.102	0.114	0.022	0.097	0.118	0.106
0	0.014	0.093	0.105	0.126	0.024	0.097	0.109	0.103
0	0.014	0.089	0.096	0.116	0.026	0.109	0.112	0.116
$\bar{X}$	0.014	0.092	0.101	0.119	0.024	0.101	0.113	0.108
% RSD	0	2.5	4.5	5.4	8.3	6.9	4.1	6.3
% of initial	0.6	5.5	7.6	8.2	1.1	6.0	8.5	7.5
1	LD	0.005	LD	0.010	0.006	0.019	LD	LD
1	LD	0.004	LD	LD	LD	0.018	LD	0.011
1	LD	0.005	LD	LD	0.006	0.016	LD	LD
$\bar{X}$	LD	0.005	LD	LD	<0.004	0.018	LD	<0.010
% RSD		12				8.3		
% of initial	—	0.3	—	—	—	1.1	—	—
4	LD	LD	LD	LD	LD	LD	LD	LD
4	LD	LD	LD	LD	LD	LD	LD	LD
4	LD	LD	LD	LD	LD	LD	LD	LD
$\bar{X}$	LD	LD	LD	LD	LD	LD	LD	LD
MDL	0.001	0.003	0.008	0.009				

LD = less than detection limit.

Table A7. First pesticide study—Effect of no treatment.

<i>Analyte concentration (µg/L) in control A</i>				
	<i>Lindane</i>	<i>Heptachlor</i>	<i>Aldrin</i>	<i>Dieldrin</i>
A	585	47.1	198	195
B	570	47.2	194	191
C	572	48.3	191	191
$\bar{X}$	576	47.5	194	192
% RSD	1.4	1.4	1.8	1.2

<i>Material</i>	<i>Solution concentration (µg/L) after 10-min sorption</i>				<i>Desorbed concentration (µg/L) after 10 min</i>			
	<i>Lindane</i>	<i>Heptachlor</i>	<i>Aldrin</i>	<i>Dieldrin</i>	<i>Lindane</i>	<i>Heptachlor</i>	<i>Aldrin</i>	<i>Dieldrin</i>
PVC-A	564	43.5	172	174	7.00	LD	3.44	4.21
PVC-B	559	51.1	190	177	8.07	LD	4.37	3.94
PVC-C	571	46.1	174	177	7.75	LD	3.93	3.82
$\bar{X}$	565	46.9	179	176	7.61	LD	3.91	3.99
% RSD	1.1	8.2	5.5	1.0	7.2		12	5.0
% initial	98	99	92	92	1.3		2.0	2.1
PTFE-A	570	48.4	175	182	3.04	0.713	2.76	5.52
PTFE-B	560	51.8	190	174	3.14	0.711	2.31	6.03
PTFE-C	559	45.2	188	176	1.97	0.624	2.30	4.93
$\bar{X}$	563	48.5	184	177	2.72	0.683	2.46	5.49
% RSD	1.1	6.8	4.4	2.3	24	7.4	11	10
% initial	98	102	95	92	0.47	1.4	1.3	2.9
SS-A	569	47.2	173	174	13.3	LD	5.17	3.11
SS-B	557	45.1	187	174	12.0	LD	4.10	2.44
SS-C	554	46.8	189	174	11.6	LD	4.45	2.32
$\bar{X}$	560	46.4	183	174	12.3	LD	4.57	2.62
% RSD	1.4	2.4	4.8	0	7.2		12	16
% initial	97	98	94	90	2.1		2.4	1.4

<i>Analyte concentration (µg/L) in control B</i>				
	<i>Lindane</i>	<i>Heptachlor</i>	<i>Aldrin</i>	<i>Dieldrin</i>
A	618	34.9	197	192
B	624	37.6	179	194
C	616	36.1	195	190
$\bar{X}$	619	36.2	190	192
% RSD	0.6	3.8	5.2	1.0

<i>Material</i>	<i>Solution concentration (µg/L) after 24-hr sorption</i>				<i>Desorbed concentration (µg/L) after 10 min</i>			
	<i>Lindane</i>	<i>Heptachlor</i>	<i>Aldrin</i>	<i>Dieldrin</i>	<i>Lindane</i>	<i>Heptachlor</i>	<i>Aldrin</i>	<i>Dieldrin</i>
PVC-A	589	19.3	162	137	5.79	0.839	3.86	8.23
PVC-B	590	17.6	161	131	6.80	0.685	4.66	7.75
PVC-C	587	14.2	160	125	7.79	0.811	4.39	7.97
$\bar{X}$	589	17.0	161	131	6.79	0.778	4.30	7.98
% RSD	0.3	15	0.6	4.6	15	11	9.5	3.0
% initial	95	47	85	68	1.1	2.2	2.3	4.2
PTFE-A	620	23.0	166	161	2.02	1.58	2.90	9.28
PTFE-B	614	22.6	165	159	2.70	1.71	3.04	9.91
PTFE-C	615	21.0	164	157	2.67	1.74	2.86	9.53
$\bar{X}$	616	22.2	165	159	2.46	1.68	2.93	9.57
% RSD	0.5	4.8	0.6	1.3	16	5.1	3.2	3.3
% initial	99.5	61	87	83	0.4	4.6	1.5	5.0
SS-A	607	9.95	160	98.9	13.9	LD	6.43	7.81
SS-B	591	12.6	157	99.3	13.0	LD	6.11	6.04
SS-C	622	11.4	163	109	11.4	LD	5.89	6.98
$\bar{X}$	607	11.3	160	102	12.8	LD	6.14	6.94
% RSD	2.6	12	1.9	5.6	9.9		4.4	13
% initial	98	31	84	53	2.1		3.2	3.6
MDL	0.88	0.62	0.83	0.61				

Table A7 (cont'd). First pesticide study—Effect of no treatment.

	<i>Analyte concentration (µg/L) control C</i>			
	<i>Lindane</i>	<i>Heptachlor</i>	<i>Aldrin</i>	<i>Dieldrin</i>
A	611	38.9	195	189
B	632	38.6	201	194
C	620	36.2	196	190
$\bar{X}$	621	37.9	197	191
% RSD	1.7	3.9	1.6	1.4

<i>Material</i>	<i>Solution concentration (µg/L) after 24-hr sorption</i>				<i>Desorbed concentration (µg/L) after 24 hr</i>			
	<i>Lindane</i>	<i>Heptachlor</i>	<i>Aldrin</i>	<i>Dieldrin</i>	<i>Lindane</i>	<i>Heptachlor</i>	<i>Aldrin</i>	<i>Dieldrin</i>
PVC-A	597	18.2	163	134	9.67	5.47	6.80	31.3
PVC-B	595	18.0	164	132	8.48	4.83	6.40	28.8
PVC-C	593	17.9	163	130	8.89	5.62	6.64	33.6
$\bar{X}$	595	18.0	163	132	9.01	5.31	6.61	31.2
% RSD	0.3	0.8	0.4	1.5	6.7	7.9	3.0	7.7
% initial	95.8	47.8	82.8	69.1	1.5	14.0	3.3	16.3
PTFE-A	623	23.1	165	160	2.36	7.15	6.20	22.2
PTFE-B	624	25.0	165	161	2.59	6.88	7.16	23.7
PTFE-C	616	25.5	165	161	3.63	7.31	6.86	22.4
$\bar{X}$	621	24.5	165	161	2.86	7.11	6.74	22.8
% RSD	0.7	5.2	0	0.4	24	3.1	7.3	3.6
% initial	100	65	84	84	0.5	19	3.4	12
SS-A	581	10.9	153	90.0	20.9	3.52	11.7	35.9
SS-B	594	11.8	156	102	15.8	3.99	9.25	35.2
SS-C	601	11.6	158	103	15.3	4.77	10.1	39.7
$\bar{X}$	592	11.4	156	98	17.3	4.09	10.4	36.9
% RSD	1.7	4.1	1.6	7.4	18	15	12	6.6
% initial	95	30	79	51	2.8	11	5.2	19
MDL	0.88	0.62	0.83	0.61				

Table A8. Second pesticide study—Effect of a water rinse.

<i>Analyte concentration (µg/L) in control A</i>				
	<i>Lindane</i>	<i>Heptachlor</i>	<i>Aldrin</i>	<i>Dieldrin</i>
A	594	98.0	162	393
B	546	94.6	155	373
C	636	96.3	165	403
$\bar{X}$	592	96.3	161	390
% RSD	7.6	1.8	3.2	3.9

<i>Material</i>	<i>Solution concentration (µg/L) after 10-min sorption</i>				<i>Desorbed concentration (µg/L) after 10 min</i>			
	<i>Lindane</i>	<i>Heptachlor</i>	<i>Aldrin</i>	<i>Dieldrin</i>	<i>Lindane</i>	<i>Heptachlor</i>	<i>Aldrin</i>	<i>Dieldrin</i>
PVC-A	537	82.3	147	334	3.13	0.48	1.85	6.29
PVC-B	559	90.2	153	345	1.69	0.32	1.18	4.67
PVC-C	604	88.9	157	362	2.68	0.55	2.03	6.11
$\bar{X}$	567	87.1	152	347	2.50	0.45	1.69	5.69
% RSD	6.0	4.9	3.3	4.1	29	26	27	16
% of initial	96	90	95	89	0.42	0.47	1.0	1.5
PTFE-A	642	94.1	163	373	0.76	0.85	1.25	6.46
PTFE-B	570	84.8	152	352	0.66	1.35	1.22	9.29
PTFE-C	550	87.0	150	347	0.69	1.24	1.40	9.09
$\bar{X}$	587	88.6	155	357	0.70	1.15	1.29	8.28
% RSD	8.2	5.5	4.5	3.9	7.3	23	7.5	19
% of initial	99.2	92.0	96.3	91.5	0.12	1.2	0.80	2.1
SS-A	512	87.3	146	330	6.28	0.23	2.34	2.78
SS-B	643	89.7	169	363	5.71	0.31	3.31	3.69
SS-C	574	86.7	150	350	6.59	0.33	2.76	4.85
$\bar{X}$	576	87.9	155	348	6.19	0.29	2.80	3.77
% RSD	11	1.8	7.9	4.8	7.2	18	17	27
% of initial	97	91	96	89	1.0	0.30	1.7	1.0

<i>Analyte concentration (µg/L) in control B</i>				
	<i>Lindane</i>	<i>Heptachlor</i>	<i>Aldrin</i>	<i>Dieldrin</i>
A	591	84.4	161	376
B	547	75.6	146	353
C	611	89.7	166	385
$\bar{X}$	583	83.2	158	371
% RSD	5.6	8.6	6.6	4.4

<i>Material</i>	<i>Solution concentration (µg/L) after 24-hr sorption</i>				<i>Desorbed concentration (µg/L) after 10 min</i>			
	<i>Lindane</i>	<i>Heptachlor</i>	<i>Aldrin</i>	<i>Dieldrin</i>	<i>Lindane</i>	<i>Heptachlor</i>	<i>Aldrin</i>	<i>Dieldrin</i>
PVC-A	562	42.4	125	251	2.01	1.22	1.53	12.7
PVC-B	572	46.7	127	268	1.72	1.28	2.27	12.2
PVC-C	552	39.0	119	251	2.18	1.35	1.62	11.7
$\bar{X}$	562	42.7	124	257	1.97	1.28	1.81	12.2
% RSD	1.8	9.0	3.4	3.8	11.8	5.1	22.3	4.1
% of initial	96	51	78	69	0.34	1.5	1.1	3.3
PTFE-A	590	50.1	126	305	0.57	3.13	2.48	14.8
PTFE-B	578	56.0	127	317	0.26	2.55	1.98	11.3
PTFE-C	596	50.5	128	311	0.54	2.77	2.31	12.1
$\bar{X}$	588	52.2	127	311	0.46	2.82	2.26	12.7
% RSD	1.6	6.3	0.8	1.9	37	10	11	14
% of initial	101	62.7	80.4	83.8	0.08	3.4	1.4	3.4
SS-A	547	28.5	111	215	6.23	0.93	3.52	11.8
SS-B	565	30.9	121	196	6.80	0.74	3.30	10.3
SS-C	547	23.4	110	193	4.24	1.00	2.70	12.9
$\bar{X}$	553	27.6	114	201	5.76	0.89	3.17	11.7
% RSD	1.9	13.9	5.3	5.9	23	15	13	11
% of initial	95	33	72	54	0.99	1.1	2.0	3.1
MDL	0.35	0.14	0.53	0.83				

Table A8 (cont'd). Second pesticide study—Effect of a water rinse.

	<i>Analyte conc. (µg/L) in control C</i>			
	<i>Lindane</i>	<i>Heptachlor</i>	<i>Aldrin</i>	<i>Dieldrin</i>
A	592	78.7	157	357
B	581	83.7	157	366
C	602	86.4	165	376
$\bar{X}$	592	82.9	160	366
% RSD	1.8	4.7	2.9	2.6

<i>Material</i>	<i>Solution conc. (µg/L) after 24-hr sorption</i>				<i>Desorbed conc. (µg/L) after 24 hr</i>			
	<i>Lindane</i>	<i>Heptachlor</i>	<i>Aldrin</i>	<i>Dieldrin</i>	<i>Lindane</i>	<i>Heptachlor</i>	<i>Aldrin</i>	<i>Dieldrin</i>
PVC-A	553	40.4	122	257	3.92	9.55	5.79	56.5
PVC-B	578	44.8	130	268	3.51	10.8	6.31	58.4
PVC-C	552	40.4	121	257	3.88	9.68	6.00	58.1
$\bar{X}$	561	41.9	124	261	3.77	10.0	6.03	57.7
% RSD	2.6	6.1	4.0	2.4	6.0	6.9	4.3	1.8
% of initial	95	50	78	71	0.6	12	3.8	16
PTFE-A	590	50.3	128	303	1.07	13.4	9.19	39.9
PTFE-B	579	52.0	127	299	1.27	11.8	8.26	38.0
PTFE-C	556	52.1	125	307	0.83	11.0	8.26	29.3
$\bar{X}$	575	51.5	127	303	1.06	12.1	8.57	35.7
% RSD	3.0	2.0	1.2	1.3	21	10	6.3	16
% of initial	97	62	79	83	0.2	15	5.4	10
SS-A	578	26.2	119	199.9	5.97	8.79	7.11	65.7
SS-B	576	29.8	118	211	9.35	8.65	8.48	65.5
SS-C	571	26.8	115	217	5.52	10.2	7.40	73.0
$\bar{X}$	575	27.6	117	209	6.95	9.21	7.66	68.1
% RSD	0.6	7.0	1.8	4.1	30	9.3	9.4	6.3
% of initial	97	33	73	57	1.2	11	4.8	19
MDL	0.35	0.14	0.53	0.83				

Table A9. Third pesticide study—effect of a hot water wash and rinse.

Analyte conc. ($\mu\text{g/L}$) in control A *				Analyte conc. ($\mu\text{g/L}$) in control C *			
	<u>Lindane</u>	<u>Aldrin</u>	<u>Dieldrin</u>		<u>Lindane</u>	<u>Aldrin</u>	<u>Dieldrin</u>
A	587	283	380	A	583	291	390
B	590	285	390	B	596	298	396
C	606	299	403	C	576	289	384
$\bar{X}$	594	289	391	$\bar{X}$	585	293	390
% RSD	1.7	3.0	2.9	% RSD	1.7	1.6	1.5

Desorbed conc. ($\mu\text{g/L}$) after 10-min sorb / 10-min desorb				Desorbed conc. ($\mu\text{g/L}$) after 24-hr sorb / 24-hr desorb			
<u>Material</u>	<u>Lindane</u>	<u>Aldrin</u>	<u>Dieldrin</u>	<u>Material</u>	<u>Lindane</u>	<u>Aldrin</u>	<u>Dieldrin</u>
PVC-A	LD	LD	LD	PVC-A	LD	LD	LD
PVC-B	LD	LD	LD	PVC-B	LD	LD	LD
PVC-C	LD	LD	LD	PVC-C	LD	LD	LD
PTFE-A	LD	LD	LD	PTFE-A	LD	LD	LD
PTFE-B	LD	LD	LD	PTFE-B	LD	LD	LD
PTFE-C	LD	LD	LD	PTFE-C	LD	LD	LD
SS-A	LD	LD	LD	SS-A	LD	LD	LD
SS-B	LD	LD	LD	SS-B	LD	LD	LD
SS-C	LD	LD	LD	SS-C	LD	LD	LD

Analyte conc. ($\mu\text{g/L}$) in control B *			
	<u>Lindane</u>	<u>Aldrin</u>	<u>Dieldrin</u>
A	597	299	395
B	596	299	396
C	581	286	380
$\bar{X}$	591	295	390
% RSD	1.5	2.5	2.3

Desorbed conc. ($\mu\text{g/L}$) after 24-hr sorb / 10-min desorb			
<u>Material</u>	<u>Lindane</u>	<u>Aldrin</u>	<u>Dieldrin</u>
PVC-A	LD	LD	LD
PVC-B	LD	LD	LD
PVC-C	LD	LD	LD
PTFE-A	LD	LD	LD
PTFE-B	LD	LD	LD
PTFE-C	LD	LD	LD
SS-A	LD	LD	LD
SS-B	LD	LD	LD
SS-C	LD	LD	LD
MDL	0.53	0.41	0.73

LD = less than detection limit.

*Heptachlor was inadvertently left out of initial test solutions.

Table A10. Fourth pesticide study—Effect of hot water detergent wash and rinse on polymeric tubings.

	Analyte conc. (µg/L) in 10-min controls			
	Lindane	Heptachlor	Aldrin	Dieldrin
A	614	9.6	608	382
B	708	10.3	671	423
C	614	9.2	596	375
$\bar{X}$	645	9.7	625	393
% RSD	8.4	5.7	6.5	6.6

Material	Desorbed conc. (µg/L) after 10-min sorb / 10-min desorb			
	Lindane	Heptachlor	Aldrin	Dieldrin
PVDF-A	LD	LD	LD	LD
PVDF-B	LD	LD	LD	LD
PVDF-C	LD	LD	LD	LD
LDPE-A	LD	LD	LD	LD
LDPE-B	LD	LD	LD	LD
LDPE-C	LD	LD	LD	LD
P(VDF-HFP)-A	LD	LD	LD	LD
P(VDF-HFP)-B	LD	LD	LD	LD
P(VDF-HFP)-C	LD	LD	LD	LD

	Analyte conc. (µg/L) in 24-hr controls			
	Lindane	Heptachlor	Aldrin	Dieldrin
A	596	6.2	590	363
B	625	7.2	622	384
C	674	7.1	635	405
$\bar{X}$	632	6.8	616	384
% RSD	6.2	8.1	3.8	5.5

Material	Solution conc. (µg/L) after 24-hr sorption			
	Lindane	Heptachlor	Aldrin	Dieldrin
PVDF-A	613	1.8	572	177
PVDF-B	613	1.7	591	182
PVDF-C	633	1.7	588	179
$\bar{X}$	620	1.7	584	179
%R SD	1.9	3.3	1.8	1.4
% of initial	98	25	95	47
LDPE-A	182	LD	498	27.4
LDPE-B	175	LD	488	29.7
LDPE-C	185	LD	482	34.6
$\bar{X}$	181	LD	489	30.6
% RSD	2.9		1.7	12.0
% of initial	29		80	8.0
P(VDF-HFP)-A	427	1.5	468	95.3
P(VDF-HFP)-B	421	1.1	479	72.6
P(VDF-HFP)-C	381	LD	460	32.8
$\bar{X}$	410	<1.1	469	66.9
% RSD	6.1		2.1	47
% of initial	65		76	17
MDL	0.98	0.58	0.91	0.96

LD = less than detection limit.

Material	Desorbed conc. (µg/L) after 24-hr sorb/10 min desorb			
	Lindane	Heptachlor	Aldrin	Dieldrin
PVDF-A	LD	LD	LD	LD
PVDF-B	LD	LD	LD	LD
PVDF-C	LD	LD	LD	LD
LDPE-A	LD	LD	LD	LD
LDPE-B	LD	LD	LD	LD
LDPE-C	LD	LD	LD	LD
P(VDF-HFP)-A	LD	LD	LD	LD
P(VDF-HFP)-B	LD	LD	LD	LD
P(VDF-HFP)-C	LD	LD	LD	LD

Material	Desorbed conc. (µg/L) after 24-hr sorb/24 hr desorb			
	Lindane	Heptachlor	Aldrin	Dieldrin
PVDF-A	LD	LD	LD	LD
PVDF-B	LD	LD	LD	LD
PVDF-C	LD	LD	LD	LD
LDPE-A	6.3	LD	2.0	LD
LDPE-B	5.7	LD	1.7	LD
LDPE-C	4.9	LD	1.5	LD
$\bar{X}$	5.6	1.7		
%RSD	13		15.	
% initial	0.89		0.28	

P(VDF-HFP)-A	LD	LD	LD	LD
P(VDF-HFP)-B	LD	LD	LD	LD
P(VDF-HFP)-C	LD	LD	LD	LD
MDL	0.98	0.58	0.91	0.96

LD = less than detection limit.

Table A11. Fifth pesticide study—Effect of various treatments on LDPE tubing.

	Concentration ($\mu\text{g/L}$)			
	<i>Lindane*</i>	<i>Heptachlor</i>	<i>Aldrin*</i>	<i>Dieldrin</i>
Controls				
A	5518	36.5	438	107
B	5640	37.4	457	113
C	5657	40.0	444	109
$\bar{X}$	5605	38.0	446	110
% RSD	1.4	4.8	2.2	2.8
Hot detergent water wash and hot water rinse				
A	187	LD	2.79	LD
B	215	LD	2.88	LD
C	185	LD	2.84	LD
$\bar{X}$	196 ^a	LD	2.84 ^a	LD
% RSD	8.6		1.6	
Hot detergent water wash, hot water rinse, and methanol rinse				
A	158	LD	2.01	LD
B	137	LD	2.11	LD
C	105	LD	1.27	LD
$\bar{X}$	133 ^b	LD	1.80	LD
% RSD	20		26	
Hot detergent water wash, hot water rinse, and hexane rinse				
A	157	LD	3.42	LD
B	113	LD	2.57	LD
C	97.7	LD	1.93	LD
$\bar{X}$	123 ^b	LD	2.64 ^{a,b}	LD
% RSD	25		28	
Hot detergent water wash, hot water rinse, and oven dry (117°C) for 24 hours				
A	10.6	LD	LD	LD
B	10.2	LD	LD	LD
C	14.5	LD	LD	LD
$\bar{X}$	11.8 ^c	LD	LD	LD
% RSD	20			
MDL	0.74	0.84	0.55	0.85

LD = less than detection limit

*For each analyte, values with the same letter are not significantly different at the 95% confidence level using Fisher's Protected Least Significant Difference test.

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