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DIFFUSION OF TRICHLOROETHYLENE THROUGH
THE THREADED JOINTS OF PVC PIPE

A Thesis in
Environmental Engineering

by

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ABSTRACT

The data engineers and scientists use to determine if the groundwater supply is contaminated are derived from analysis of samples taken largely from monitoring wells. For these data to be reliable several factors must be considered. One factor is the integrity of the monitoring well. The well must be physically stable and should be constructed in a manner that does not influence water quality. Thus, materials must not sorb or contribute contaminants, and should be resistant to physical attack by the water or contaminants. In this project, emphasis has been placed on the potential impact on water quality caused by diffusion across the threaded joints of PVC pipe.

Many investigators have studied the permeation of solid PVC by contaminants. These studies have shown that at moderate to low contaminant concentrations (i.e., mole fraction much less than the aqueous solubility) it would take centuries for the contaminants to permeate PVC pipe. Transport of contaminants across the casing joints, however, is expected to be much faster. There are few studies on the transport of contaminants through casing joints.

In this study, the diffusion of trichloroethylene across several common types of threaded joints (i.e., square flush,

modified ACME, modified ACME stub, and ACME) has been measured. The modified ACME stub and ACME joints have been tested with the o-ring in place and with it removed. The experimental procedure involved submerging waterfilled sections of PVC pipe into three different concentrations of trichloroethylene solution (97 mg/l, 306 mg/l, and pure TCE). Sampling was conducted over a six-month time span with six sampling periods arranged in a logarithmic time sequence. Samples were obtained from the water inside the pipe sections and analyzed for trichloroethylene by gas chromatography.

Breakthrough occurs within days of the samples being placed in the baths. The softened PVC joints of the pipes in the pure trichloroethylene split before the first sample interval of 1.5 weeks. The data show great variability in casing joints from the same manufacturer, and indicate a need for increased precision in the manufacturing of the PVC pipe joints. The results reveal measurable differences between the various threading configurations. Using the joints as they are designed (e.g. use o-ring when thread has slot for o-ring) results in better performance of the threaded joint.

A one-dimensional diffusion model is used to determine an equivalent gap size through which the diffusion occurs.

Flow rates through the threaded joints are calculated by using the equivalent gap width and a formula for flow through a rectangular duct running full. Comparison of the results of the gap size calculations and of the flow rates show the Johnson with the worst performance (i.e. largest gap size and fastest flow rate) and the Triloc with new o-rings with the best performance (i.e., smallest gap size and slowest flow rate).

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DEFINITION OF TERMS

a	width of duct (l)
A_e	equivalent area (l^2)
b	height of duct (l)
C_{bath}	concentration of the bath (m/l^3)
$c(t)$	concentration diffused through the joint (m/l^3)
C_l	concentration of the lower formation (m/l^3)
C_o	concentration of the overlying formation (m/l^3)
C_s	concentration of the sample (m/l^3)
d_p	diameter of the pipe (l)
D	diffusion coefficient (l^2/t)
EPA	Environmental Protection Agency
g	32.2 ft/sec ²
g_c	32.2 lb-ft/lb _f -sec ²
GC	gas chromatograph
IARC	International Agency for Research on Cancer
$j(t)$	concentration diffused through the joint per 1 cm ² as predicted by the model (m/l^5)
J	flux ($m/l^2/t$)
K	dimensionless number based on a/b
L	length of the thread (l)
LDPE	low density polyethylene
M	molecular weight of the solvent (m/mole)
NTP	National Toxicology Program
p	static pressure

ppb	parts per billion
ppm	parts per million
PVC	polyvinylchloride
Q_l	leakage rate (l^3/t)
Q_p	pumping rate (l^3/t)
RPVC	rigid polyvinylchloride
SCH	schedule
SDR	standard dimension ratios
SEM	scanning electron microscopy
t	time
T	temperature (K)
TCE	trichloroethylene
V	volume (l^3)
VOC	volatile organic contaminant
w	weight rate of flow (m/t)
w_e	equivalent gap width (l)
x	distance along the thread (l)
α	angle between duct axis and horizontal (degrees)
μ	viscosity (m/l/t)
v	solute molal volume at the normal boiling point ($l^3/mole$)
ρ	fluid density (m/ l^3)
ϕ	association factor for the solvent

Chapter 1

INTRODUCTION

The monitoring well is one of the main tools used to determine levels of groundwater contamination. Obtaining reliable and consistent data from these wells has motivated many studies of sampling techniques. The materials used in constructing wells and the construction process are also important in determining the reliability and consistency of the data obtained from these wells. This study focuses on the rate of diffusion of trichloroethylene (TCE) across the threaded joints of four different brands of schedule 40 PVC casing with different threading configurations.

PVC well casings and threads must meet ASTM F480.88 and D1785 specifications, but modifications to these specifications are allowed as long as the minimum requirements are met. There are many manufacturers of PVC well casing. Some use their own composition of filler; others buy their filler off the shelf. Some manufacturers have their extrusion process computer controlled; others rely on the precision of their employees. Thus, uniformity among some product lines may be greater than for others. This variability in the entire process of manufacturing the PVC pipes suggests that there may be some significant differences in the way they will perform. There is also the

question of consistency of performance within a brand of pipe.

The objective of this work is to determine the rate of diffusion of trichloroethylene through jointed pipe having different threading configurations. The effect of the use of o-rings on the diffusion of the chemical contaminant through the threaded joint is also examined for two brands of pipe. The results from this work may provide information about diffusion through similar joints in other casing materials.

The experimental protocol involves the following steps:

1. Six to eighteen inch lengths of schedule 40 PVC pipe threaded at both ends are filled with distilled water and placed in baths of different concentrations of trichloroethylene.
2. Baths are opened, the pipes removed and samples taken at times ranging from 1 week to 24 weeks.
3. Headspace analysis of the samples for trichloroethylene (TCE) is performed using a gas chromatograph (GC). In addition, scanning electron microscopy (SEM) is used to identify physical changes in the pipe due to reactions with TCE. The results of the SEM analysis will be presented as a separate report.

Data for each pipe are used to calibrate a one-dimensional diffusion model based on Fick's Laws. The model assumes that the movement of liquid is through a gap in the pipe, with the thread length (i.e., normal to the radial direction) being the distance over which diffusion occurs. The output of the model is the width of this gap. The gap width is proportional to the leakage from the joint. Gap width or leakage is a measure of the performance of the tested joints in relationship to one another. Using the model output, the significance of the results will be determined by calculating the volumetric flow rate from the gap and comparing it to the typical pumping rate of monitoring wells.

The study is conducted at the Savannah River Site, Aiken, SC, a Department of Energy nuclear production facility operated by Westinghouse Savannah River Company. Analytical support is provided by the Environmental Sciences Section, an environmental/geotechnical group focusing on research and development associated with fate and transport of contaminants in the subsurface.

Chapter 2

LITERATURE REVIEW

2.1 Use of PVC in the Water Supply and Groundwater Monitoring Industries

Rigid PVC pipe is commonly used as a construction material in water supply and groundwater monitoring applications. In the water supply industry, PVC is used for distribution lines and for lines and machinery parts within the treatment plant. Production wells are usually not constructed of PVC. However, many wells constructed to monitor the chemical nature of groundwater are now and have been constructed of PVC. Reasons for using PVC have been its combination of low cost and physical/chemical properties (strong and flexible while reasonably chemically inert).

At the Savannah River Site all casing for shallow monitoring wells must be Triloc, Johnson, or an approved equivalent schedule 40 threaded PVC (E.I. du Pont de Nemours and Company, Savannah River Plant, 1988). Sealing gaskets (o-rings) are not used in the construction of any monitoring wells on the site.

2.2 Use of VOCs

VOCs are a general category of synthetic organic chemicals that include low-molecular weight, volatile aliphatic and aromatic hydrocarbons, many of which are halogenated (Westrick, 1984). Trichloroethylene (TCE) is a chlorinated, low molecular weight, aliphatic VOC. PVC is dissolved by pure TCE. At lower concentrations, TCE and other VOCs permeate PVC at rates ranging from 10^{-14} cm²/sec to 10^{-16} cm²/sec (Pfau, 1987; Berens, 1979).

VOCs have been found in all parts of this country as groundwater contaminants (Gordon, 1982; Barker, 1987; Fischer et al., 1987). This is not surprising, because of their many uses. Chlorinated VOCs have been widely used as degreasers. For example, these compounds have been used in the dry cleaning industry. TCE is used to clean septic systems. Other historic and present uses for VOCs include pest and weed control chemicals, fumigation chemicals, and household solvents and cleaning agents. From this list we can see that some of the uses of VOCs lead to direct application onto the soil, others lead to introduction into the water system and others are indirectly introduced to the groundwater system through inadequate disposal procedures and careless disposal practices.

Many VOCs are suspected carcinogens, mutagens, or teratogens (International Agency for Research on Cancer, 1979; National Toxicology Program, 1982). Wide use, persistence, and toxicity combine to make VOCs an important source of contaminants of ground waters.

2.3 Studies Involving PVC and VOCs

Over the past few years there have been numerous studies of PVC and VOCs. Studies involving pure trichloroethylene and PVC have shown that the trichloroethylene will dissolve the PVC. Other studies concluded that at measured groundwater concentrations (activities less than 0.25 mole fraction), it would take hundreds of years for the contaminants to break through the PVC. While most studies were conducted using powders and films of PVC, Pfau and Sharpe (1987) studied lengths of unjointed PVC pipe. All of the studies suggest that the permeation of unjointed PVC by dilute solutions of VOC is a slow process that would not be a factor in monitoring well performance.

The study by Pfau and Sharpe (1987) included limited data on jointed pipe. No information was given about the types of joints and the solvent cements used to seal the joints except that they were "off-the-shelf" pipes with cements provided by the manufacturer. Pfau and Sharpe observed differences between jointed and unjointed pipe; contaminants

were more likely to move through the joints and transport seemed a function of the cements used to seal the joints. However, because of the lack of information on the joints and the cements used it is difficult to draw meaningful conclusions or to extrapolate from the limited experimental data.

Many studies have examined the movement of chemicals, both as liquids and gasses, into, out of and through unjointed PVC and other polymers (Lee, 1985; Vonk, 1984; Curran, 1983; Salame, 1961). Some work has been done using pure chemicals and high concentrations of chemicals, but most of the work has centered around the lower concentrations (activities < 0.25). At these lower concentrations, Fickian diffusion appears to be the dominant transport process. At higher concentrations extensive swelling of the polymer is evident and the diffusion behavior cannot be adequately described by a concentration-dependent form of Fick's law with constant boundary conditions. This deviation from Fickian behavior is thought to be associated with the finite rates at which the polymer structure may change in response to the sorption or desorption of the contaminant molecules (Crank, 1985). Diffusion through the PVC appears to be a function of molecular size and sorption onto the polymer. Recent work by Reynolds (1990) on a variety of polymers including PVC, indicated that halocarbons are absorbed by polymers at

different rates dependent on the diffusivities of the compounds in the polymers. Flexible polymers such as low-density polyethylene (LDPE) have higher sorption rates than rigid polymers like PVC. This is because more energy is required for passage of the diffusing compound through a rigid polymer than through a flexible polymer.

Vonk (1984) exposed PVC and LDPE to high, but unsaturated, concentrations of organic chemicals (methylbromide and toluene) to establish the mechanism of permeation. LDPE exposed to toluene showed Fickian behavior, Case I diffusion. PVC exposed to toluene showed Case II diffusion (advancing boundaries), where diffusion is very rapid compared with the relaxation processes. For Case II diffusion, when the liquid diffuses into the polymer three boundaries are formed. The inner boundary indicates the distance the liquid has penetrated, while the outer boundary indicates the limit of the swollen gel. The intermediate boundary marks the interface of the elastic rubbery state and the glassy polymer. This can be identified by such techniques as scanning electron microscopy. Thus, for Case II diffusion, the thickness of the wall and/or the concentration of the contaminant will have an effect on the permeation of that contaminant through the PVC. Scanning electron microscopy conducted by Reynolds (1990) showed Case II diffusion in PVC at high concentrations of organic

contamination. Physical methods, such as SEM, are one technique for determining the type of diffusion.

2.4 Studies of Threaded PVC Joints

Little work has been done to characterize the effects of the different configurations of joints on the transport of contaminants into plastic pipe. There are two basic types of joints, cemented and threaded. Monitoring wells are commonly constructed using threaded joints. This eliminates the possibility that contaminants will leach from the cements and give erroneous measurements.

Helium leak tests have led to conclusions concerning design of joints (Varian, 1980). The test results indicate that all common joints leak and that threaded pipe joints provide long leak paths. Some manufacturers incorporate o-rings into the pipe joint to provide a tighter seal. Varian (1980) found that the inside diameter of the o-ring groove should be equal to or slightly larger than the inside diameter of the o-ring in order to prevent the o-ring from sliding when the negative pressure is on the inside.

Several different configurations of threaded joints are described in Table 2.1. Those listed are not the only configurations in use, but they appear to be widely used.

Table 2.1 Threaded Joint Information

<u>COMPANY</u>	<u>THREAD</u>	<u>THREADS/INCH</u>	<u>O-RING</u>	<u>THREAD LENGTH</u> (CH)
Atlantic Screen 1.2	square flush	4	with and without	4.92
Brady 2	modified ACME	2	with	4.76
Brainard-Kilman (Iriloc) 2	modified ACME stub	4	with and without	5.48
Johnson 1.2	ACME	5	with	6.03
Monoflex	modified ACME	2, 4	with	4.44, 5.48
Timco	square	2, 4	with and without	4.76, 5.32
Aardvark	modified ACME	2	with and without	4.52

NOTE: 1: The Atlantic Screen and the Johnson products are not designed with a groove for the o-ring.
2: The following joint types and configurations were tested in this study:
Atlantic with and without o-ring, Brady with o-ring, Triloc with and without (fluorescein test) o-ring, Johnson with o-ring.

Figures 2.1 through 2.4 are sketches of each of the four thread types.

ASTM Standard F 480-88a specifies minimum requirements for thermoplastic well casing pipe and couplings made in standard dimension ratios (SDR), SCH 40 and SCH 80. The basic requirements for the threads are that they shall have either American Standard ACME 2G screw threads, American Standard Stub ACME 2G screw threads, or Buttress screw threads, Class 2, or square form flush joint threads, in accordance with the applicable ANSI Standard. The joints shall not leak when tested with an internal pressure of 25 psi for 24 hours in accordance to testing procedures set forth in ASTM Standard F 480-88a. The test procedures require that two specimens of well casing pipe be assembled together with a male and female two-piece threaded well casing pipe coupling. The male and female well casing pipe coupling are then solvent cemented to each specimen of well casing pipe and allowed to stand for 24 hours at room temperature. An approved thread lubricant (not defined in ASTM F 480-88a) is applied to the threads of the male and female two-piece well casing pipe coupling and assembly. The specimen is then subjected to an internal pressure of 25 psi with water as the medium, for 24 hours. If the threads

Figure 2.1 Schematic Diagram of Square Flush Joint

Figure 2.2 Schematic Diagram of Modified ACME Joint

Figure 2.3 Schematic Diagram of Modified ACME Stub Joint

Figure 2.4 Schematic Diagram of ACME Joint

are an integral part of the casing, the assembling of the coupling to the pipe is omitted.

2.5 Importance of Studying the Effects of Contaminants on Well Components

For a thorough assessment of the extent of contamination, quantitative measurements must be made. These measurements are made using a variety of techniques including, geophysical logging, soil sampling, and groundwater sampling. The accuracy of the values obtained from these techniques depends on many factors, such as analytical technique used, sample preparation technique and sampling technique. In the case of groundwater sampling the condition of the well from which the sample is taken is also important. Improper installation or any change in the structure that will affect the integrity of the well will lead to inaccurate test results and possibly an inappropriate plan of action. For example, improperly placing the screen across two different formations will produce inaccurate samples and a conduit between the two formations. Another example, improperly grouting the well may produce a conduit between different formations or it may decrease the amount of sample that can be withdrawn from the well. Use of a reputable driller, who specializes in installing groundwater monitoring well, increases the

chances of having a well properly installed. The general integrity of the well can be evaluated using downhole technology such as cameras and infrared equipment. However, the goal is to construct these wells in such a way and from material that will enable these wells to maintain their integrity throughout their expected life, i.e., the length of time required for monitoring the site.

One possible point of weakness in a monitoring well is the joints in the casing. Many monitoring wells are currently constructed using threaded pipe without solvent bonding glues or cements. While glues and cements might improve the joint seals, these materials are not used because they might contribute contaminants to groundwater samples. When a monitoring well is screened in a "clean" formation below the contaminated zone, it is possible to contaminate the "clean" zone due to the diffusion/leakage through the threaded joints of the casing located in the contaminated zone. Figure 2.5 is representative of a site where the situation described above could potentially occur. It depicts a situation at the Savannah River Site, Aiken, SC. The contaminant source, TCE, is located in the upper zones of the Tertiary age formations, which include the discontinuous Green Clay aquitard. Wells screened in the lower part of the Tertiary formations and/or the Ellenton

Figure 2.5 Representation of a Site Where Contamination of a Clean Formation is Possible due to Transfer of Contaminants Through the Threaded Joints of the Well Casings

Formation are subject to contamination from the overlying zones, if water from these contaminated zones enter the well. One possible route of contamination is through leaky threaded joints. The significance of this scenario is a function of the diffusion/leakage rate of the threaded joint, the head differential between the formations, and the tightness of the formation in which the joints are located.

2.6 Summary

PVC pipe, long used in the construction of monitoring wells, has not been extensively examined for the effect the contaminants present in the groundwater system will have on its strength and durability. It is known that pure trichloroethylene will dissolve PVC. Trichloroethylene contamination of groundwater is prevalent at many waste sites, but typically not in the pure state. The studies that have been conducted show that diffusion through PVC does occur and the concentration of the contaminant effects the rate and type of diffusion. At low concentrations, diffusion is Fickian in nature and may take hundreds of years to diffuse through the pipe. At near saturated concentrations, diffusion is believed to be non-Fickian and may only take several days or weeks to diffuse through the pipe.

Little work has been done to evaluate the effects of different threading configurations of joints on the transport of contaminants into plastic pipe. Threaded joints are used in the construction of monitoring wells because cements may leach contaminants to the groundwater. There are several types of basic thread configurations with many modifications to the basic design. ASTM Standard F 480-88a sets the minimum requirements all Schedule 40 and 80 thermoplastic well casing pipe and couplings must meet. Helium leak tests have shown that pipe threads provide leak paths with long travel times and that incorporation of an o-ring into the pipe joint may increase the travel time and may decrease the rate of leakage.

Chapter 3

MATERIALS AND METHODS

3.1 Materials

Commercially available 2-inch Schedule 40 PVC pipe with threaded joints cut to the shortest lengths the vendor could manufacture is the test material. Four different joint configurations fitted with O-rings and two configurations without O-rings are to be studied. Table 2.1 provides information on the four types of joints. Each pipe section is fitted with end caps and/or plugs to produce a closed system.

The end caps and plugs as delivered by the manufacturers are all constructed from two pieces of PVC. They have been fitted together either by insertion of the threaded length of the cap into a cup-shaped endpiece or by riveting a plug-like end piece to the threaded length of the cap. This two piece construction leads to leakage around the seam where the pieces of the cap are fitted together. Epoxy is poured into the caps to form a plug to eliminate the leakage. After sealing the Atlantic pipes with o-rings that contain the epoxy plug, a small amount of leakage is still visible

to the naked eye. To eliminate this, a coat of epoxy is applied to the outside of the Atlantic pipes with o-rings.

Materials used are:

1. 2-inch Schedule 40 Threaded PVC pipe
2. Reagent grade trichloroethylene
3. 200 ppm TCE standard (certified) Supplier:
Supelco
4. Dow Corning 1200 Primer, 730 Sealant (recommended
for use with trichloroethylene) and 732 Sealant
5. distilled water
6. Bostik 7087 a & b epoxy
7. stainless steel steamtable pans and lids (reaction
vessels)
8. electric hand drill
9. 50 ml glass syringe
10. Eppendorf variable microliter pipettes
11. 22-ml headspace vials with Teflon-lined
polyethylene septa
12. triple beam balance
13. fluorescein dye

3.2 Methods

3.2.1 Physical Setup

The caps and plugs are filled to a depth of approximately 1 inch with epoxy and cured for 2 days. After the epoxy sets the pipe samples are filled with distilled water. The pipes, with a cap on one end, are submerged in a bath of distilled water to be filled and sealed. This ensures no headspace inside the pipes. The pipes are removed from the water and the threaded joints are hand-tightened to approximately 5 ft-lbs of torque. The Johnson pipes are placed in baths of distilled water until they can be placed in the baths containing the TCE solutions. This is done to reduce the chance of leakage.

Three concentrations of TCE are used, Table 3.1. A high concentration solution of TCE is made by mixing 1.7 ml of TCE with 2.3 liters of water. These solutions are allowed to mix for 15 minutes. The low concentration baths are filled by mixing distilled water with the high concentration solution at a ratio of 1:1. The published solubility of TCE in water is 1100 mg/l (EPA, Treatability Manual, EPA-600/2-82-0012,

Table 3.1 Information on Baths

BATH	AVERAGE CONCENTRATION (ppm)	NUMBER OF BATHS
control (distilled water)	0.69	6
pure TCE	1.46×10^6	2
low concentration solution	97.19	6
high concentration solution	306.38	6

Sept 1981). The high concentration solution (shown in Table 3.1) is less than 1/3 the maximum solubility.

Three samples of each pipe are placed in each set of reaction vessels for a period of 1 week to 24 weeks. To decrease the chance for loss of TCE due to volatilization, the reaction vessels are sealed using Dow Corning sealants and C-clamps. Individual pipes are opened after the time intervals listed in Table 3.2, where the contents of each bath are indicated by the letters C(control), H(low concentration), S(high concentration), and P(pure product). (Appendix A gives a more complete description of the identification process.)

3.2.2 Preparation of Samples for Analysis

Upon removing the samples from the reaction vessels the following steps are taken:

1. The filled pipes are dried and weighed on a triple beam balance.
2. The filled pipes are shaken by hand for approximately two minutes. This was to homogenize the sample.
3. A hole is drilled in the pipe. This alleviates the possibility of contamination

Table 3.2 Sampling Schedule

BATH	DATE FILLED	DATE OPENED	TOTAL # OF DAYS
C1	10/12/89	10/21/89	10
H1	9/19/89	9/29/89	11
S1	9/20/89	9/29/89	10
P1	9/21/89	9/30/89	10
C2	11/10/89	12/4/89	25
H2	9/19/89	10/14/89	26
S2	9/20/89	10/14/89	25
P2	9/20/89	10/13/89	24
C3	10/12/89	11/16/89	36
H3	11/8/89	12/12/89	35
S3	11/7/89	12/11/89	35
C4	11/27/89	2/4/90	70
H4	11/8/89	1/16/90	70
S4	11/7/89	1/15/90	70
C5	9/18/89	1/8/90	113
H5	9/18/89	1/8/90	113
S5	9/19/89	1/9/90	113
C6	9/18/89	3/8/90	172
H6	9/18/89	3/9/90	173
S6	9/18/89	3/9/90	173

of the sample by residual TCE on the outside of the pipe or in the threading.

4. A minimum of 4 samples (10 mls per sample) per pipe are withdrawn using a 50 ml glass syringe for undiluted samples and an Eppendorf microliter pipette for diluted samples. The samples are placed in individual 22 ml headspace vials.
5. After the samples are withdrawn, the pipes are uncapped at both ends and allowed to dry for 1 day before the pipe plus both caps are reweighed. Subtracting the weight of the empty pipes from the weight of the full pipes allows for calculation of the volume of liquid inside each pipe.
6. Two-thirds of the pipe samples from periods 3 and 5 will be examined by gold-plated SEM. Sections of the o-rings and of the PVC pipe from these samples will be removed and sent to the Analytic Section of the Savannah River Laboratory for analysis.

After the pipes are removed from the baths samples of the bath solutions will be collected and analyzed for TCE.

3.2.3 GC Analytical Setup

All of the samples will be tested for the presence of trichloroethylene. Appendix A contains the analytical results. A Hewlett Packard HP 5890A GC with a HP 19395A Headspace Sampler and a HP 3392A Integrator will be used to analyze the samples. The equipment parameters are listed in Table 3.3.

The GC contains a 60 m Supelco SPB-1 (non-polar), 0.75mm diameter capillary column and a ^{63}Ni electron-capture detector.

3.2.4 GC Calibration

The GC will be calibrated for TCE by headspace analysis of seven TCE standard solutions (0.1, 0.5, 1.0, 5.0, 10.0, 50.0 and 100.0 ppb).

Two primary standard solutions are prepared. For the first standard solution, 3.4 μl of pure TCE is diluted to 100 ml using distilled water to obtain a 50 ppm TCE standard. For the second standard solution 1 ml of a purchased, certified 200 ppm TCE analytical standard is diluted to 100 ml in distilled water to obtain a 2 ppm TCE standard. Dilutions are made as listed in

Table 3.3 Equipment Parameters

HEADSPACE SAMPLER

Setpoints:

Equilibration time	0	
Bath temperature	75	C
Valve/Loop temperature	80	C
Sampling interval	3	(automatic, based on GC run time)
Last vial number	24	(filled carousel)
Method sequence	1	

Injection Program:

Probe on	01	
Pressure on		(vials were not pressurized)
Pressure off		
Vent/fill loop on	03	
Vent/fill loop off	13	
Inject on	15	
Inject off	1:15	
Probe off	1:17	

GAS CHROMATOGRAPH

Setpoints:

Initial temperature	35	C
Initial time	10.00	minutes
Injector A temperature	175	C
Detector B temperature	325	C
Oven max	300	C
Equilibration time	1.0	minute
Signal 1	B	
Attenuation Signal 1	0	
Detector A FID	off	
Detector B ECD	on	
Purge A	off	
Purge B	on	
Flow	no flow sensor	

Table 3.3 (continued)

INTEGRATOR

Setpoints:

Zero	0
Att 2	9
Chart speed	0.9
Peak width	0.04
Threshold	0
Ar Rej	0

FLOW AND CARRIER SETTINGS

Carrier Gas	Ultra high purity nitrogen
Bottle regulator pressure	60 psi
Line regulator pressure	46 psi
Headspace sampler carrier gas	5.8 psi
Headspace sampler servo air	52.2 psi
Gas Chromatograph detector B	6 psi

Table 3.4, always diluting to 100 ml with distilled water. Each solution is mixed for 0.5 hours. Fresh standards are made one day prior to the start of each analysis period.

One set of the standards is run each day that samples are analyzed. A minimum of three sets of standards are analyzed for each sampling period and a standard curve of concentration vs area count is constructed.

Appendix B contains the standard curve.

3.2.5 Fluorometric Test

Fluorometric techniques are used to examine differences in the rates of diffusion across Triloc joints with and without the o-ring. Samples of Brady and Atlantic with o-ring pipes are also tested. This testing is done to 1) verify the use of the model with a chemical other than TCE and 2) to verify the results obtained using the TCE. There is concern that the o-rings on the Triloc samples placed in the TCE baths did not perform to their optimum, because of cracking that was observed during the filling operation. To confirm, new o-rings obtained from the manufacturer are placed on three unused pipes to be tested in the fluorescein baths. Cracks were not evident on the Brady and Atlantic

Table 3.4 Serial Dilutions of Standards

pure TCE			analytical std.		
amount solute	solute conc	soln conc	amount solute	solute conc	soln conc
3.4 ul	pure TCE	50 ppm	1 ml	200 ppm std	2 ppm
1 ml	50 ppm	500 ppb	5 ml	2 ppm	100 ppb
20 ml	500 ppb	100 ppb	50 ml	100 ppb	50 ppb
50 ml	100 ppb	50 ppb	20 ml	50 ppb	10 ppb
20 ml	50 ppb	10 ppb	50 ml	10 ppb	5 ppb
50 ml	10 ppb	5 ppb	20 ml	5 ppb	1 ppb
20 ml	5 ppb	1 ppb	50 ml	1 ppb	0.5 ppb
50 ml	1 ppb	0.5 ppb	20 ml	0.5 ppb	0.1 ppb
20 ml	0.5 ppb	0.1 ppb			

o-rings, but to verify the results from the TCE baths, samples of these two brands of pipe are also tested.

The pipe samples are filled with water as described previously and placed in baths of fluorescein, a fluorescent dye, for a period of 6 weeks. The concentrations of the baths vary from 390 to 397 mg/l. The pipes are removed from the baths, towed dried and weighed. A hole is drilled in each pipe and 4-3.5 ml samples are drawn. These samples are placed in cuvettes to which 0.5 ml of 0.1 N NaOH solution is added. The NaOH is added to increase the fluorescent capabilities of the fluorescein. The samples are shaken and placed in a Turner Digital Filter Fluorometer, Model 112, for analysis. Appendix C contains the analytical results. Due to the fluorometer's limited range, many of the samples had to be diluted. Dilution is accomplished by placing 5 ml of sample, drawn from the pipe, into an erlenmeyer flask and diluting with 1, 2 or 3 parts distilled water. A calibration curve for the fluorometer is constructed. After analyzing the samples the caps are removed from both ends of the pipes. The pipes and caps are allowed to dry for 1 day before being reweighed.

Chapter 4

DIFFUSIVE TRANSPORT MODEL

The data are analyzed by a one-dimensional diffusive transport model, with an equivalent gap width as the output. The experimental system has been used to represent two continuously stirred tank reactors separated by a "solid" sheet of rigid polyvinyl chloride (RPVC). It has also been used to evaluate diffusion across membranes and diffusion through PVC pipe. One dimensional geometry is used because it is assumed the TCE moves across the threads of the joint and not into the PVC, as shown in Figure 4.1.

It will be assumed the diffusion is Fickian in behavior. The two equations that relate the concentration inside the pipes, $c(t)$, to that in the bath, c_{bath} , are:

$$J = -D \frac{\partial c}{\partial x} \quad (1)$$

Figure 4.1 Representation of the Movement of Liquid Across the Joints of the PVC Pipe

$$\frac{\partial c}{\partial t} = D \frac{\partial^2 c}{\partial x^2} \quad (2)$$

where J is the flux ($\mu\text{g}/\text{cm}^2/\text{day}$) and D is the diffusivity (cm^2/day). D is assumed to be constant at a value of $8.4 \times 10^{-6} \text{ cm}^2/\text{sec}$. This value was calculated from a formula to define the diffusivity of a solute in a very dilute solution. The system is finite and diffusion occurs only in the x -direction. The initial and boundary conditions are:

$$c(t) = 0 \text{ for } 0 < x < L \text{ and } t = 0 \quad (3)$$

$$c(t) = 0 \text{ for } x = 0 \text{ and } t = 0 \quad (4)$$

$$c(t) = c_{\text{bath}} \text{ for } x = L \text{ and } t \geq 0 \quad (5)$$

where $x = 0$ on the inside of the pipe, L is the thread length (cm) and t is the residence time in the bath (days).

The solution for this problem is set forth in Diffusion (Jost, 1960). The solution is the following infinite series:

$$c_g = \frac{Dc_1 t}{VL} + \frac{2c_1 L}{V\pi^2} \sum_{n=1}^{\infty} \frac{(-1)^n}{n^2} (1 - \exp^{-\left(\frac{n\pi}{L}\right)^2 Dt}) + \frac{4c_0 L}{V\pi^2} \sum_{n=0}^{\infty} \left(\frac{1}{(2n+1)^2} \right) (1 - \exp^{-\left(\frac{(2n+1)\pi}{L}\right)^2 Dt}) \quad (6)$$

The first term to the right of the equality sign represents the linear portion of the curve or where steady state diffusion is occurring. The terms involving the summations describe the effect of the lag time on the diffusion due to the unsteady movement across the threads.

$$\text{Letting } c_g = j(t) \quad (7)$$

$$c_1 = c_{\text{bath}} \quad (8)$$

$$c_0 = 0 \quad (9)$$

$$n = 7, \text{ which is appropriate for small } t \quad (10)$$

then substituting into equation 6 and dividing through by c_{bath} gives equation 11:

$$\frac{j(t)}{c_{\text{bath}}} = \frac{Dt}{VL} + \left(\frac{2L}{V\pi^2} \right) \sum_{n=1}^7 \left(\frac{(-1)^n}{n^2} \right) (1 - \exp^{-(\frac{n\pi}{L})^2 Dt}) \quad (11)$$

where V is the volume of liquid in each pipe (ml).

Plotting $c(t)V$ versus time yields the curve that is shown in Figure 4.2.

Figure 4.2 Establishment of a Steady State in Diffusion Across the Threaded Joint of PVC Pipe.

The time lag, t_L , in Figure 4.2 is defined as:

$$t_L = \frac{L^2}{6D} \quad (12)$$

The time lag is depicted as the distance to the extrapolated x-intercept. It represents the time required for the system to come to equilibrium.

The slope of the straight portion of the line where steady state transport controls is defined by:

$$\text{slope} = \frac{A_e D C_{\text{bath}}}{L} \quad (13)$$

The model generated data and the measured data are used to calculate an equivalent area, A_e , (cm^2). The equivalent area, A_e , is defined as:

$$A_e = \frac{c(t)}{j(t)} \quad (14)$$

where $c(t)$ is the measured concentration inside the pipe ($\mu\text{g/l}$) and $j(t)$ is the concentration that diffused through the joint per 1 cm^2 as predicted by the model ($\mu\text{g/l/cm}^2$).

The equivalent gap width, w_e , (cm) is then calculated by the following:

$$w_e = \frac{\frac{A_e}{2}}{\pi d_p} \quad (15)$$

where d_p is the diameter of the pipe (cm). The equivalent area is divided by 2 to account for the pipe sections being threaded at both ends. This area can be thought of as a slice of the pipe threads with gap width w_e .

The model chosen requires a constant diffusion coefficient. A value of $8.4 \times 10^{-6} \text{ cm}^2/\text{sec}$ ($0.7204 \text{ cm}^2/\text{day}$) was calculated using equation 16 to define the diffusivity of a solute in a very dilute solution (Treybal, 1980).

$$D = \frac{117.3 \times 10^{-18} (\phi M)^{0.5} T}{\mu v^{0.6}} \quad (16)$$

where

D = diffusion coefficient in m²/sec

M = molecular weight of the solvent (distilled water)
in kg/kmol

T = temperature in degrees Kelvin, (20 C = 293 K)

μ = solution viscosity

(viscosity of water = 0.001005 kg/m/sec)

v = solute molal volume at the normal boiling point
in m³/kmol (0.1071 m³/kmol)

ϕ = association factor for the solvent (2.26 for water)

Appendix D contains the average values for solution volumes and concentrations used in the model. Appendix E is an example of the model setup using an EXCEL spreadsheet.

Chapter 5

RESULTS AND DISCUSSION

5.1 Pure Product Tests

The first results to be discussed deal with the pipe samples placed in pure TCE. Samples were removed from baths of pure product at 10 and 24 days. For both time periods, all of the pipes are swollen and flexible. Discoloration is noted in some of the pipes. Swelling is greatest at the threaded joints and it is possible to pull the joints apart without unscrewing the threads. Flexibility is greatest at the threaded joints. This may be caused by the pipe being thinnest at this point or by increased surface area per PVC mass due to the threads. It is also noted that the o-rings are swollen. As much as a 25% increase in circumference is measured for some of the o-rings.

Nothing other than a visual examination was made of these pipes. There was no reason to run a GC analysis on these samples, because the swelling had split either the joint or the two pieces of the cap or in some cases both and TCE had freely moved across these locations as well as across the threaded joint.

5.2 Control Tests

The control baths show the presence of small amounts of TCE. This may be due to desorption of TCE from the epoxy placed in the well of the stainless steel pan lids to reduce the amount of headspace. Due to limited laboratory space, the pans were used more than once. Some of the pans in which the controls were placed had contained the TCE solutions previously. Even though the epoxy is recommended for use with TCE; apparently, it will absorb some of the TCE. When the distilled water was placed in the containers that had held the TCE, the TCE that had been absorbed by the epoxy was desorbed. However, the concentrations present in the controls are insignificant, being several orders of magnitude less than the concentrations of the low and high concentration baths as shown in Table 5.1 and Figure 5.1 (e.g. 0.0075 ppm vs 186 ppm and 275 ppm). Therefore, no corrections will be made for the concentrations in the control baths.

Table 5.1 Average Concentrations of Baths

time (days)	average bath concentrations (ppm)		
	control	low conc	high conc
10	0.0075	186.365	274.6
25	0.14805	63.9	330.65
35	0.176	101.35	291.3
70	0.0482	52.075	*
113	0.00495	92.2	354.75
172	0.0011	132.3	280.6

* The concentration of the high concentration bath is similar to that of the low concentration bath, so the high concentration bath is included in the low concentration category

Figure 5.1 Plot of Average Concentrations of Baths

5.3 Diffusion Experiments Using Low Concentration and High Concentration Solutions of TCE

The cumulative transfer of TCE into the closed pipes is plotted as a function of time for each joint configuration in Figures 5.2 through 5.6. The cumulative transfer of TCE is obtained by multiplying the concentration inside the pipe, $c(t)$, by the volume of liquid inside the pipe, V . Each plotted point is the mean of 12 analyses (i.e., quadruplicate analyses for each of three pipe samples). In several cases, significant variability in the 3 concentrations are recorded for a single brand of pipe in a single bath (e.g. 129788 ppb, 42225 ppb, 108 ppb for the Johnson pipe in the high concentration bath at 5 weeks). This is observed for all brands of pipe used in the test. Some brands of pipe display more variance of behavior than others.

The concentrations and volumes along with the residence times are used to calculate equivalent gap widths and lag times for each type of pipe. Table 5.2 presents calculated time lags, number of days to offset the "0" time, and the equivalent gap widths for a diffusion coefficient of $8.4 \times 10^{-6} \text{ cm}^2/\text{sec}$. The "0" time is offset because it is believed that pressure built up inside the pipes when they were sealed. This pressure inside the pipes had to come to

Figure 5.2 Plot of Amount of TCE Diffused Through Threaded Joints of PVC Pipe as a Function of Time:

ATLANTIC PIPE WITH O-RING

Figure 5.3 Plot of Amount of TCE Diffused Through Threaded Joints of PVC Pipe as a Function of Time:

TRILOC PIPE

Figure 5.4 Plot of Amount of TCE Diffused Through Threaded Joints of PVC Pipe as a Function of Time:

JOHNSON PIPE

Figure 5.5 Plot of Amount of TCE Diffused Through Threaded Joints of PVC Pipe as a Function of Time:

ATLANTIC PIPE WITH NO O-RING

Figure 5.6 Plot of Amount of TCE Diffused Through Threaded Joints of PVC Pipe as a Function of Time:

BRADY PIPE

Table 5.2 Values for Lag Time, "0" Offset and Equivalent Gap Widths for High and Low Concentration Solutions for each Different Pipe when $D = 8.4 \times 10^{-6} \text{ cm}^2/\text{sec}$

PIPE	LAG TIME (days)	"0" OFFSET (days)	GAP WIDTH (cm)	
			HIGH CONC	LOW CONC
Atlantic no o-ring	5.60	20	8.54×10^{-4}	1.99×10^{-4}
Atlantic o-ring	5.60	35	1.61×10^{-2}	1.09×10^{-2}
Brady	5.24	28	2.80×10^{-3}	5.48×10^{-3}
Brainard-Kilman (Triloc)	6.95	22	2.98×10^{-3} (9.25×10^{-5} *)	8.86×10^{-4}
Johnson	8.41	5	1.96×10^{-2}	1.13×10^{-2}

* This value was calculated using data from the fluorescein test. The $D = 3.0 \times 10^{-6} \text{ cm}^2/\text{sec}$.

equilibrium with the pressure outside the pipes before the diffusion process into the pipes could begin.

The Johnson and Atlantic with o-ring pipes show the worst performance thus the fastest rate of diffusion. The Atlantic pipe with no o-ring show the best performance thus the slowest rate of diffusion. Variability in the amount of TCE diffusing through the joints was noted for all brands tested. This variability was greatest in the Johnson pipes (e.g. high conc. at 5 weeks, sample 1- 42,225 ppb, sample 2- 129,788 ppb, sample 3- 108 ppb). The rate of diffusion in increasing order is Atlantic with no o-ring< Brainard-Kilman (Triloc)< Brady< Atlantic with o-ring< Johnson. The fluorescein tests found the rate of diffusion in increasing order is Brainard-Kilman (Triloc) with o-ring< Brady< Atlantic with o-ring< Triloc without o-ring.

It was expected that the Triloc samples would perform better than the other brands of pipe because of their design. The o-ring sits in a groove that is one-half the depth of the threads. The end of the threading is cut at an angle that will fit into the lip of the thread of its mate, which is cut at the reverse angle. The Triloc pipes offered the most resistance when the threaded joints were tightened, indicating the o-rings act as a seal. The results of the

TCE tests did not support the initial predictions. Review of the experimental notes show the o-rings on the Triloc samples placed in the TCE solutions had been exposed to the atmosphere for several weeks before being placed in the baths. Exposure to the atmosphere led to deterioration of the o-rings (e.g. cracking). It is assumed that the deteriorated o-rings may have effected the Triloc results. It had also been learned during the TCE testing, that the Savannah River Site does not use the o-rings in the construction of monitoring wells. To test the idea that deteriorated o-rings have an effect on the diffusion rate through the joint and to see the effect of removing the o-ring from the joint it was decided to use a fluorescein test. Logistic problems made it difficult to continue using TCE. The Triloc samples used in the fluorescein test had either new o-rings or no o-rings. Based on the fact the Triloc with no o-rings allowed a larger amount of the fluorescein dye to diffuse through the joints than the Triloc with new o-rings, it is likely the cracks in the o-rings contributed to the faster rate of diffusion of TCE than was expected.

From initial inspection of the pipes it was expected that the Johnson product would not perform well. The Johnson product is constructed without a groove for the o-ring to

sit in. The o-rings do not fit well; there is no resistance when the threaded joint is closed indicating the o-ring is not acting as a seal. Proof of this was seen when the Johnson pipes were filled with water and sealed. There was severe leakage from the joints of several of the pipes and minor leakage from a majority.

It was not predicted the Atlantic pipes with no o-rings would perform as well as observed. Leakage was not seen from the Atlantic pipes with no o-rings, but the resistance to tightening the threaded joints was not significant.

It was expected the results from the Brady pipes would compare with the results from the Triloc pipes. They are fabricated in a similar manner. There is a groove for the o-ring, the ends and lips of the threaded sections have angled surfaces, and there is resistance when the threaded joints are sealed. The major difference in these two brands of pipe is the Brady is threaded at 2 threads per inch whereas the Triloc is threaded at 4 threads per inch.

One concern with the Triloc pipes and the Brady pipes was that the pressure applied when tightening the threaded joints may have caused the epoxy plugs in the caps to separate from the walls of the caps. The separation of the

plug from the cap can introduce another pathway for diffusion of the TCE to the inside of the pipe. Evidence of this was noted when the Triloc and Brady pipes were filled with water and the threaded joints tightened. Water droplets formed outside the threaded joints and around the area where the two pieces of the caps come together. This problem was not noted in the Johnson and Atlantic caps, which are constructed differently from the Triloc and Brady caps. Fluorescein data support TCE tests except as noted above for Triloc with cracked o-rings.

The pressure built up in the pipes may effect the "zero time", the time when the diffusion process across the joints begins. Before movement into the pipe can occur, the pressure built up inside the Triloc, Brady, and Atlantic with o-ring samples must come to equilibrium with the atmosphere. Table 5.2 lists the calculated lag times based on the model and the "0" offset determined from fitting the data to the theoretical curve. The Johnson pipe has the shortest "0" offset of 5 days and a lag time of 8.4 days. From the visual inspections, a "0" offset approaching 0 days is expected for the Johnson pipe. The variability in the data and fitting the curves by hand may be contributing factors to an offset time greater than 0 days. From Table 5.2 it can be seen that the actual lag times are greater

than the calculated lag times, supporting the theory that the pressure created inside the pipes during sealing must dissipate before diffusion into the pipes can occur.

5.4 Flow Calculations

The rate of flow of possibly contaminated groundwater into a well through the gap widths listed in Table 5.2 was calculated to allow a comparison of flow through the joints to the typical pumping rate of monitoring wells. The rate of flow was calculated using a formula for flow through a rectangular duct running full (Perry, 1973). The equations used are listed below:

$$w = \frac{ab^3N}{K} \quad (17)$$

$$N = \frac{\rho g_c}{\mu} \left(\frac{g \rho \sin \alpha}{g_c} + \frac{P_1 - P_2}{L} \right) \quad (18)$$

where,

$$g = 32.2 \text{ ft/sec}^2$$

$$g_c = 32.2 \text{ lb-ft/lb}_f\text{-sec}^2$$

$$L = \text{length of passage, ft} = \text{length of thread}$$

$$P_1, P_2 = \text{upstream/downstream static pressures, lb}_f\text{/ft}^2$$

- α = angle between duct axis and horizontal, degrees
 = 0°
- ρ = fluid density, lb/ft³ = 62.43 lb/ft³
- μ = absolute viscosity, lb/ft/sec
 = 0.000675 lb/ft/sec
- a = width, ft = πd
- b = height, ft = equivalent gap width
- K = dimensionless number based on a/b
 if $a/b > 10$, $K = 12$
- w = weight rate of flow, lb/sec

A head differential of 20 feet was assumed.

Appendix F contains the actual calculations. Table 5.3 presents the weight rate and volumetric rate of flow for each pipe tested. The flow rates range from 1.8×10^{-7} gpm at the low end for the Triloc products to 1.6 gpm at the high-end for the Johnson products. The calculated flow through the Triloc joints ranges from 1.8×10^{-7} gpm to 6.0×10^{-3} gpm. The flow through the Johnson joints ranges from 0.3 gpm to 1.6 gpm.

The impact of the leakage from the joints is seen in the results of samples withdrawn from the well. For wells screened in "clean" formations below contaminated

Table 5.3 Weight Rate of Flow (lb/sec) and Volumetric Rate of Flow (gal/min) Through One Joint for each Type Pipe Tested for a 20 ft Head Differential

PIPE	WEIGHT RATE OF FLOW (lb/sec)		VOLUMETRIC RATE OF FLOW (gal/min)	
	minimum	maximum	minimum	maximum
Atlantic with no o-ring	2.79×10^{-7}	2.20×10^{-5}	2.00×10^{-6}	1.58×10^{-4}
Atlantic with o-ring	4.58×10^{-2}	1.48×10^{-1}	3.29×10^{-1}	1.06×10^0
Brady	8.00×10^{-4}	5.99×10^{-3}	5.75×10^{-3}	4.31×10^{-2}
Brainerd-Kilman (Triloc)	2.48×10^{-8}	8.34×10^{-4}	1.78×10^{-7} *	6.00×10^{-3} **
Johnson	4.15×10^{-2}	2.17×10^{-1}	2.98×10^{-1}	1.56×10^0

* based on fluorescein test results

** based on TCE tests (cracked o-rings)

formations the leakage through the joints may have an impact on the system (i.e., contamination of the "clean" formation) or on measurements from the well. The factors which contribute to the impact on the system are the leakage rate through the joints in the contaminated formation, the number of joints in the contaminated formation, the concentration in the contaminated formation, and the pumping rate. The first three factors will increase the impact on the system as they increase (e.g. an increase the number of joints in the contaminated formation will lead to an increase in the contaminant concentration in the sample drawn from the well). An increase in the pumping rate will lead to a decrease in the contaminant concentration in the sample drawn from the well when all other factors remain constant. The concentration of the sample is related to the above listed factors by the following:

$$C_s = \frac{Q_L * C_o}{Q_p} + (1 - \frac{Q_L}{Q_p}) * C_1 \quad (19)$$

where

C_s = concentration of sample drawn from the well
($\mu\text{g/l}$ or ppb)

C_o = concentration of contaminant in overlying
formation ($\mu\text{g/l}$ or ppb)

C_l = concentration of contaminant in lower
formation ($\mu\text{g/l}$ or ppb)

Q_l = leakage rate (gpm)

Q_p = pumping rate (gpm)

Table 5.4 shows the effects of different leakage rates and different contaminant concentrations in the overlying formation on the concentration of the sample withdrawn from the well. The pumping rate of the well is set at 5 gpm. The concentrations of the samples taken from the "clean" formation range from 2×10^{-8} ppb for a leakage rate of 10^{-7} gpm and a concentration in the overlying formation of 1 ppb to 2000 ppb for a leakage rate of 1 gpm and a concentration in the overlying formation of 10000 ppb. Comparison of the values in Table 5.4 with the leakage rates for the threaded joints tested shows that the Johnson and the Atlantic with o-ring threaded joints have the potential to impact samples from a lower "clean" formation even with concentrations in the overlying formation as low as 1 ppb. Assuming one joint

Table 5.4 Concentration ($\mu\text{g}/\text{l}$ or ppb) of Samples Drawn from Wells for
Different Leakage Rates Through the Threaded Joints and for
Different Concentrations in the Overlying Formation

Leakage rate (gpm)	Concentration of overlying formation ($\mu\text{g}/\text{l}$ or ppb)					
	1	10	100	1000	10000	
0.0000001	0.000000002	0.00000002	0.0000002	0.000002	0.00002	0.0002
0.0000001	0.00000002	0.0000002	0.000002	0.0002	0.002	0.002
0.000001	0.0000002	0.000002	0.0002	0.002	0.02	0.02
0.0001	0.000002	0.0002	0.002	0.02	0.2	0.2
0.001	0.0002	0.002	0.02	0.2	2	2
0.01	0.002	0.02	0.2	2	20	20
0.1	0.02	0.2	2	20	200	200
1	0.2	2	20	200	2000	2000

Note: Pumping rate is set at 5 gpm.
Concentration in the lower formation is negligible.

of either the Johnson or the Atlantic with o-ring pipes is placed in the overlying formation, with concentrations ranging from 1 to 10000 ppb, the increase in the concentration of the sample withdrawn from the well could be in the range of 0.02 ppb to 2000 ppb. The Brady pipes under the same conditions will not have as great of an impact on the system until the higher concentrations of contaminants in the overlying formation are present (i.e., concentrations >100 ppb). The concentrations seen in the Atlantic samples without o-rings is less than 1 ppb for concentrations in the overlying formation of up to and including 10000 ppb. The results of the Triloc tests indicate that with new o-rings in the joints the concentrations seen in the samples withdrawn from the wells will be less than 10^{-3} ppb for concentrations in the overlying formation up to and including 10000 ppb. However, use of Triloc casing with deteriorated o-rings may impact the results of the samples withdrawn from the well by as much as 12 ppb for concentrations of 10000 ppb in the overlying formation.

CHAPTER 6

CONCLUSIONS AND FUTURE WORK

6.1 Conclusions

This experimental work has led to the following conclusions.

1. Contact with pure trichloroethylene will lead to the physical breakdown of PVC pipe in less than one week. Swelling of the PVC and a decrease in rigidity is visible to the naked eye.
2. Leakage occurred through all the joints tested.
3. The Brainard-Kilman (Triloc) joints outperformed the other joints when the o-rings were new (i.e., leakage rate of 1.78×10^{-7} gpm). Performance of Triloc decreased when using no o-ring or deteriorated o-rings (i.e., leakage rate of 6×10^{-3} gpm). The increase in concentration due to a joint with deteriorated or no o-rings is 5 orders of magnitude greater than the increase in concentration due to a joint with new o-rings (e.g. 3.6×10^{-6} ppb to 1.2×10^{-1} ppb).
4. Use of an o-ring does not guarantee a high rate of performance. Design is also important. The Johnson joints use an o-ring. However, the Johnson products are designed with no groove for the o-ring to sit in and the two pieces of the joint do not fit tightly when joined. The Johnson

pipe had the lowest rate of performance of the types of threaded joints tested (i.e., leakage rate ranging from 0.3 to 1.6 gpm). The Triloc joints are an example of a more effective design; Triloc joints are designed with a groove for the o-ring and the ends of the pieces of the joint are cut in at an angle to allow the two pieces to fit tightly into each other.

5. Each of the types of threads/brands of pipes tested have the potential to impact the system in which they are placed by producing incorrect sample results and/or contamination of a "clean" formation. The Brainard-Kilman (Triloc) threaded joint when used with a new o-ring shows the least potential to provide a pathway for cross contamination (i.e., increasing the apparent concentration of the "clean" formation by less than 10^{-3} ppb for concentrations of up to and including 10000 ppb in the overlying formation). The Johnson and the Atlantic with o-ring show the greatest potential to provide a pathway for cross contamination (i.e., increasing the concentration of the "clean" formation by 2000 ppb for a concentration of 10000 ppb in the overlying formation).

6.2 Future Work

The following recommendations for further study are suggested:

1. Evaluate the length of time for swelling and other physical changes to occur at various concentrations of TCE.
2. Examine PVC using other chlorinated aliphatic hydrocarbons to determine if the response is similar.
3. Examine one type of thread from several manufacturers. This would allow better evaluation of the role the manufacturing process has on the behavior of the threads.
4. Study other components of wells to evaluate how they are effected by the contaminants which enter the well.
5. Reevaluate the policy of not using solvent cements to seal casing/screen joints.
6. Reevaluate the policy to remove the o-rings from the casing joints.

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APPENDIX A

RAW DATA

Explanation of Identification of Samples

Sampling Period: The sampling period is defined by a letter and a number. The letter represents the bath:

- C Control
- H Low Concentration
- S High Concentration
- P Pure Product

Initially, the goal was to have half-saturated (H) and saturated (S) solutions. After testing the solutions it was determined that this goal was not fulfilled so the terms low and high concentration were used. The number represents the time period from 1 to 6. Because the exact day the baths would be opened was not known it was decided to use this type of numbering system with 1 being the shortest sampling period and 6 being the longest sampling period.

Sample Number: The sample number is defined by a letter, a number, a letter, dash, a letter (e.g. C1A-A). The first letter and the number are the sampling period. The next letter is the bath from which the pipe was pulled, either A or B. Two baths per sampling period per concentration were used because of the size of the pipes. The lengths of some of the pipes made it impossible to place all 15 pipes in one bath. The last letter was the identifier for the duplicate samples taken from each pipe.

RAW DATA/CONTROL BATH

SAMPLING PERIOD	SAMPLE NUMBER	VOLUME (liters)	GC		
			area count	conc (ppb)	avg conc (ppb)

C1	C1A-A	10.40	SATURATED DETECTOR		7.47
	C1A-B		SATURATED DETECTOR		
	C1A-C		SATURATED DETECTOR		
	C1A-D		SATURATED DETECTOR		
	C1A-E		SATURATED DETECTOR		
	C1A-F		SATURATED DETECTOR		
C1	C1B-A	13.00	SATURATED DETECTOR		
	C1B-B		SATURATED DETECTOR		
	C1B-C		SATURATED DETECTOR		
	C1B-D		SATURATED DETECTOR		
	C1B-E		933050	7.478	
	C1B-F		931980	7.456	
C2	C2A-A	10.75	22649000	128.986	135.77
	C2A-B		24038000	138.433	
	C2A-C		23666000	135.837	
	C2A-D		24606000	142.493	
	C2A-E		4330600	197.532	
	C2A-F		NOT ANALYZED		
	C2A-G		NOT ANALYZED		
	C2A-H		NOT ANALYZED		
	C2A-I		465170	133.092	
	C2A-J		NOT ANALYZED		
	C2A-K		NOT ANALYZED		
	C2A-L		NOT ANALYZED		
C2	C2B-A	13.53	SATURATED DETECTOR		160.36
	C2B-B		NOT ANALYZED		
	C2B-C		NOT ANALYZED		
	C2B-D		NOT ANALYZED		

RAW DATA/CONTROL BATH

SAMPLING PERIOD	SAMPLE NUMBER	VOLUME (liters)	GC		
			area count	cono (ppb)	avg cono (ppb)

	C2B-E		SATURATED DETECTOR		
	C2B-F		NOT ANALYZED		
	C2B-G		NOT ANALYZED		
	C2B-H		NOT ANALYZED		
	C2B-I		26446000	158.479	
	C2B-J		27494000	165.051	
	C2B-K		27302000	163.446	
	C2B-L		26445000	158.471	
C3	C3A-A	13.50	15402000	79.956	71.63
	C3A-B		12690000	65.518	
	C3A-C		13842000	72.007	
	C3A-D		13331000	69.053	
	C3A-E		428470	105.582	
	C3A-F		NOT ANALYZED		
	C3A-G		NOT ANALYZED		
	C3A-H		NOT ANALYZED		
	C3A-I		166080	113.456	
	C3A-J		NOT ANALYZED		
	C3A-K		NOT ANALYZED		
	C3A-L		NOT ANALYZED		
C3	C3B-A	11.00	SATURATED DETECTOR		280.40
	C3B-B		NOT ANALYZED		
	C3B-C		NOT ANALYZED		
	C3B-D		NOT ANALYZED		
	C3B-E		1012500	309.818	
	C3B-F		984920	294.461	
	C3B-G		980120	291.868	
	C3B-H		938440	270.284	

RAW DATA/CONTROL BATH

SAMPLING PERIOD	SAMPLE NUMBER	VOLUME (liters)	GC		
			area count	conc (ppb)	avg conc (ppb)
	C3B-I		218890	254.878	
	C3B-J		NOT ANALYZED		
	C3B-K		NOT ANALYZED		
	C3B-L		NOT ANALYZED		
C4	C4A-A	11.00	10571000	69.78	76.98
	C4A-B		NOT ANALYZED		
	C4A-C		NOT ANALYZED		
	C4A-D		NOT ANALYZED		
	C4A-E		1287800	76.58	
	C4A-F		1381100	82.9	
	C4A-G		1279400	77.18	
	C4A-H		1301000	78.36	
C4	C4B-A	13.82	3088700	17.26	19.41
	C4B-B		3408800	19.25	
	C4B-C		3579200	20.4	
	C4B-D		3623900	20.72	
	C4B-E		362470	32.27	
	C4B-F		NOT ANALYZED		
	C4B-G		NOT ANALYZED		
	C4B-H		NOT ANALYZED		
C5	C5A-A	13.10	92711	16.89	3.75
	C5A-B		NOT ANALYZED		
	C5A-C		NOT ANALYZED		
	C5A-D		NOT ANALYZED		
	C5A-E		512	77.24	
	C5A-F		NOT ANALYZED		
	C5A-G		NOT ANALYZED		
	C5A-H		NOT ANALYZED		

RAW DATA/CONTROL BATH

SAMPLING PERIOD	SAMPLE NUMBER	VOLUME (liters)	GC		
			area count	conc (ppb)	avg conc (ppb)

	C5A-I		558000	4.06	
	C5A-J		544740	3.97	
	C5A-K		507020	3.74	
	C5A-L		538700	3.93	
	C5A-M		123940	3.04	
	C5A-N		NOT ANALYZED		
	C5A-O		NOT ANALYZED		
	C5A-P		NOT ANALYZED		
C5	C5B-A	12.10	46094	7.01	6.06
	C5B-B		NOT ANALYZED		
	C5B-C		NOT ANALYZED		
	C5B-D		NOT ANALYZED		
	C5B-E		38297	60.5	
	C5B-F		NOT ANALYZED		
	C5B-G		NOT ANALYZED		
	C5B-H		NOT ANALYZED		
	C5B-I		743910	5.53	
	C5B-J		793620	6	
	C5B-K		758330	5.66	
	C5B-L		800570	6.08	
	C5B-M		121130	2.89	
	C5B-N		NOT ANALYZED		
	C5B-O		NOT ANALYZED		
	C5B-P		NOT ANALYZED		
C6	C6A-A	11.80	87166	0.47	0.49
	C6A-B		88083	0.48	
	C6A-C		91364	0.52	
	C6A-D		90126	0.5	

RAW DATA/CONTROL BATH

SAMPLING PERIOD	SAMPLE NUMBER	VOLUME (liters)	GC		
			area count	conc (ppb)	avg conc (ppb)

	C6A-E		19285	0.98	
	C6A-F		NOT ANALYZED		
	C6A-G		NOT ANALYZED		
	C6A-H		NOT ANALYZED		
C6	C6B-A	13.50	221080	1.67	1.69
	C6B-B		225140	1.71	
	C6B-C		224060	1.7	
	C6B-D		223270	1.69	
	C6B-E		35089	1.42	
	C6B-F		NOT ANALYZED		
	C6B-G		NOT ANALYZED		
	C6B-H		NOT ANALYZED		

RAW DATA/LOW CONCENTRATION BATHS

SAMPLING PERIOD	SAMPLE NUMBER	VOLUME (liters)	GC		
			area count	conc (ppm)	avg conc (ppm)
H1	H1A-A	11.00	2239900	145.89	152.29
	H1A-B		2435300	159.72	
	H1A-C		2315800	151.27	
H1	H1B-A	13.90	3238800	217.55	220.43
	H1B-B		3354800	228.63	
	H1B-C		3232800	217.11	
H2	H2A-A	11.25	2249900	79.72	78.69
	H2A-B		2265700	80.94	
	H2A-C		2114400	69.4	
	H2A-D		1754200	45.68	
H2	H2B-A	13.70	1727200	43.59	51.12
	H2B-B		1188400	13.95	
	H2B-C		2216300	77.2	
	H2B-D		2118900	69.73	
H3	H3A-A	10.60	VIAL LEAKED		
	H3A-B		NOT ANALYZED		
	H3A-C		NOT ANALYZED		
	H3A-D		NOT ANALYZED		
	H3A-E		1285800	82.9	91.08
	H3A-F		1395000	94.4	
	H3A-G		1400000	95	
	H3A-H		1373100	92	
H3	H3B-A	13.40	14759000		
	H3B-B		NOT ANALYZED		
	H3B-C		NOT ANALYZED		
	H3B-D		NOT ANALYZED		
	H3B-E		1963800	128.8	111.63
	H3B-F		1731100	114.5	

RAW DATA/LOW CONCENTRATION BATHS

SAMPLING PERIOD	SAMPLE NUMBER	VOLUME (liters)	GC		
			area count	conc (ppm)	avg conc (ppm)
	H3B-G		1600900	106.4	
	H3B-H		1432700	96.8	
H4	H4A-A	10.40	4743600	43.66	61.02
	H4A-B		6407400	60.99	
	H4A-C		6209000	59.06	
	H4A-D		6186100	58.8	
	H4A-E		736760	65.23	
	H4A-F		NOT ANALYZED		
	H4A-G		NOT ANALYZED		
	H4A-H		NOT ANALYZED		
H4	H4B-A	12.60	4066500	36.43	50.34
	H4B-B		5473400	51.52	
	H4B-C		4908200	45.52	
	H4B-D		5173900	48.69	
	H4B-E		595450	55.64	
	H4B-F		NOT ANALYZED		
	H4B-G		NOT ANALYZED		
	H4B-H		NOT ANALYZED		
H5	H5A-A	13.70	3538500	28.32	24.47
	H5A-B		3203600	25.14	
	H5A-C		2909700	22.61	
	H5A-D		2825600	21.82	
	H5A-E		617430	44.72	
	H5A-F		NOT ANALYZED		
	H5A-G		NOT ANALYZED		
	H5A-H		NOT ANALYZED		
H5	H5B-A	11.00	16813000	> 100	159.92
	H5B-B		NOT ANALYZED		

RAW DATA/LOW CONCENTRATION BATHS

SAMPLING PERIOD	SAMPLE NUMBER	VOLUME (liters)	GC		
			area count	conc (ppm)	avg conc (ppm)

	H5B-C		NOT ANALYZED		
	H5B-D		NOT ANALYZED		
	H5B-E		2185900	166.03	
	H5B-F		1893000	143.68	
	H5B-G		2188700	166.23	
	H5B-H		2153400	163.73	
H6	H6A-A	13.60	13917000	110.36	139.04
	H6A-B		NOT ANALYZED		
	H6A-C		NOT ANALYZED		
	H6A-D		NOT ANALYZED		
	H6A-E		1605400	132.58	
	H6A-F		1879900	149.98	
	H6A-G		2088900	163.85	
	H6A-H		1698800	138.41	
H6	H6B-A	11.60	14364000	114.22	125.58
	H6B-B		NOT ANALYZED		
	H6B-C		NOT ANALYZED		
	H6B-D		NOT ANALYZED		
	H6B-E		1539500	128.62	
	H6B-F		1799600	144.98	
	H6B-G		1375800	110.28	
	H6B-H		1403600	120.81	

RAW DATA/HIGH CONCENTRATION BATHS

SAMPLING PERIOD	SAMPLE NUMBER	VOLUME (liters)	GC		
			area count	conc (ppm)	avg conc (ppm)

S1	S1A-A	11.10	3703700	258.227	258.55
	S1A-B		3576400	245.004	
	S1A-C		3840300	268.415	
S1	S1B-A	13.60	3963000	279.41	292.58
	S1B-B		3957000	278.862	
	S1B-C		4372600	319.482	
S2	S2A-A	10.60	4245500	237.08	221.21
	S2A-B		3671800	190.25	
	S2A-C		4142100	228.84	
	S2A-D		4139800	228.86	
S2	S2B-A	13.30	6329300	408.04	440.14
	S2B-B		6903400	454.4	
	S2B-C		7119800	473.19	
	S2B-D		6545700	424.93	
S3	S3A-A	10.30	23369000	-----	232.30
	S3A-B		NOT ANALYZED		
	S3A-C		NOT ANALYZED		
	S3A-D		NOT ANALYZED		
	S3A-E		3585400	251.4	
	S3A-F		3190800	219.2	
	S3A-G		3370200	233.4	
	S3A-H		3266500	225.2	
S3	S3B-A	12.10	SATURATED DETECTOR		350.33
	S3B-B		NOT ANALYZED		
	S3B-C		NOT ANALYZED		
	S3B-D		NOT ANALYZED		
	S3B-E		4105700	299	
	S3B-F		4940200	376.6	

RAW DATA/HIGH CONCENTRATION BATHS

SAMPLING PERIOD	SAMPLE NUMBER	VOLUME (liters)	GC		
			area count	conc (ppm)	avg conc (ppm)
	S3B-G		5123000	392.1	
	S3B-H		4486500	333.6	
S4	S4A-A	10.90	5687300	53.6	45.25
	S4A-B		4344900	39.35	
	S4A-C		4667200	42.82	
	S4A-D		4884300	45.24	
	S4A-E		771680	67.82	
	S4A-F		NOT ANALYZED		
	S4A-G		NOT ANALYZED		
	S4A-H		NOT ANALYZED		
S4	S4B-A	13.60	5501000	51.78	51.85
	S4B-B		4530400	41.36	
	S4B-C		5340400	50.26	
	S4B-D		5678700	53.52	
	S4B-E		923130	79.3	
	S4B-F		NOT ANALYZED		
	S4B-G		NOT ANALYZED		
	S4B-H		NOT ANALYZED		
S5	S5A-A	10.90	SATURATED DETECTOR		300.10
	S5A-B		NOT ANALYZED		
	S5A-C		NOT ANALYZED		
	S5A-D		NOT ANALYZED		
	S5A-E		3176400	249.08	
	S5A-F		3903900	321.81	
	S5A-G		3308500	261.1	
	S5A-H		4322100	368.4	
S5	S5B-A	13.30	SATURATED DETECTOR		409.40
	S5B-B		NOT ANALYZED		

RAW DATA/HIGH CONCENTRATION BATHS

SAMPLING PERIOD	SAMPLE NUMBER	VOLUME (liters)	GC		
			area count	cono (ppm)	avg cono (ppm)
	S5B-C		NOT ANALYZED		
	S5B-D		NOT ANALYZED		
	S5B-E		4760900	421.12	
	S5B-F		4673700	409.61	
	S5B-G		4867200	435.58	
	S5B-H		4348300	371.28	
S6	S6A-A	13.60	SATURATED DETECTOR		321.35
	S6A-B		NOT ANALYZED		
	S6A-C		NOT ANALYZED		
	S6A-D		NOT ANALYZED		
	S6A-E		4107100	311.37	
	S6A-F		4288500	328.13	
	S6A-G		4387600	334.49	
	S6A-H		4132800	313.42	
S6	S6B-A	11.00	SATURATED DETECTOR		239.84
	S6B-B		NOT ANALYZED		
	S6B-C		NOT ANALYZED		
	S6B-D		NOT ANALYZED		
	S6B-E		3145200	240.45	
	S6B-F		3191700	243.9	
	S6B-G		3433000	282.13	
	S6B-H		2765300	212.88	

RAW DATA/CONTROL/ATLANTIC WITH NO O-RING

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg conc (ppb)

C1A	251A	843.9	410.8	0.4331	317550	0.08	0.078
	251B				304300	0.08	
	251C				309640	0.08	
	251D				310390	0.08	
C1A	252A	840.9	401.7	0.4392	215890	0.05	0.057
	252B				233730	0.06	
	252C				220120	0.05	
	252D				251360	0.06	
C1B	261A	797.8	392.5	0.4053	317120	0.08	0.075
	261B				282600	0.07	
	261C				262630	0.06	
	261D				336500	0.09	
C2A	280A	828.8	396.1	0.4327	354300	1.05	0.604
	280B				285550	0.48	
	280C				250260	0.28	
	280D				241550	0.61	
C2A	281A	830.4	411	0.4194	259950	0.33	0.533
	281B				269430	0.38	
	281C				288880	0.50	
	281D				328970	0.92	
C2A	282A	843.6	412.2	0.4314	348340	1.03	0.312
	282B				276270	0.42	
	282C				255240	0.30	
	282D				232160	0.21	
C3B	270A	855.2	418.4	0.4368	255750	0.45	0.549
	270B				277990	0.54	
	270C				281580	0.55	
	270D				283610	0.58	

RAW DATA/CONTROL/ATLANTIC WITH NO O-RING

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg conc (ppb)

C3B	271A	849.8	419.8	0.4302	127840	0.08	0.075
	271B				139580	0.08	
	271C				140370	0.08	
	271D				137590	0.07	
C3B	272A	805.9	387.8	0.4181	187390	0.16	0.237
	272B				214950	0.24	
	272C				203840	0.20	
	272D				239210	0.35	
C4A	398A	829.9	408.7	0.4212	81424	0.22	0.278
	398B				97168	0.29	
	398C				105860	0.33	
	398D				94094	0.27	
C4A	402A	831.6	416.9	0.4147	92292	0.26	0.253
	402B				88382	0.25	
	402C				87501	0.24	
	402D				92030	0.26	
C4A	405A	850.9	408.8	0.4441	93820	0.27	0.268
	405B				94547	0.27	
	405C				87995	0.25	
	405D				96072	0.28	
C5A	323A	835.8	408.2	0.4276	198580	1.08	1.165
	323B				214830	1.20	
	323C				216430	1.21	
	323D				212430	1.18	
C5A	324A	844.3	418.5	0.4258	91554	0.17	0.174
	324B				95937	0.18	
	324C				96313	0.18	
	324D				93647	0.17	

RAW DATA/CONTROL/ATLANTIC WITH NO O-RING

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg conc (ppb)

C5A	325A	824.3	394.7	0.4296	63073	0.10	0.102
	325B				70400	0.11	
	325C				64292	0.10	
	325D				65129	0.10	
C6A	420A	835.2	401.8	0.4334	55835	0.23	0.2275
	420B				52245	0.21	
	420C				55233	0.22	
	420D				59979	0.25	
C6B	423A	809.5	377.5	0.432	61472	0.26	0.2675
	423B				61592	0.26	
	423C				62921	0.27	
	423D				64944	0.28	
C6B	426A	841	387.4	0.4536	72175	0.33	0.33
	426B				72387	0.33	
	426C				73172	0.34	
	426D				70287	0.32	

RAW DATA/CONTROL/ATLANTIC WITH O-RING

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg conc (ppb)

C1A	249A	855.5	401.5	0.454	333490	0.09	0.099
	249B				388340	0.11	
	249C				398680	0.11	
	249D				363130	0.10	
C1A	250A	850	414.5	0.4355	289300	0.07	0.068
	250B				269610	0.07	
	250C				267340	0.07	
	250D				273990	0.07	
C1B	262A	844.2	425.7	0.4185	158470	0.04	0.043
	262B				148600	0.04	
	262C				152610	0.04	
	262D				171230	0.05	
C2A	279A	839.3	394.7	0.4446	399920	1.15	0.205
	279B				254150	0.30	
	279C				213210	0.16	
	279D				210070	0.15	
C2B	291A	851.2	419.5	0.4317	263460	0.34	0.324
	291B				342330	1.02	
	291C				268820	0.37	
	291D				243790	0.26	
C2B	292A	840.7	403.7	0.437	288320	0.50	0.534
	292B				284820	0.47	
	292C				303260	0.63	
	292D				345690	1.03	
C3A	267A	831.6	408.6	0.423	213030	0.23	0.175
	267B				207380	0.21	
	267C				175940	0.13	
	267D				169320	0.12	

RAW DATA/CONTROL/ATLANTIC WITH O-RING

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	GC		
					area count	cono (ppb)	avg cono (ppb)

C3A	268A	856.2	416.8	0.4394	166440	0.11	0.24
	268B				209250	0.22	
	268C				224020	0.28	
	268D				210140	0.22	
C3A	269A	839.4	412.9	0.4265	119400	0.06	0.13
	269B				180310	0.14	
	269C				162160	0.11	
	269D				181060	0.14	
C4A	400A	776.9	381.5	0.3974	134790	0.54	0.587
	400B				147140	0.66	
	400C				137220	0.56	
	400D				101000	0.30	
C4B	408A	850.9	401	0.4499	50664	0.13	0.125
	408B				46734	0.12	
	408C				49426	0.13	
	408D				46378	0.12	
C4E	411A	799.7	396.7	0.403	131050	0.50	0.428
	411B				107340	0.34	
	411C				121760	0.43	
	411D				123270	0.44	
C5B	335A	845.9	422.7	0.4232	50668	0.08	0.082
	335B				55399	0.08	
	335C				57138	0.09	
	335D				76725	0.13	
C5B	336A	843.2	391.3	0.4519	68511	0.11	0.125
	336B				77698	0.13	
	336C				79561	0.13	
	336D				80387	0.13	

RAW DATA/CONTROL/ATLANTIC WITH O-RING

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg conc (ppb)

C5B	337A	844.9	406.7	0.4382	58950	0.09	0.106
	337B				67788	0.11	
	337C				67557	0.11	
	337D				68499	0.11	
C6A	413A	841.4	429.2	0.4122	175170	1.32	1.3225
	413B				171020	1.30	
	413C				179680	1.35	
	413D				174400	1.32	
C6A	414A	846.9	391.7	0.4562	77537	0.38	0.36
	414B				73370	0.34	
	414C				74533	0.35	
	414D				76954	0.37	
C6A	415A	759.2	375	0.3842	70630	0.27	0.265
	415B				62705	0.27	
	415C				62100	0.26	
	415D				62472	0.26	

RAW DATA/CONTROL/BRADY

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	GC		
					area count	conc(ppb)	avg. cdhc (ppb)

C1A	253A	935.4	574.7	0.3607	313230	0.08	0.079
	253B				331410	0.08	
	253C				336580	0.09	
	253D				279890	0.07	
C1B	259A	942	518.6	0.4234	257250	0.06	0.064
	259B				249450	0.06	
	259C				276880	0.07	
	259D				439080	0.13	
C1B	260A	938.9	536.4	0.4025	230980	0.06	0.055
	260B				219660	0.05	
	260C				220630	0.06	
	260D				300470	0.08	
C2A	286A	940.8	501.1	0.4397	327680	0.91	0.603
	286B				339250	1.01	
	286C				247300	0.27	
	286D				235990	0.23	
C2B	287A	934.7	592.9	0.3418	453430	1.30	1.242
	287B				431400	1.24	
	287C				455730	1.30	
	287D				390120	1.13	
C2B	288A	946.8	596.9	0.3499	758840	2.53	2.471
	288B				763270	2.55	
	288C				722870	2.34	
	288D				977600	4.07	
C3A	265A	939	536.8	0.4022	255810	0.45	0.325
	265B				225900	0.28	
	265C				242090	0.36	
	265D				203870	0.20	

RAW DATA/CONTROL/BRADY

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	GC		
					area count	conc(ppb)	avg. conc (ppb)
C3A	266A	942.8	567.8	0.375	184650	0.15	0.252
	266B				226290	0.29	
	266C				240090	0.35	
	266D				208830	0.22	
C3B	273A	939.6	560.6	0.379	225710	0.28	0.461
	273B				255970	0.45	
	273C				253490	0.43	
	273D				263110	0.50	
C4A	404A	947.1	583.9	0.3632	143290	0.62	0.668
	404B				149520	0.69	
	404C				150330	0.70	
	404D				147440	0.66	
C4B	409A	944.2	559.3	0.3849	148190	0.67	0.553
	409B				126390	0.48	
	409C				139270	0.58	
	409D				128410	0.48	
C4B	412A	957.5	573	0.3845	60699	0.16	0.153
	412B				56943	0.15	
	412C				55968	0.14	
	412D				63511	0.16	
C5A	326A	956.9	545.3	0.4116	88410	0.16	0.11
	326B				67172	0.10	
	326C				71815	0.11	
	326D				70654	0.11	
C5A	327A	934	520.8	0.4132	71486	0.11	0.105
	327B				58337	0.09	
	327C				64938	0.10	
	327D				65704	0.10	

RAW DATA/CONTROL/BRADY

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	GC		
					area count	conc(ppb)	avg. cqpc (ppb)

C5B	334A	944.4	515	0.4294	57538	0.09	0.097
	334B				65045	0.10	
	334C				61906	0.09	
	334D				68880	0.11	
C6A	416A	954	540.4	0.4136	76565	0.37	0.335
	416B				69514	0.31	
	416C				70997	0.32	
	416D				73086	0.34	
C6B	424A	943.6	539.7	0.4039	124430	1.02	0.9975
	424B				120420	1.00	
	424C				123970	1.02	
	424D				117960	0.95	
C6B	427A	935.3	556.6	0.3787	146410	1.14	0.91
	427B				146590	1.14	
	427C				100560	0.64	
	427D				105520	0.72	

RAW DATA/CONTROL/JOHNSON

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg. conc (ppb)
C1A	254A	1162.5	509.7	0.6528	299740	0.07	0.064
	254B				255160	0.06	
	254C				249260	0.06	
	254D				226720	0.06	
C1A	255A	1160.2	506.2	0.654	270150	0.07	0.063
	255B				250040	0.06	
	255C				246370	0.06	
	255D				267100	0.07	
C1A	256A	1157.4	496.4	0.661	321830	0.08	0.074
	256B				299900	0.07	
	256C				283300	0.07	
	256D				278650	0.07	
C2A	283A	1158.6	522.9	0.6357	309890	0.69	0.394
	283B				272620	0.40	
	283C				254980	0.30	
	283D				222610	0.19	
C2A	284A	1160.3	508.3	0.652	289000	0.51	0.479
	284B				308580	0.68	
	284C				285490	0.48	
	284D				243510	0.25	
C2A	285A	1157.5	507.8	0.6487	486430	1.39	1.334
	285B				486190	1.39	
	285C				414930	1.19	
	285D				474080	1.36	
C3B	275A	1155.7	501.1	0.6546	408550	1.02	0.154
	275B				189510	0.16	
	275C				182430	0.15	
	275D				262990	0.50	

RAW DATA/CONTROL/JOHNSON

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	a/g. conc (ppb)
C3B	276A	1163.3	511.1	0.6522	202550	0.20	0.136
	276B				169310	0.12	
	276C				169310	0.12	
	276D				162890	0.11	
C3B	277A	1162.5	502.8	0.6597	219850	0.26	0.253
	277B				220930	0.26	
	277C				220280	0.26	
	277D				211970	0.23	
C4A	401A	1161.9	496.2	0.6657	66678	0.17	0.153
	401B				48907	0.13	
	401C				57852	0.15	
	401D				63746	0.16	
C4A	403A	1169.7	508.8	0.6609	62197	0.16	0.158
	403B				62204	0.16	
	403C				63630	0.16	
	403D				58789	0.15	
C4A	406A	1163.9	514.8	0.6491	66510	0.17	0.170
	406B				----		
	406C				67172	0.17	
	406D				66410	0.17	
C5A	328A	1172.8	522.3	0.6505	56213	0.09	0.087
	328B				55659	0.08	
	328C				57983	0.09	
	328D				60525	0.09	
C5A	329A	1159.6	497.7	0.6619	87631	0.15	0.143
	329B				81271	0.14	
	329C				80296	0.13	
	329D				85775	0.15	

RAW DATA/CONTROL/JOHNSON

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg. conc (ppb)
C5A	330A	1169.3	502.6	0.6667	64889	0.10	0.101
	330B				64482	0.10	
	330C				66365	0.10	
	330D				65989	0.10	
C6A	417A	1155.9	497.6	0.6583	114090	0.87	0.835
	417B				109460	0.78	
	417				112980	0.85	
	417D				112730	0.84	
C6A	419A	1163.8	503.7	0.6601	103010	0.68	1.043
	419B				122160	1.01	
	419C				137830	1.10	
	419D				124300	1.02	
C6A	421A	1156.3	497.3	0.659	78753	0.39	0.368
	421B				72515	0.34	
	421C				74797	0.35	
	421D				78984	0.39	

RAW DATA/CONTROL/TRILOC

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg. conc (ppb)

C1A	248A	1605.3	744.1	0.8612	422920	0.12	0.078
	248B				302090	0.08	
	248C				326390	0.08	
	248D				309360	0.08	
C1B	257A	1662	744.4	0.9176	1190300	1.40	6.661
	257B				1586800	3.40	
	257C				3183600	15.18	
	257D				11701000	85.90	
C1B	258A	1592	739.6	0.8524	714960	0.38	0.153
	258B				546080	0.20	
	258C				466730	0.14	
	258D				423640	0.12	
C2A	278A	1603.1	727.1	0.876	336120	1.00	0.298
	278B				195470	0.12	
	278C				267120	0.36	
	278D				274790	0.41	
C2B	289A	1618.6	738.6	0.88	298720	0.59	0.568
	289B				302180	0.62	
	289C				304090	0.64	
	289D				278790	0.43	
C2B	290A	1602.2	736.5	0.8657	288330	0.50	0.411
	290B				273410	0.40	
	290C				281170	0.45	
	290D				253020	0.29	
C3A	263A	1614.5	743.8	0.8707	256760	0.46	0.287
	263B				226480	0.29	
	263C				225860	0.28	
	263D				227610	0.29	

RAW DATA/CONTROL/TRILOC

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg. conc (ppb)

C3A	264A	1604.5	723.8	0.8807	225650	0.28	0.224
	264B				215560	0.24	
	264C				206990	0.21	
	264D				188490	0.16	
C3B	274A	1613.5	731.8	0.8817	155540	0.10	0.122
	274B				172360	0.13	
	274C				168140	0.12	
	274D				184940	0.15	
C4A	399A	1612.8	732.6	0.8802	43801	0.12	0.13
	399B				48917	0.13	
	399C				54022	0.14	
	399D				50550	0.13	
C4B	407A	1621.5	773.4	0.8481	35256	0.10	0.103
	407B				31605	0.10	
	407C				38249	0.11	
	407D				35959	0.10	
C4B	410A	1618.2	775.8	0.8424	----		0.157
	410B				61601	0.16	
	410C				57327	0.15	
	410D				61651	0.16	
C5A	331A	1596.1	722.4	0.8737	122690	0.30	0.291
	331B				111740	0.24	
	331C				119950	0.28	
	331D				122100	0.29	
C5B	332A	1607.4	748.9	0.8585	82444	0.14	0.141
	332B				81047	0.14	
	332C				83222	0.14	
	332D				85462	0.15	

RAW DATA/CONTROL/TRILOC

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg. conc (ppb)

C5B	333A	1654	723.1	0.9309	118420	0.27	0.179
	333B				96689	0.18	
	333C				93359	0.17	
	333D				97595	0.19	
C6A	418A	1600.6	748.4	0.8522	89178	0.49	0.93
	418B				118120	0.96	
	418C				115930	0.91	
	418D				116590	0.92	
C6B	422A	1602.5	739	0.8635	91276	0.52	0.5
	422B				38732	0.15	
	422C				88089	0.48	
	422D				90134	0.50	
C6B	425A	1605.5	729.1	0.8764	63902	0.27	0.28
	425B				62382	0.26	
	425C				62148	0.26	
	425D				59365	0.25	

RAW DATA/LOW CONCENTRATION/ATLANTIC WITH NO O-RING

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg conc (ppb)

H1A	97A	822.6	383.7	0.4389	150260	0.17	0.171
	97B				149560	0.17	
	97C				164360	0.18	
	97D				NOT ANALYZED		
H1A	98A	828.6	387.2	0.4414	79441	0.12	0.110
	98B				59922	0.11	
	98C				63691	0.11	
	98D				62837	0.11	
H1A	100A	838.6	402	0.4366	131060	0.15	0.171
	100B				200410	0.22	
	100C				197810	0.21	
	100D				57056	0.11	
H2B	165A	843.9	407	0.4369	401760	11.12	9.605
	165B				318930	8.04	
	165C				397190	10.92	
	165D				328470	8.34	
H2B	166A	827.1	379.4	0.4477	337380	8.64	8.543
	166B				337020	8.63	
	166C				332420	8.47	
	166D				331280	8.43	
H2B	167A	829.2	385.8	0.4434	375480	10.03	8.698
	167B				348530	9.02	
	167C				333420	8.50	
	167D				292220	7.24	
H3A	308A	816.5	389.7	0.4268	403620	9.89	0.883
	308B				240410	0.83	
	308C				238630	0.81	
	308D				252880	1.01	

RAW DATA/LOW CONCENTRATION/ATLANTIC WITH NO O-RING

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg conc (ppb)

H3A	309A	799.1	380.1	0.419	336880	3.60	2.565
	309B				279270	1.50	
	309C				347900	4.25	
	309D				246550	0.91	
H3A	310A	841	401.9	0.4391	387860	7.79	3.501
	310B				287180	1.69	
	310C				275360	1.42	
	310D				327190	3.11	
H4A	384A	831.3	396.1	0.4352	83736	20.18	18.725
	384B				69790	15.90	
	384C				77770	18.27	
	384D				84830	20.55	
H4A	385A	843.7	430.5	0.4132	118840	36.21	31.087
	385B				101230	27.00	
	385C				107640	30.05	
	385D				136770	48.82	
H4A	386A	808.2	393.5	0.4147	91272	22.88	21.373
	386B				91990	22.77	
	386C				83631	20.14	
	386D				82306	19.70	
H5B	345A	839.2	413.9	0.4253	379310	247.78	233.830
	345B				334530	219.54	
	345C				326990	215.11	
	345D				386860	252.89	
H5B	346A	846.3	408.1	0.4382	214180	119.13	105.120
	346B				198800	107.91	
	346C				191930	103.24	
	346D				193380	104.21	

RAW DATA/LOW CONCENTRATION/ATLANTIC WITH NO O-RING

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg conc (ppb)

H5B	347A	835.8	397.7	0.4381	465470	320.11	301.720
	347B				466780	321.87	
	347C				418.20	276.53	
	347D				435430	288.37	
H6B	434A	820.1	382.8	0.4373	55075	22.42	22.263
	434B				55497	22.64	
	434C				60714	25.54	
	434D				46597	18.45	
H6B	438A	835.9	390.7	0.4452	40757	16.13	15.625
	438B				40049	15.87	
	438C				38804	15.42	
	438D				37832	15.08	
H6B	441A	839.5	393.1	0.4464	62290	26.48	22.883
	441B				49279	19.62	
	441C				56149	22.99	
	441D				55095	22.44	

RAW DATA/LOW CONCENTRATION/ATLANTIC WITH O-RING

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg. conc (ppb)
H1A	99A	828.5	394.4	0.4341	398170	0.58	0.321
	99B				178310	0.19	
	99C				196650	0.21	
	99D				264930	0.30	
H1B	107A	837.3	389.1	0.4482	174980	0.19	0.169
	107B				148820	0.17	
	107C				150360	0.17	
	107D				130630	0.15	
H1B	108A	847	405.8	0.4412	278680	0.32	0.314
	108B				261780	0.32	
	108C				265770	0.30	
	108D				NOT ANALYZED		
H2A	161A	854.9	408.4	0.4485	455250	13.70	8.170
	161B				339450	8.71	
	161C				310670	7.78	
	161D				318250	8.02	
H2A	162A	846	421.7	0.4243	515580	17.36	11.323
	162B				393150	10.75	
	162C				282320	6.96	
	162D				380190	10.22	
H2B	168A	842.6	388.6	0.454	553680	20.15	15.732
	168B				530020	18.37	
	168C				432160	12.52	
	168D				419040	11.89	
H3A	311A	822.3	395.1	0.4272	NO RESULTS		1.524
	311B				271880	1.34	
	311C				264510	1.20	
	311D				299210	2.03	

RAW DATA/LOW CONCENTRATION/ATLANTIC WITH O-RING

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg. conc (ppb)

H3B	321A	853.5	409.7	0.4438	515010	51.86	2.028
	321B				300500	2.07	
	321C				297270	1.97	
	321D				299550	2.04	
H3B	322A	816.1	390.5	0.4256	765010	282.06	39.691
	322B				483950	33.44	
	322C				482890	32.91	
	322D				517050	52.72	
H4A	387A	844.1	403.7	0.4404	149720	60.58	74.710
	387B				159980	71.87	
	387C				163460	76.16	
	387D				163410	76.10	
H4B	393A	831.4	393.2	0.4382	1871600	766.57	740.955
	393B				1695900	722.90	
	393C				1726100	730.22	
	393D				1782600	744.13	
H4B	395A	825.8	417.3	0.4085	504970	244.24	244.737
	395B				547470	259.64	
	395C				511400	246.51	
	395D				502750	243.46	
H5A	340A	853.7	417.7	0.436	1944500	1475.67	1402.785
	340B				1744100*	1329.90	
	340C				NO RESULTS		
	340D				NO RESULTS		
H5A	341A	818.7	387.6	0.4311	910440	704.68	704.680
	341B				NO RESULTS		
	341C				NO RESULTS		
	341D				NO RESULTS		

RAW DATA/LOW CONCENTRATION/ATLANTIC WITH O-RING

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg. conc (ppb)

H5B	348A	865.6	416.4	0.4492	983900	763.15	780.810
	348B				1034700	806.41	
	348C				995560	772.87	
	348U				1170300	930.52	
H6A	428A	842.3	409.7	0.4326	2722500	2098.97	2115.738
	428B				2653100	2054.81	
	428C				2731200	2105.01	
	428D				2870600	2204.18	
H6A	430A	850.4	398.9	0.4515	3620900	2750.18	2804.550
	430B				3444000	2628.69	
	430C				3898000	2951.81	
	430D				3811800	2887.54	
H6A	432A	821.1	400.8	0.4203	1291200	1141.93	1183.078
	432B				1352800	1180.21	
	432C				1354300	1181.03	
	432D				1441000	1229.14	

* PROBLEMS WITH GC, RESULTS QUESTIONABLE

RAW DATA/LOW CONCENTRATION/BRADY

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg. conc (ppb)

H1A	101A	942.4	589.7	0.3527	1027900	6.54	5.104
	101B				846350	5.15	
	101C				791390	4.23	
	101D				003640	4.50	
H1B	109A	935.3	513.5	0.4218	1274200	8.70	8.873
	109B				1311200	8.95	
	109C				1314200	8.97	
	109D				NOT ANALYZED		
H1B	110A	952.5	562.8	0.3897	1943400	12.66	11.890
	110B				1672500	11.13	
	110C				1809100	11.88	
	110D				NOT ANALYZED		
H2A	159A	940.4	596.9	0.3435	402030	11.13	9.955
	159B				395710	10.86	
	159C				343850	8.86	
	159D				347070	8.97	
H2A	160A	950.9	557.9	0.393	311390	7.80	6.975
	160B				285020	7.04	
	160C				264740	6.50	
	160D				266920	6.56	
H2B	164A	953	548.7	0.4043	476070	14.87	9.653
	164B				304440	7.59	
	164C				287360	7.10	
	164D				349390	9.05	
H3A	316A	950	584.3	0.3657	454720	21.47	2.497
	316B				311160	2.44	
	316C				300260	2.06	
	316D				324730	2.99	

RAW DATA/LOW CONCENTRATION/BRADY

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg. conc (ppb)

H3B	317A	948.5	548	0.4005	268130	1.27	2.433
	317B				135580	0.17	
	317C				321500	1.85	
	317D				375350	6.44	
H3B	318A	940.6	539.8	0.4008	478090	30.60	3.636
	318B				351520	4.49	
	318C				69474	...	
	318D				319930	2.78	
H4A	388A	956.9	608.4	0.3485	1099000	473.86	501.668
	388B				1208200	528.07	
	388C				1147500	497.74	
	388D				1165700	507.00	
H4B	394A	935.7	539.9	0.3958	404810	211.47	207.965
	394B				385520	203.93	
	394C				398920	209.54	
	394D				392710	206.92	
H4B	397A	948.9	549.8	0.3991	213220	143.81	129.750
	397B				189000	116.56	
	397C				200060	140.02	
	397D				190050	118.61	
H5A	342A	952.4	593.5	0.3589	1169900	930.13	930.130
	342B				NO RESULTS		
	342C				NO RESULTS		
	342D				NO RESULTS		
H5A	343A	950.6	569.7	0.3809	200050	108.78	74.648
	343B				143680	46.74	
	343C				142250	43.00	
	343D				187090	100.07	

RAW DATA/LOW CONCENTRATION/BRADY

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg. conc (ppb)

H5B	344A	931.6	536.4	0.3952	857820	665.56	563.940
	344B				732720	542.36	
	344C				641090	465.24	
	344D				775470	582.60	
H6A	431A	948.1	567.1	0.381	1056600	1012.50	1069.158
	431B				1126000	1053.90	
	431C				1243700	1122.38	
	431D				1180900	1087.85	
H6B	435A	947.7	557.3	0.3904	1242700	1121.86	943.540
	435B				936000	918.32	
	435C				960770	941.70	
	435D				990580	970.60	
H6B	440A	942.3	523.4	0.4189	1791700	1444.57	1398.053
	440B				1647100	1351.51	
	440C				1685000	1375.31	
	440D				1755700	1420.82	

RAW DATA/LOW CONCENTRATION/JOHNSON

BATH	SAMPLE NO.	FULL WT (gm)	EMPTY WEIGHT (gm)	SOLN VOLUME (liters)	GC		
					area count	conc (ppb)	avg. conc (ppb)

H1A	103A	1158	497.5	0.6605	797180	4.36	4.968
	103B				870280	5.31	
	103C				859440	5.24	
	103D				NOT ANALYZED		
H1A	104A	1164.9	509.5	0.6554	SATURATED DETECTOR		167.999
	104B				SATURATED DETECTOR		
	104C				SATURATED DETECTOR		
	104D				NOT ANALYZED		
	104A-A				49952	1009.28	
	104A-B				46858	993.66	
	104A-C				46291	990.83	
	104B-A				45606	987.42	
	104B-B				51240	1015.85	
	104B-C				50068	1009.87	
	104C-A				50579	1012.47	
	104C-B				50064	1009.85	
	104C-C				50868	1013.95	
	104D-A				54457	1032.45	
	104D-B				51194	1015.61	
	104D-C				58328	1052.78	
	104D-D				152270	169.01	
	104D-E				131180	151.97	
	104D-F				168070	183.02	
H1A	105A	1162.2	504.9	0.6573	SATURATED DETECTOR		334.957
	105B				SATURATED DETECTOR		
	105C				SATURATED DETECTOR		
	105D				NOT ANALYZED		

RAW DATA/LOW CONCENTRATION/JOHNSON

BATCH	SAMPLE NO.	FULL WT (gm)	EMPTY WEIGHT (gm)	SOLN VOLUME (liters)	GC		
					area count	conc (ppb)	avg. conc (ppb)
	105A-A				67271	1101.31	
	105A-B				72615	1131.37	
	105A-C				56532	1043.30	
	105B-A				54492	1032.63	
	105B-B				61780	1071.26	
	105B-C				65673	1092.48	
	105C-A				78172	1151.83	
	105C-B				66637	1097.80	
	105C-C				68376	1107.46	
	105D-A				87847	1221.62	
	105D-B				92991	1253.70	
	105D-C				93819	1258.94	
	105D-D				276030	315.31	
	105D-E				300790	357.21	
	105D-F				286480	332.36	
H2B	169A	1161.3	492.1	0.6692	288440	7.13	8.040
	169B				255990	6.28	
	169C				364920	9.62	
	169D				351620	9.13	
H2B	170A	1163.7	506.9	0.6568	400480	11.06	8.483
	170B				344370	8.88	
	170C				328620	8.35	
	170D				324640	8.22	
H2B	171A	1163.1	510.1	0.653	430300	12.43	10.590
	171B				381350	10.26	
	171C				370290	9.83	
	171D				370780	9.84	

RAW DATA/LOW CONCENTRATION/JOHNSON

BATH	SAMPLE NO.	FULL WT (gm)	EMPTY WEIGHT (gm)	SOLN VOLUME (liters)	GC		
					area count	conc (ppb)	avg. conc (ppb)

H3A	313A	1161.1	504.4	0.6567	454360	21.35	1.228
	313B				227790	0.69	
	313C				258050	1.09	
	313D				295110	1.91	
H3A	314A	1165.7	507.7	0.658	400690	9.46	0.869
	314B				202950	0.47	
	314C				252130	1.00	
	314D				261090	1.14	
H3A	315A	1154.2	495.6	0.6586	446890	19.07	1.937
	315B				274910	1.41	
	315C				309340	2.37	
	315D				299430	2.04	
H4A	389A	1163	512.3	0.6507	1299900	564.06	435.020
	389B				998970	428.17	
	389C				1028600	441.22	
	389D				1016100	435.67	
H4A	390A	1164.9	514	0.6509	173150	89.50	55.160
	390B				143800	54.89	
	390C				144630	55.65	
	390D				143860	54.94	
H4A	391A	1154.1	491.4	0.6627	314040	176.42	169.308
	391B				275030	163.01	
	391C				295080	169.77	
	391D				289990	168.03	
H5B	350A	1168.5	506.2	0.6623	1326400	1017.32	759.993
	350B				906240	701.47	
	350C				954330	739.05	

RAW DATA/LOW CONCENTRATION/JOHNSON

BATH	SAMPLE NO.	FULL WT (gm)	EMPTY WEIGHT (gm)	SOLN VOLUME (liters)	GC		
					area count	conc (ppb)	avg. conc (ppb)

	350D				1072300	839.46	
H5B	351A	1163.5	501.7	0.6618	285600	184.10	124.777
	351B				231300	133.00	
	351C				209780	115.81	
	351D				222300	125.52	
H5B	352A	1159.3	498.3	0.661	2234000	1694.98	1781.488
	352B				2288900	1735.44	
	352C				2385100	1808.67	
	352D				2483600	1886.86	
H6B	437A	1148	485.7	0.6623	1450000	1234.24	1231.010
	437B				1343500	1175.17	
	437C				1447300	1232.71	
	437D				1435600	1226.08	
H6B	439A	1161.2	506.3	0.6549	1338700	1172.57	1137.015
	439B				1223500	1111.99	
	439C				1283000	1142.88	
	439D				1240300	1120.62	
H6B	442A	1154.6	499.7	0.6549	132970	106.82	102.900
	442B				129560	104.98	
	442C				123050	101.56	
	442D				119230	98.24	

RAW DATA/LOW CONCENTRATION/TRILOC

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WEIGHT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg. conc (ppb)

H1A	102A	1614.3	740.4	0.8739	105460	0.13	0.132
	102B				99463	0.13	
	102C				102720	0.13	
	102D				NOT ANALYZED		
H1B	106A	1591.4	726.4	0.865	539340	1.19	0.654
	106B				448180	0.75	
	106C				413400	0.63	
	106D				397730	0.58	
H1B	111A	1585.1	716.2	0.8689	103440	0.13	0.123
	111B				87936	0.12	
	111C				83718	0.12	
	111D				82856	0.12	
H2A	157A	1609.2	739.9	0.8693	318310	8.02	7.015
	157B				276060	6.79	
	157C				261730	6.42	
	157D				277390	6.83	
H2A	158A	1597.7	728.4	0.8693	332550	8.48	7.910
	158B				350690	9.10	
	158C				298450	7.42	
	158D				270020	6.64	
H2B	163A	1613.5	732.9	0.8806	466320	14.31	6.170
	163B				257280	6.31	
	163C				239440	5.89	
	163D				257120	6.31	
H3A	312A	1599.3	727.2	0.8721	391620	21.47	2.497
	312B				364720	2.44	
	312C				287510	2.06	
	312D				401580	2.99	

RAW DATA/LOW CONCENTRATION/TRILOC

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WEIGHT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg. conc (ppb)

H3B	319A	1609.1	723.7	0.8854	269130	1.29	1.964
	319B				315640	2.61	
	319C				295300	1.91	
	319D				299810	2.05	
H3B	320A	1599.9	746.2	0.8537	269850	1.30	1.041
	320B				222910	0.64	
	320C				256360	1.06	
	320D				262520	1.16	
H4A	383A	1604	758	0.846	86579	21.16	10.010
	383B				42164	10.09	
	383C				39811	9.70	
	383D				43008	10.24	
H4B	392A	1598.5	732.7	0.8658	47423	11.02	10.553
	392B				44628	10.52	
	392C				44844	10.55	
	392D				45029	10.59	
H4B	396A	1573.2	702.8	0.8704	57860	13.11	11.810
	396B				55313	12.57	
	396C				49894	11.48	
	396D				42060	10.08	
H5A	338A	1617.8	748.4	0.8694	135250	37.68	35.920
	338B				128680	33.28	
	338C				117740	27.08	
	338D				134000	36.80	
H5A	339A	1606.6	751	0.8556	1037000	808.42	808.420
	339B				866390		
	339C				62993		
	339D				NO RESULTS		

RAW DATA/LOW CONCENTRATION/TRILOC

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WEIGHT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg. conc (ppb)

H5B	349A	1591.2	731.5	0.8597	147000	77.32	76.897
	349B				166220	87.50	
	349C				150130	78.89	
	349D				141180	74.48	
H6A	429A	1577	729.5	0.8475	872520	861.03	841.850
	429B				818150	814.81	
	429C				860840	850.89	
	429D				848940	840.67	
H6A	433A	1592.1	734	0.8581	55217	22.50	25.023
	433B				53684	21.72	
	433C				62816	26.80	
	433D				66340	29.07	
H6B	436A	1589.8	738.7	0.8511	46561	18.43	17.600
	436B				42961	16.97	
	436C				38768	15.40	
	436D				49224	19.60	

*PROBLEMS WITH GC, QUESTIONABLE RESULTS

RAW DATA/HIGH CONCENTRATION/ATLANTIC WITH NO O-RING

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WEIGHT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg. conc (ppb)

S1A	112A	819.8	413	0.4068	281630	0.32	0.299
	112B				287840	0.30	
	112C				246240	0.27	
	112D				NOT ANALYZED		
S1A	113A	838	394.7	0.4433	155320	0.17	0.177
	113B				156080	0.17	
	113C				171840	0.19	
	113D				NOT ANALYZED		
S1A	114A	833.3	385.1	0.4482	88738	0.12	0.125
	114B				104660	0.13	
	114C				92359	0.13	
	114D				83797	0.12	
S2A	143A	832.2	392.8	0.4394	553420	20.1	20.065
	143B				545160	19.49	
	143C				575410	21.94	
	143D				534610	18.70	
S2A	144A	829.8	391.1	0.4387	541300	19.20	19.930
	144B				561090	20.74	
	144C				545420	19.51	
	144D				555230	20.27	
S2A	145A	843.2	405.5	0.4377	588790	23.12	14.547
	145B				450230	13.44	
	145C				486540	15.49	
	145D				473280	14.71	
S3A	295A	841.2	408.6	0.4328	463990	24.71	137.707
	295B				506260	46.91	
	295C				707800	235.68	
	295D				718230	243.53	

RAW DATA/HIGH CONCENTRATION/ATLANTIC WITH NO O-RING

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WEIGHT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg conc (ppb)

S3B	306A	838.2	411.9	0.4263	521740	54.75	12.260
	306B				407690	10.52	
	306C				414490	11.67	
	306D				429260	14.59	
S3B	307A	795.9	397.4	0.3985	572330	82.28	116.804
	307B				650870	154.86	
	307C				675480	188.79	
	307D				497850	41.29	
S4A	372A	847.7	404	0.4437	74274	17.23	17.215
	372B				66989	15.26	
	372C				84201	20.33	
	372D				69066	16.04	
S4B	377A	840.5	402.8	0.4377	61949	14.04	14.535
	377B				56986	12.92	
	377C				75286	17.53	
	377D				60290	13.65	
S4B	378A	843.5	395.9	0.4476	77820	18.28	18.317
	378B				76074	17.76	
	378C				79848	18.91	
	378D				86514	21.13	
S5A	353A	817.2	391	0.4262	215710	120.31	141.107
	353B				239500	140.21	
	353C				238580	139.38	
	353D				243350	143.73	
S5A	354A	827.7	379.8	0.4479	406520	266.69	370.610
	354B				507770	374.62	
	354C				492690	358.83	
	354D				514060	378.38	

RAW DATA/HIGH CONCENTRATION/ATLANTIC WITH NO O-RING

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WEIGHT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg. conc (ppb)

S5A	355A	811.5	382.7	0.4288	178130	84.60	84.605
	355B				178360	84.97	
	355C				184380	95.19	
	355D				170790	73.66	
S6B	451A	787.5	373.4	0.4141	398800	397.77	331.070
	451B				339590	301.14	
	451C				345030	308.94	
	451D				380400	364.81	
	451E				1879800	282.69	
	451F				NOT ANALYZED		
	451G				NOT ANALYZED		
	451H				NOT ANALYZED		
S6B	453A	819.1	402.5	0.4166	175060	132.35	135.535
	453B				170640	129.40	
	453C				190800	143.39	
	453D				212520	160.15	
	453E				103570	137.00	
	453F				NOT ANALYZED		
	453G				NOT ANALYZED		
	453H				NOT ANALYZED		
S6B	457A	816.8	391.7	0.4251	1164900	1077.85	1061.418
	457B				1123200	1052.20	
	457C				1161800	1075.92	
	457D				1102500	1039.70	
	457E				598970	1197.56	
	457F				NOT ANALYZED		
	457G				NOT ANALYZED		
	457H				NOT ANALYZED		

RAW DATA/HIGH CONCENTRATION/ATLANTIC WITH O-RING

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg. conc (ppb)

S1A	115A	833.1	400.3	0.4328	7514200	59.65	62.084
	115B				7808900	61.96	
	115C				8128200	64.65	
	115D				NOT ANALYZED		
S1B	121A	829.8	402.3	0.4275	162560	0.18	0.161
	121B				121610	0.15	
	121C				139710	0.16	
	121D				425030	0.67	
S1B	122A	842.1	411.3	0.4308	289140	0.34	0.397
	122B				333820	0.42	
	122C				337930	0.43	
	122D				486840	0.91	
S2A	146A	841.2	395.8	0.4454	752070	43.82	23.287
	146B				610830	25.20	
	146C				598400	24.01	
	146D				559960	20.65	
S2B	155A	836.6	401.5	0.4351	1202100	143.83	24.873
	155B				619360	26.06	
	155C				537620	18.92	
	155D				652260	29.64	
S2B	156A	844.4	413	0.4314	847420	59.18	23.623
	156B				637050	27.93	
	156C				564450	21.02	
	156D				575130	21.92	
S3A	293A	846.5	402.2	0.4443	548310	67.81	56.592
	293B				457020	22.23	
	293C				516190	52.36	

RAW DATA/HIGH CONCENTRATION/ATLANTIC WITH O-RING

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg. conc (ppb)

	293D				574860	83.97	
S3A	294A	807	376.5	0.4305	507300	47.65	52.937
	294B				504600	45.74	
	294C				511120	50.28	
	294D				548830	68.09	
S3A	296A	832.6	401.8	0.4308	9229700	9183.70	10307.199
	296B				9949200	10556.69	
	296C				10246000	11181.21	
	296D				6895300	1265.05	
S4A	369A	832.5	405.7	0.4268	818830	358.71	367.643
	369B				835860	382.92	
	369C				874180	377.30	
	369D				884570	373.64	
S4A	370A	839.2	401.3	0.4379	91584	23.00	20.130
	370B				93078	23.58	
	370C				69668	15.96	
	370D				76824	17.98	
S4A	371A	843.3	387.2	0.4561	107320	29.89	27.495
	371B				89301	22.14	
	371C				100320	26.60	
	371D				110180	31.35	
S5A	356A	862.1	403.4	0.4587	8938800	7931.03	7785.810
	356B				8330900	7337.20	
	356C				8679700	7674.73	
	356D				9218700	8200.28	
S5B	363A	832.4	400.6	0.4318	1436700	1093.63	1039.913
	363B				1276300	990.35	
	363C				1319900	1013.00	

RAW DATA/HIGH CONCENTRATION/ATLANTIC WITH O-RING

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg. conc (ppb)

	363D				1392900	1062.67	
S5B	364A	837.6	409.3	0.4283	5404600	4906.79	4373.375
	364B				4262800	3619.72	
	364C				4347500	3711.87	
	364D				5766500	5255.12	
S6A	444A	841.4	387.4	0.454	4826700	3741.80	5403.110
	444B				6654300	5577.75	
	444C				6326500	5322.73	
	444D				6313200	5308.85	
	444E				2662800	4116.00	
	444F				NOT ANALYZED		
	444G				NOT ANALYZED		
	444H				NOT ANALYZED		
S6A	447A	842.7	412.4	0.4303	6947800	5787.02	5182.720
	447B				5009400	3920.51	
	447C				5709000	4687.36	
	447D				6048900	5040.44	
	447E				3413100	5216.06	
	447F				NOT ANALYZED		
	447G				NOT ANALYZED		
	447H				NOT ANALYZED		
S6B	455A	842.7	399.3	0.4434	9642400	7824.14	6586.250
	455B				7894800	6517.28	
	455C				8095900	6660.93	
	455D				11932000	9473.90	
	455E				4323100	6580.54	
	455F				NOT ANALYZED		
	455G				NOT ANALYZED		

RAW DATA/HIGH CONCENTRATION/ATLANTIC WITH O-RING

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg. conc (ppb)

	455H				NOT ANALYZED		
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RAW DATA/HIGH CONCENTRATION/BRADY

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg. conc (ppb)

S1A	117A	943.3	553.4	0.3899	570060	1.39	1.290
	117B				531860	1.14	
	117C				562900	1.34	
	117D				NOT ANALYZED		
S1B	124A	940.5	576.5	0.364	993670	6.25	7.080
	124B				1130000	7.48	
	124C				915220	5.64	
	124D				1312500	8.96	
S1B	125A	956.4	449.8	0.5066	690150	2.54	2.952
	125B				767560	3.75	
	125C				691920	2.56	
	125D				NOT ANALYZED		
S2A	147A	938.9	509.8	0.4291	913080	70.81	60.810
	147B				811560	53.65	
	147C				873690	63.58	
	147D				821990	55.20	
S2B	153A	943.3	554.8	0.3885	547530	19.67	19.330
	153B				562670	20.87	
	153C				545260	19.50	
	153D				514460	17.28	
S2B	154A	940.4	572.5	0.3679	527850	18.21	21.353
	154B				599240	24.09	
	154C				573290	21.76	
	154D				416790	11.79	
S3A	301A	933.4	578	0.3554	537920	62.37	25.274
	301B				486920	34.96	
	301C				450690	20.20	
	301D				452120	20.64	

RAW DATA/HIGH CONCENTRATION/BRADY

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg. conc (ppb)

S3B	304A	961.6	560.3	0.4013	464130	24.76	27.057
	304B				472100	27.94	
	304C				473320	28.47	
	304D				377380	6.65	
S3B	305A	953.6	599.8	0.3538	548290	67.80	19.375
	305B				443310	18.06	
	305C				433810	15.64	
	305D				463240	24.43	
S4A	373A	949.4	580	0.3694	243720	152.96	148.375
	373B				217210	144.96	
	373C				220610	145.96	
	373D				232560	149.50	
S4B	381A	952.7	532.7	0.42	377420	200.61	199.023
	381B				371360	196.16	
	381C				364740	195.52	
	381D				380350	201.80	
S4B	382A	949.2	580.4	0.3668	483190	248.58	256.703
	382B				507410	261.09	
	382C				506190	259.92	
	382D				500050	257.22	
S5A	358A	932	509.7	0.4223	815590	623.07	556.863
	358B				763290	570.84	
	358C				754230	562.24	
	358D				727350	537.51	
S5B	361A	942	530.7	0.4113	9057300	8043.93	8399.807
	361B				8096000	7118.30	
	361C				9394900	8374.44	
	361D				9792400	8761.05	

RAW DATA/HIGH CONCENTRATION/BRADY

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg. conc (ppb)

S5B	362A	945.2	590.7	0.3545	1189000	948.99	887.340
	362B				1038300	809.56	
	362C				1077900	844.41	
	362D				1186400	946.40	
S6A	445A	946.1	543.6	0.4025	1011400	986.41	1116.133
	445B				1237200	1119.02	
	445C				1261500	1131.62	
	445D				1196600	1097.76	
	445E				439560	866.85	
	445F				NOT ANALYZED		
	445G				NOT ANALYZED		
	445H				NOT ANALYZED		
S6A	448A	954	592.6	0.3614	4636600	3564.50	3336.296
	448B				4294700	3266.50	
	448C				4023900	3048.25	
	448D				4248800	3228.43	
	448E				2293800	3573.80	
	448F				NOT ANALYZED		
	448G				NOT ANALYZED		
	448H				NOT ANALYZED		
S6B	454A	943.6	566.5	0.3771	1502600	1264.50	1223.692
	454B				1559600	1298.25	
	454C				1122100	1051.53	
	454D				1293000	1148.15	
	454E				685030	1356.03	
	454F				NOT ANALYZED		
	454G				NOT ANALYZED		
	454H				NOT ANALYZED		

RAW DATA/HIGH CONCENTRATION/JOHNSON

BATH	SAMPLE NO.	FULL WT (gm)	EMPTY WEIGHT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg. conc (ppb)

S1A	118A	1168.5	511.9	0.6566	SATURATED DETECTOR		241.184
	118B				SATURATED DETECTOR		
	118C				SATURATED DETECTOR		
	118A-A				190600	204.91	
	118A-B				186830	201.16	
	118A-C				180260	194.61	
	118B-A				157170	173.24	
	118B-B				196330	211.02	
	118B-C				253010	280.78	
	118C-A				133910	154.08	
	118C-B				155380	171.68	
	118C-C				147320	164.85	
	118D-A				321900	397.30	
	118D-B				436800	708.84	
	118D-C				329260	412.31	
S1A	119A	1156.6	506.5	0.6481	5404800	42.01	39.403
	119B				4948900	37.41	
	119C				5089500	38.79	
	119D				NOT ANALYZED		
S1A	120A	1164.6	526.7	0.6379	250180	0.28	0.245
	120B				248240	0.27	
	120C				170660	0.19	
	120D				530730	1.14	
S2A	148A	1167.4	500.8	0.6666	1769500	469.01	588.600
	148B				2213100	769.69	
	148C				1901100	553.10	
	148D				1917100	562.60	
S2A	149A	1160.6	492.8	0.6678	3388900	1689.84	1844.858

RAW DATA/HIGH CONCENTRATION/JOHNSON

BATH	SAMPLE NO.	FULL WT (gm)	EMPTY WEIGHT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg. conc (ppb)

	149B				3706800	1930.30	
	149C				3627900	1868.19	
	149D				3657300	1891.10	
S2A	150A	1166.4	519	0.6474	628550	27.02	23.873
	150B				720960	38.79	
	150C				572490	21.69	
	150D				586470	22.91	
S3A	298A	1160.4	491	0.6694	20148000	76075.8	42225.0
	298B				16136000	34981.4	
	298C				17073000	41941.0	
	298D				17955000	49752.6	
S3A	299A	1158.9	518.2	0.6407	23394000	142638	129788
	299B				22033000	109591	
	299C				23225000	138046	
	299D				22870000	128875	
S3A	300A	1156.1	493.9	0.6622	577270	85.62	107.976
	300B				652550	156.97	
	300C				568910	80.04	
	300D				607580	109.28	
S4A	374A	1161.9	496.6	0.6653	84584	40.93	36.643
	374B				78858	37.20	
	374C				138980	101.30	
	374D				69440	31.80	
S4A	375A	1153.7	490.8	0.6629	114410	67.27	55.527
	375B				102620	55.28	
	375D				104340	56.88	
	375D				101680	54.42	
S4A	376A	1165.3	498.9	0.6664	540820	514.34	441.670

RAW DATA/HIGH CONCENTRATION/JOHNSON

BATH	SAMPLE NO.	FULL WT (gm)	EMPTY WEIGHT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg. conc (ppb)

	376B				414010	428.58	
	376C				438220	443.77	
	376D				452010	452.66	
S5A	365A	1165	508	0.657	765270	1145.46	920.215
	365B				551270	802.71	
	365C				579970	840.05	
	365D				696900	1021.59	
	365E				306110	1016.51	
	365F				NOT ANALYZED		
	365G				NOT ANALYZED		
	365H				NOT ANALYZED		
S5A	366A	1158.5	513.9	0.6446	2279300	3456.59	3602.003
	366B				2362100	3581.77	
	366C				2469300	3750.60	
	366D				2366200	3619.05	
	366E				1113800	4384.38	
	366F				NOT ANALYZED		
	366G				NOT ANALYZED		
	366H				NOT ANALYZED		
S5A	367A	1165.6	511.6	0.654	2019500	3068.49	2883.193
	367B				1773200	2700.28	
	367C				1966500	2965.24	
	367D				1828400	2778.76	
	367E				861980	3342.88	
	367F				NOT ANALYZED		
	367G				NOT ANALYZED		
	367H				NOT ANALYZED		
S6B	450A	1163.3	507.6	0.6557	1123200	1052.20	1087.143

RAW DATA/HIGH CONCENTRATION/JOHNSON

BATH	SAMPLE NO.	FULL WT (gm)	EMPTY WEIGHT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg. conc (ppb)

	470B				1244500	1122.79	
	450C				1203900	1102.00	
	450D				1154800	1071.58	
	450E				623030	1240.33	
	450F				NOT ANALYZED		
	450G				NOT ANALYZED		
	450H				NOT ANALYZED		
S6B	452A	1157.3	484.9	0.6724	371420	349.74	322.420
	452B				422090	418.34	
	452C				350170	316.50	
	452D				296350	245.40	
	452E				188350	282.12	
	452F				NOT ANALYZED		
	452G				NOT ANALYZED		
	452H				NOT ANALYZED		
S6B	456A	1162	482.8	0.6792	393950	388.80	299.703
	456B				333790	293.04	
	456C				306790	258.12	
	456D				337490	298.18	
	456E				204750	307.89	
	456F				NOT ANALYZED		
	456G				NOT ANALYZED		
	456H				NOT ANALYZED		

RAW DATA/HIGH CONCENTRATION/TRILOC

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg. conc (ppb)
S1A	116A	1611.2	739.6	0.8716	202060	0.22	0.209
	116B				191250	0.21	
	116C				188960	0.20	
	116D				NOT ANALYZED		
S1B	123A	1616.8	741.2	0.8756	757020	3.56	2.669
	123B				562200	1.33	
	123C				609280	1.69	
	123D				784800	4.09	
S1B	126A	1597.4	746.3	0.8511	186310	0.20	0.193
	126B				127310	0.15	
	126C				213430	0.23	
	126D				418460	0.66	
S2A	142A	1589.9	745	0.8449	569120	21.41	19.843
	142B				523390	17.90	
	142C				554510	20.22	
	142D				744310	42.51	
S2B	151A	1609.6	730.1	0.8796	525460	18.04	17.600
	151B				539490	19.06	
	151C				515440	17.35	
	151D				493980	15.95	
S2B	152A	1609.7	760.9	0.8488	510270	17.00	18.837
	152B				867490	62.51	
	152C				591050	23.32	
	152D				497810	16.19	
S3A	297A	1613.8	738.9	0.8749	361240	5.20	2.382
	297B				307940	2.32	
	297C				309800	2.39	
	297D				311340	2.44	

RAW DATA/HIGH CONCENTRATION/TRILOC

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg. conc (ppb)

S3B	302A	1613.4	744.5	0.8689	626800	127.57	66.486
	302B				605310	107.30	
	302C				431860	15.18	
	302D				434870	15.89	
S3B	303A	1617	758	0.859	507720	47.96	41.578
	303B				504150	45.43	
	303C				479690	31.35	
	303D				688140	209.05	
S4A	368A	1598.2	734.4	0.8618	42199	10.10	11.243
	368B				50378	11.57	
	368C				52871	12.06	
	368D				75498	17.59	
S4B	379A	1616	752.7	0.8633	61145	13.85	15.030
	379B				68682	15.70	
	379C				65232	14.82	
	379D				68861	15.75	
S4B	380A	1611.6	738	0.8733	54689	12.44	13.550
	380B				60461	13.69	
	380C				63972	14.52	
	380D				80949	19.26	
S5A	357A	1589.9	729.9	0.86	59943	9.10	9.108
	357B				57862	8.75	
	357C				61374	9.35	
	357D				60707	9.23	
S5B	359A	1593.9	727.2	0.8667	253780	153.30	153.673
	359B				283250	181.63	
	359C				251040	150.90	
	359D				257720	156.82	

RAW DATA/HIGH CONCENTRATION/TRILOC

BATH	SAMPLE NUMBER	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	GC		
					area count	conc (ppb)	avg. conc (ppb)

S5B	360A	1592	726.9	0.8651	1173900	934.04	799.713
	360B				912200	706.02	
	360C				963230	746.23	
	360D				1041700	812.56	
S6A	443A	1617.3	740.2	0.8771	778870	776.00	815.745
	443B				924090	907.29	
	443C				836810	830.39	
	443D				754530	749.30	
	443E				295940	489.77	
	443F				NOT ANALYZED		
	443G				NOT ANALYZED		
	443H				NOT ANALYZED		
S6A	446A	1601.3	728.8	0.8725	1353200	1180.43	1326.518
	446B				1585300	1313.59	
	446C				1689500	1365.53	
	446D				1823500	1464.40	
	446E				660300	1308.64	
	446F				NOT ANALYZED		
	446G				NOT ANALYZED		
	446H				NOT ANALYZED		
S6B	449A	1585	709.9	0.8751	205880	154.82	157.695
	449B				197290	148.21	
	449C				210810	158.77	
	449D				236380	287.11	
	449E				112680	168.98	
	449F				NOT ANALYZED		
	449G				NOT ANALYZED		
	449H				NOT ANALYZED		

APPENDIX B
CALIBRATION CURVE

CALIBRATION CURVE FOR TCE ANALYSIS

APPENDIX C
FLUORESCEIN TEST RESULTS

Concentration of Fluorescein in each Bath

<u>Bath Number</u>	<u>Concentration (mg/L)</u>
1	392
2	397
3	390

FLUORESCIN TEST RAW DATA

BATH	PIPE	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	DILUTION soln H ₂ O	READING in COUNTS (conc. in ppb)			AVG. CONC. (ppb)
						1X	3X	10X	

1	TRILOC	1608.1	752.5	855.6	none	5.1 (5.63)	16.0 (0.77)	OS	2.65
	O-RING					4.2 (1.41)	17.4 (3.05)	OS	
						4.8 (4.22)	16.7 (1.91)	OS	
1	TRILOC	1605.9	747.5	858.4	none	62.3 (273.78)	OS	NR	277.85
	NO O-RING					64.3 (283.16)	OS	NR	
						62.9 (276.60)	OS	NR	
1	ATLANTIC	832.9	420.0	412.9	none	OS	NR	NR	745.40
	O-RING				1:1	86.4 (773.52)	OS	NR	
					1:2	65.2 (862.13)	OS	NR	
					1:3	42.9 (731.34)	OS	NR	
						42.9 (731.34)	OS	NR	
						39.2 (661.96)	OS	NR	
1	BRADY	954.9	572.1	382.8	none	53.6 (233.00)	OS	NR	230.76
	O-RING				1:3	17.4 (253.16)	50.3 (226.72)	OS	
						16.8 (241.91)	49.5 (221.50)	OS	
						16.2 (230.66)	48.2 (213.02)	OS	

BATH	PIPE	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	DILUTION soln:H ₂ O	READING in COUNTS (conc. in ppb)			AVG. CONC. (ppb)
						1X	3X	10X	

2	TRILOC	1600.2	754.0	846.2	none	50.3 (217.53)	OS	NR	219.97
	NO O-RING				1:3	16.8 (241.91)	48.7 (216.28)	OS	
						16.0 (226.91)	47.5 (208.46)	OS	
						16.2 (230.66)	46.0 (198.68)	OS	
2	TRILOC	1600.2	745.0	855.2	none	5.1 (5.63)	16.3 (1.26)	OS	1.92
	O-RING					4.6 (3.28)	16.0 (0.77)	OS	
						4.4 (2.35)	15.8 (0.44)	OS	
2	BRADY	947.3	574.6	372.7	none	36.7 (153.77)	OS	NR	155.00
	O-RING				1:1	21.7 (166.90)	61.2 (148.89)	OS	
						21.1 (161.27)	60.8 (147.59)	OS	
						21.3 (163.15)	60.9 (147.91)	OS	
2	ATLANTIC	857.5	430.1	427.4	none	103.2 (465.52)	OS	NR	454.45
	O-RING				1:3	30.0 (489.44)	92.1 (499.25)	OS	
						27.8 (448.18)	82.1 (434.05)	OS	
						27.1 (435.06)	81.6 (430.79)	OS	
3	TRILOC	1610.9	741.0	869.9	none	39 (0)	11.9 (0)	49.9 (0)	0
	O-RING					4.6 (3.28)	13.2 (0)	48.9 (0)	
						3.6 (0)	12.1 (0)	50.8 (0)	

BATH	PIPE	FULL WT (gm)	EMPTY WT (gm)	SOLN VOL (liters)	DILUTION soln:H ₂ O	READING in COUNTS (conc. in ppb)			AVG. CONC. (ppb)
						1X	3X	10X	

3	TRILOC	1604.5	771.0	833.5	none	27.7 (111.58)	81.8 (108.02)	OS	92.82
	NO O-RING				1:1	13.9 (93.77)	42.0 (86.3)	OS	
						13.8 (92.83)	41.9 (85.97)	OS	
						13.5 (90.02)	38.2 (73.91)	OS	
3	ATLANTIC	832.1	416.7	415.4	none	60.7 (266.28)	OS	NR	251.06
	O-RING				1:3	17.4 (253.16)	52.0 (237.80)	OS	
						18.4 (271.92)	52.8 (243.02)	OS	
						17.5 (255.04)	52.0 (237.80)	OS	
3	BRADY	936.0	506.4	429.6	none	OS	NR	NR	555.02
	O-RING				1:3	33.9 (562.57)	102.3 (565.76)	OS	
						34.1 (566.32)	101.5 (560.54)	OS	
						32.2 (530.69)	97.0 (531.20)	OS	

OS = OFF SCALE

NR = NO READING TAKEN

AVERAGE VALUES FOR TOTAL VOLUME AND CONCENTRATION IN THE THREE FLUORESCEIN BATHS, PLUS RESIDENCE TIMES

PIPE	RESIDENCE TIME (days)	SOLUTION VOLUME (liters)	CONCENTRATION (PPB)
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TRILOC WITH O-RING	43	860.2	1.52
TRILOC WITH NO O-RING	43	848.0	196.88
ATLANTIC WITH O-RING	39	418.6	483.64
BRADY WITH O-RING	39	395.0	313.59

APPENDIX D
AVERAGE VALUES FOR SOLUTION VOLUMES
AND
CONCENTRATIONS THAT WERE USED IN THE DIFFUSION MODEL

PIPE	SAMPLING PERIOD	SAMPLE NUMBERS	SOLUTION VOLUME (ml)	CONCENTRATION (ppb)
ATLANTIC	H1	97, 98, 100	439	0.2
WITH NO O-RING	H2	165, 166, 167	443	9
	H3	308, 309, 310	428	2.3
	H4	372, 377, 378	432	20.2
		384, 385, 386		
	H5	345, 346, 347	434	213.6
	H6	434, 438, 441	443	20.2
	S1	112, 113, 114	433	0.2
	S2	143, 144, 145	439	18.2
	S3	295, 307	410	127.3
	S5	353, 354, 355	434	196.8
	S6	451, 453, 457	419	509.3
ATLANTIC	H1	99, 107, 108	441	0.3
WITH O-RING	H2	161, 162, 168	441	11.7
	H3	311, 321	436	1.8
	H4	296, 369, 370	435	245.9
		387, 393, 395		
	H5	341, 348	440	742.7
	H6	428, 430, 432	435	2034.5
	S1	121, 122	429	0.03
	S2	146, 155, 156	437	23.9
	S3	293, 294	437	54.8
	S5	358, 363, 364	440	4399.7
	S6	444, 447, 455	443	5724

PIPE	SAMPLING PERIOD	SAMPLE NUMBERS	SOLUTION VOLUME (ml)	CONCENTRATION (ppb)
BRADY	H1	101, 109, 110	388	8.6
	H2	159, 160, 164	380	8.9
	H3	316, 317, 318	389	2.9
	H4	388, 394, 397	391	188.4
		373, 381, 382		
	H5	342, 343, 344	378	522.9
	H6	431, 435, 440	397	1136.9
	S1	117, 124, 125	420	3.8
	S2	147, 153, 154	378	20.3
	S3	301, 304, 305	370	23.9
	S5	358, 361, 362	396	722.1
	S6	445, 448, 454	380	1892
JOHNSON	H1	103, 104, 105	657	169.3
	H2	169, 170, 171	600	9
	H3	313, 314, 315	658	1.34
	H4	389, 390, 391	600	198.9
		374, 375, 376		
	H5	350, 351, 352	662	888.8
	H6	437, 439, 442	659	1184
	S1	118, 119, 120	648	93.6
	S2	148, 149, 150	661	819.1
	S3	298, 299, 300	657	57373.4
	S5	365, 366, 367	649	3242.6
	S6	450, 452, 456	676	311.1

PIPE	SAMPLING PERIOD	SAMPLE NUMBERS	SOLUTION VOLUME (ml)	CONCENTRATION (ppb)
BRAINARD-KILMAN	H1	102, 106, 111	869	0.3
(TRILOC)	H2	157, 158, 163	873	7
	H3	312, 319, 320	870	1.8
	H4	383, 392, 396	864	12
		368, 379, 380		
	H5	338, 349	865	56.4
	H6	429, 433, 435	855	21.3
	S1	116, 126	861	0.2
	S2	142, 151, 152	858	18.8
	S3	302, 303	864	54
	S5	357, 359, 360	864	320.8
	S6	443, 446, 449	875	766.6

APPENDIX E**EXAMPLE OF MODEL SETUP USING EXCEL SPREADSHEET**

BRADY PIPE												
Input Data			Model Data									
D =	0.7204	cm ² /day	Leg-	5.24	days							
x =	4.76	cm	Slope 1-	4147								
			Slope 2-	2537								
			equivalent area 1-	8.94e-02	cm ²							
			equivalent gap 1-	2.80e-03	cm							
			equivalent area 2-	1.72e-01	cm ²							
			equivalent gap 2-	5.40e-03	cm							
Data for Cbath=			ug/L									
Time	Volume	J(t)/Cbath	Sum(t)	C(t)	C(t) / J(t)	C(t)/Cbath		C(t)*V				
						measured	predicted	measured	predicted			
-16	420	0.00	0	3.8	0	1.24e-05	0.00	1.60e+03	0.00			
-3	378	5.63e+15	2.2055e+18	20.3	1.177e-20	6.63e-05	5.03e+14	7.67e+03	5.83e+22			
7	370	9.86e-04	-0.7201029	23.9	0.0791161	7.80e-05	8.82e-05	8.84e+03	1.00e+04			
85	396	3.05e-02	-0.8312415	722.1	0.077374	2.36e-03	2.72e-03	2.86e+05	3.30e+05			
144	380	5.52e-02	-0.8312415	1892	0.1117878	6.18e-03	4.94e-03	7.19e+05	5.75e+05			

BRADY PIPE													
Data for Cbath=		9/190	ug/L										
Time	Volume	J(t)/Cbath	Sum(t)	C(t)	C(t) / J(t)	C(t)/Cbath		C(t)*V					
						measured	predicted	measured	predicted				
-15	388	0.00	0	8.6	0	8.85e-05	0.00	3.34e+03		0.00			
-1	360	2.41e+02	95064.4341	8.9	0.0000004	9.16e-05	2.16e+01	3.38e+03		7.97e+08			
8	389	1.25e-03	-0.7500197	2.9	0.0238191	2.98e-05	1.12e-04	1.13e+03		4.24e+03			
43	391	1.46e-02	-0.8312401	188.4	0.132832	1.94e-03	1.31e-03	7.37e+04		4.96e+04			
86	378	3.23e-02	-0.8312415	522.9	0.1665087	5.38e-03	2.89e-03	1.98e+05		1.06e+05			
146	397	5.36e-02	-0.8312415	1136.9	0.2180839	1.17e-02	4.80e-03	4.51e+05		1.85e+05			

Points for model generated line

Time	$(i(t)/C_b)*V$	Sum(t)	PRED1	PRED2	
0.01	-0.0013878	-3.01e-03	-3.80e+01	-2.33e+01	-2.98e-03
0.05	-0.005026	-1.31e-02	-1.38e+02	-8.43e+01	-1.19e-02
0.1	-0.0070865	-2.30e-02	-1.94e+02	-1.19e+02	-1.90e-02
0.4	-0.0084592	-7.15e-02	-2.32e+02	-1.42e+02	-3.12e-02
0.7	-0.0084628	-1.19e-01	-2.32e+02	-1.42e+02	-3.25e-02
1	-0.0084237	-1.66e-01	-2.31e+02	-1.41e+02	-3.26e-02
2	-0.0033661	-3.17e-01	-9.22e+01	-5.64e+01	-3.26e-02
3	0.02293431	-4.47e-01	6.28e+02	3.84e+02	-3.26e-02
4	0.07690881	-5.48e-01	2.11e+03	1.29e+03	-3.26e-02
5	0.15534398	-6.23e-01	4.26e+03	2.60e+03	-3.26e-02
6	0.25291025	-6.79e-01	6.93e+03	4.24e+03	-3.26e-02
7	0.36481661	-7.20e-01	1.00e+04	6.12e+03	-3.26e-02
8	0.48730401	-7.50e-01	1.34e+04	8.17e+03	-3.26e-02
9	0.61755199	-7.72e-01	1.69e+04	1.04e+04	-3.26e-02
10	0.75347875	-7.88e-01	2.06e+04	1.26e+04	-3.26e-02
11	0.89355715	-8.00e-01	2.45e+04	1.50e+04	-3.26e-02
12	1.03666968	-8.08e-01	2.84e+04	1.74e+04	-3.26e-02
13	1.18199933	-8.14e-01	3.24e+04	1.98e+04	-3.26e-02
14	1.32894899	-8.19e-01	3.64e+04	2.23e+04	-3.26e-02
15	1.47708236	-8.22e-01	4.05e+04	2.48e+04	-3.26e-02
16	1.62608062	-8.25e-01	4.46e+04	2.73e+04	-3.26e-02
17	1.77571082	-8.26e-01	4.87e+04	2.98e+04	-3.26e-02
18	1.92580276	-8.28e-01	5.28e+04	3.23e+04	-3.26e-02
19	2.07623207	-8.29e-01	5.69e+04	3.48e+04	-3.26e-02
20	2.22690783	-8.29e-01	6.10e+04	3.73e+04	-3.26e-02
21	2.37776381	-8.30e-01	6.51e+04	3.98e+04	-3.26e-02
22	2.52875134	-8.30e-01	6.93e+04	4.24e+04	-3.26e-02
23	2.67983503	-8.31e-01	7.34e+04	4.49e+04	-3.26e-02
24	2.83096897	-8.31e-01	7.76e+04	4.75e+04	-3.26e-02
25	2.98219425	-8.31e-01	8.17e+04	5.00e+04	-3.26e-02

Time	$(j(t)/C_b)^*V$	Sum(i)	PRED1	PRED2	
26	3.13343703	-8.31e-01	8.59e+04	5.25e+04	-3.26e-02
27	3.28470722	-8.31e-01	9.00e+04	5.51e+04	-3.26e-02
28	3.43599744	-8.31e-01	9.41e+04	5.76e+04	-3.26e-02
29	3.58730229	-8.31e-01	9.83e+04	6.01e+04	-3.26e-02
30	3.73861782	-8.31e-01	1.02e+05	6.27e+04	-3.26e-02
31	3.88994117	-8.31e-01	1.07e+05	6.52e+04	-3.26e-02
32	4.04127023	-8.31e-01	1.11e+05	6.77e+04	-3.26e-02
33	4.19260345	-8.31e-01	1.15e+05	7.03e+04	-3.26e-02
34	4.34393972	-8.31e-01	1.19e+05	7.28e+04	-3.26e-02
35	4.49527822	-8.31e-01	1.23e+05	7.54e+04	-3.26e-02
36	4.64661835	-8.31e-01	1.27e+05	7.79e+04	-3.26e-02
37	4.79795966	-8.31e-01	1.31e+05	8.04e+04	-3.26e-02
38	4.94930184	-8.31e-01	1.36e+05	8.30e+04	-3.26e-02
39	5.10064466	-8.31e-01	1.40e+05	8.55e+04	-3.26e-02
40	5.25198734	-8.31e-01	1.44e+05	8.80e+04	-3.26e-02
41	5.40333156	-8.31e-01	1.48e+05	9.06e+04	-3.26e-02
42	5.55467543	-8.31e-01	1.52e+05	9.31e+04	-3.26e-02
43	5.70601947	-8.31e-01	1.56e+05	9.56e+04	-3.26e-02
44	5.85736366	-8.31e-01	1.60e+05	9.82e+04	-3.26e-02
45	6.00870793	-8.31e-01	1.65e+05	1.01e+05	-3.26e-02
46	6.16005227	-8.31e-01	1.69e+05	1.03e+05	-3.26e-02
47	6.31139667	-8.31e-01	1.73e+05	1.06e+05	-3.26e-02
48	6.46274111	-8.31e-01	1.77e+05	1.08e+05	-3.26e-02
49	6.61408557	-8.31e-01	1.81e+05	1.11e+05	-3.26e-02
50	6.76543005	-8.31e-01	1.85e+05	1.13e+05	-3.26e-02
51	6.91677455	-8.31e-01	1.90e+05	1.16e+05	-3.26e-02
52	7.06811908	-8.31e-01	1.94e+05	1.18e+05	-3.26e-02
53	7.21946358	-8.31e-01	1.98e+05	1.21e+05	-3.26e-02
54	7.3708081	-8.31e-01	2.02e+05	1.24e+05	-3.26e-02
55	7.52215263	-8.31e-01	2.06e+05	1.26e+05	-3.26e-02
56	7.67349716	-8.31e-01	2.10e+05	1.29e+05	-3.26e-02
57	7.82484169	-8.31e-01	2.14e+05	1.31e+05	-3.26e-02

Time	(I(t)/Cb)*V	Sum(t)	PRED1	PRED2	
58	7.97618622	-8.31e-01	2.19e+05	1.34e+05	-3.26e-02
59	8.12753076	-8.31e-01	2.23e+05	1.36e+05	-3.26e-02
60	8.27887529	-8.31e-01	2.27e+05	1.39e+05	-3.26e-02
61	8.43021983	-8.31e-01	2.31e+05	1.41e+05	-3.26e-02
62	8.58156436	-8.31e-01	2.35e+05	1.44e+05	-3.26e-02
63	8.7329089	-8.31e-01	2.39e+05	1.46e+05	-3.26e-02
64	8.88425344	-8.31e-01	2.43e+05	1.49e+05	-3.26e-02
65	9.03559797	-8.31e-01	2.48e+05	1.51e+05	-3.26e-02
66	9.18694251	-8.31e-01	2.52e+05	1.54e+05	-3.26e-02
67	9.33828705	-8.31e-01	2.56e+05	1.57e+05	-3.26e-02
68	9.48963159	-8.31e-01	2.60e+05	1.59e+05	-3.26e-02
69	9.64097613	-8.31e-01	2.64e+05	1.62e+05	-3.26e-02
70	9.79232066	-8.31e-01	2.68e+05	1.64e+05	-3.26e-02
71	9.9436652	-8.31e-01	2.72e+05	1.67e+05	-3.26e-02
72	10.0950097	-8.31e-01	2.77e+05	1.69e+05	-3.26e-02
73	10.2463543	-8.31e-01	2.81e+05	1.72e+05	-3.26e-02
74	10.3976988	-8.31e-01	2.85e+05	1.74e+05	-3.26e-02
75	10.5490434	-8.31e-01	2.89e+05	1.77e+05	-3.26e-02
76	10.7003879	-8.31e-01	2.93e+05	1.79e+05	-3.26e-02
77	10.8517324	-8.31e-01	2.97e+05	1.82e+05	-3.26e-02
78	11.003077	-8.31e-01	3.01e+05	1.84e+05	-3.26e-02
79	11.1544215	-8.31e-01	3.06e+05	1.87e+05	-3.26e-02
80	11.305766	-8.31e-01	3.10e+05	1.90e+05	-3.26e-02
81	11.4571106	-8.31e-01	3.14e+05	1.92e+05	-3.26e-02
82	11.6084551	-8.31e-01	3.18e+05	1.95e+05	-3.26e-02
83	11.7597997	-8.31e-01	3.22e+05	1.97e+05	-3.26e-02
84	11.9111442	-8.31e-01	3.26e+05	2.00e+05	-3.26e-02
85	12.0624887	-8.31e-01	3.30e+05	2.02e+05	-3.26e-02
86	12.2138333	-8.31e-01	3.35e+05	2.05e+05	-3.26e-02
87	12.3651778	-8.31e-01	3.39e+05	2.07e+05	-3.26e-02
88	12.5165223	-8.31e-01	3.43e+05	2.10e+05	-3.26e-02
89	12.6678669	-8.31e-01	3.47e+05	2.12e+05	-3.26e-02

Time	$(j(t)/C_b) \cdot V$	Sum(t)	PRED1	PRED2	
90	12.8192114	-8.31e-01	3.51e+05	2.15e+05	-3.28e-02
91	12.970556	-8.31e-01	3.55e+05	2.17e+05	-3.28e-02
92	13.1219005	-8.31e-01	3.60e+05	2.20e+05	-3.28e-02
93	13.273245	-8.31e-01	3.64e+05	2.22e+05	-3.28e-02
94	13.4245896	-8.31e-01	3.68e+05	2.25e+05	-3.28e-02
95	13.5759341	-8.31e-01	3.72e+05	2.28e+05	-3.28e-02
96	13.7272786	-8.31e-01	3.76e+05	2.30e+05	-3.28e-02
97	13.8786232	-8.31e-01	3.80e+05	2.33e+05	-3.28e-02
98	14.0299677	-8.31e-01	3.84e+05	2.35e+05	-3.28e-02
99	14.1813123	-8.31e-01	3.89e+05	2.38e+05	-3.28e-02
100	14.3326568	-8.31e-01	3.93e+05	2.40e+05	-3.28e-02
110	15.8461022	-8.31e-01	4.34e+05	2.66e+05	-3.28e-02
120	17.3595476	-8.31e-01	4.76e+05	2.91e+05	-3.28e-02
130	18.8729929	-8.31e-01	5.17e+05	3.16e+05	-3.28e-02
140	20.3864383	-8.31e-01	5.59e+05	3.42e+05	-3.28e-02
150	21.8998837	-8.31e-01	6.00e+05	3.67e+05	-3.28e-02
160	23.4133291	-8.31e-01	6.41e+05	3.92e+05	-3.28e-02
170	24.9267744	-8.31e-01	6.83e+05	4.18e+05	-3.28e-02
180	26.4402196	-8.31e-01	7.24e+05	4.43e+05	-3.28e-02
190	27.9536652	-8.31e-01	7.66e+05	4.69e+05	-3.28e-02
200	29.4671106	-8.31e-01	8.07e+05	4.94e+05	-3.28e-02

NOTE: The last column in this table are values that are included in the Sum(t) [Column 3].

APPENDIX F
CALCULATION OF FLOW RATES

Brady Pipe

small gap (2.8×10^{-3} cm)

length of thread = 4.76 cm = 0.156 ft

diameter = 2 inches

$$N = \frac{\rho g_c}{\mu} \left(\frac{g \rho \sin \alpha}{g_c} + \frac{p_1 - p_2}{L} \right)$$

$$g = 32.2 \text{ ft/sec}^2$$

$$g_c = 32.2 \text{ lb-ft/lb}_f\text{-sec}^2$$

$$\alpha = 0^\circ$$

$$\rho = 62.43 \text{ lb/ft}^3$$

$$\mu = 0.000675 \text{ lb/ft-sec}$$

$$p_1 - p_2 = 20 \text{ ft H}_2\text{O} \times \frac{2.116 \frac{\text{lb}_f}{\text{ft}^2}}{33.9 \text{ ft H}_2\text{O}} = 1248.4 \frac{\text{lb}_f}{\text{ft}^2}$$

$$L = 0.156 \text{ ft}$$

$$N = \frac{62.43 \times 32.2}{0.000675} \left(\frac{32.2 \times 62.43 \times \sin 0}{32.2} + \frac{1248.4}{0.156} \right) = 2.38 \times 10^{10} \frac{\text{lb}}{\text{ft}^2\text{-sec}}$$

$$w = \frac{ab^3N}{K}$$

$$a = 6.28 \text{ inches} = 0.52 \text{ ft}$$

$$b = 2.8 \times 10^{-3} \text{ cm} = 9.19 \times 10^{-5} \text{ ft}$$

$$a/b = 5658 > 10, \text{ therefore } K = 12$$

$$w = \frac{(0.52) (9.19 \times 10^{-5})^3 (2.38 \times 10^{10})}{12} = 8.00 \times 10^{-4} \text{ lb/sec}$$

$$8.00 \times 10^{-4} \frac{\text{lb}}{\text{sec}} \left(60 \frac{\text{sec}}{\text{min}} \right) \left(0.1198 \frac{\text{gal}}{\text{lb}} \right) = 5.75 \times 10^{-3} \frac{\text{gal}}{\text{min}}$$

Table F.1: Dimensions Used in Flow Rate Calculations and the Calculated Flow Rates for each Thread Configuration

PIPE	L (ft)	a (ft)	b (ft)	N (lb/ft ⁴ /sec)	w (lb/sec)	w (gal/min)
Brady	0.156	0.52	9.19×10^{-5}	2.38×10^{10}	8.00×10^{-4}	5.75×10^{-3}
Brady	0.156	0.52	1.80×10^{-4}	2.38×10^{10}	5.99×10^{-3}	4.31×10^{-2}
Atlantic with no o-ring	0.161	0.52	6.53×10^{-6}	2.31×10^{10}	2.79×10^{-7}	2.00×10^{-6}
Atlantic with no o-ring	0.161	0.52	2.80×10^{-5}	2.31×10^{10}	2.20×10^{-5}	1.58×10^{-4}
Atlantic with o-ring	0.161	0.52	3.58×10^{-4}	2.31×10^{10}	4.58×10^{-2}	3.29×10^{-1}
Atlantic with o-ring	0.161	0.52	5.28×10^{-4}	2.31×10^{10}	1.48×10^{-1}	1.06×10^0
Brainard-Kilman (Triloc)	0.180	0.52	3.03×10^{-6}	2.06×10^{10}	2.48×10^{-8}	1.78×10^{-7}
Brainard-Kilman (Triloc)	0.180	0.52	9.78×10^{-5}	2.06×10^{10}	8.34×10^{-4}	6.00×10^{-3}
Johnson	0.198	0.52	3.71×10^{-4}	1.88×10^{10}	4.15×10^{-2}	2.98×10^{-1}
Johnson	0.198	0.52	6.43×10^{-4}	1.88×10^{10}	2.17×10^{-1}	1.56×10^0

Table F.2: Dimensions Used in Flow Rate Calculations and the Calculated Flow Rates for the Thread Configurations Tested in the Fluorescein Baths

PIPE	L (ft)	a (ft)	b (ft)	N (lb/ft ⁴ /sec)	w (lb/sec)	W (gal/min)
Brady	0.156	0.52	1.45×10^{-4}	2.38×10^{10}	3.14×10^{-3}	2.26×10^{-2}
Atlantic with o-ring	0.161	0.52	4.30×10^{-4}	2.31×10^{10}	7.96×10^{-2}	5.72×10^{-1}
Brinard-Kilman with o-ring	0.180	0.52	3.03×10^{-6}	2.06×10^{10}	2.48×10^{-8}	1.78×10^{-7}
Brinard-Kilman without o-ring	0.180	0.52	3.90×10^{-4}	2.06×10^{10}	5.31×10^{-2}	3.82×10^{-1}

END

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