BEFORE THE PUBLIC UTILITIES COMMISSION
OF THE STATE OF SOUTH DAKOTA

IN THE MATTER OF THE APPLICATION BY TRANSCANADA KEYSTONE PIPELINE, LP FOR A PERMIT UNDER THE SOUTH DAKOTA ENERGY CONVERSION AND TRANSMISSION FACILITIES ACT TO CONSTRUCT THE KEYSTONE PIPELINE PROJECT	)))))))	HP 07-001 **REBUTTAL TESTIMONY OF HEIDI TILLQUIST**

1. State your name and occupation

A: Heidi Tillquist, Senior Project Manager and Environmental Toxicologist, ENSR, Fort Collins, CO.

2. Did you provide direct testimony in this proceeding?

A. Yes

3. In rebuttal, to whose direct testimony are you responding?

A. I am responding to the direct testimonies of Dan Hannan, Bryan Murdock, Brenda Winkler, David Wade and Jerauld Glanzer.

4. Mr. Dan Hannan, at p. 3 of his testimony, discusses drain tiles and jurisdictional ditches and indicates a need to account for these in the risk assessment. Can you comment?

A. As discussed in Jenny Hudson's testimony, transport along drain tiles has been accounted for through the proximity criteria. Section 4.3.4 of the Risk Assessment states that "*Keystone will develop and implement a risk-based integrity management program (IMP). The IMP will use state-of-the-practice technologies applied within a comprehensive risk-based* *methodology to assess and mitigate risks associated with all pipeline segments including HCAs.*" Broadly, the risk assessment process is an iterative procedure in which information is continually updated and refined in an effort to continually improve the realism and accuracy of the assessment. As Keystone collects additional information to support the risk assessment through additional engineering design work and environmental field surveys, the preliminary risk assessment and its supporting reference documents will continue to evolve. Refinements to the preliminary assessment will include site-specific information, such as the location of drain tiles and jurisdictional ditches.

Further, Appendix C of the Integrity Management Rule (49 CFR Part 195) provides guidance on factors an operator should consider in determining whether a pipeline can affect an HCA, such as drain tiles. Keystone's Integrity Management Plan will meet or exceed requirements of federal pipeline safety regulations.

5. Mr. Hannan, at page 6, indicates that downstream planning distances should be increased in the risk assessment. Can you comment?

A. As discussed in Jenny Hudson's testimony, it is acceptable for a preliminary risk assessment to use assumptions, such as the proximity criteria. Downstream proximity criteria (transport distance) selected for the preliminary risk assessment was 5 miles. This value would overestimate transport distance in intermittent streams when they are not flowing (representing the majority of type of streambeds crossed and intermittent streams flow 50 percent of the time or less), but could underestimate transport distance in flowing streams, depending on stream flow. As this assessment is refined, stream flow data and other site-specific information will be incorporated.

To comply with the Integrity Management Rule (49 CFR Part 195), Keystone is responsible for considering the specific circumstances of the pipeline in the vicinity of high consequence areas (HCAs), and determining the analytical assumptions that are appropriate. Keystone will incorporate stream flow rates and terrain to assure the analysis is reasonably conservative. PHMSA may review the technical basis for these assumptions during integrity management inspections.

6. Mr. Hannan, at page 7, indicates that consultation is required with the South Dakota Department of Game, Fish and Parks for emergency response planning. Can you comment?

A. HCAs were developed by PHMSA in cooperation with federal, state, and non-governmental organizations. Ecological HCAs (known as Unusually Sensitive Areas [USAs]) were identified utilizing the data from these information sources, including the Natural Heritage database. Further, Keystone has continually consulted with SD DGFP since September 2006 regarding sensitive species. Emergency response planning will account for response to protect ecological USAs.

7. Mr. Bryan Murdock, at page 2 of his testimony indicates that Source Water Protection Areas in South Dakota need to be identified. Can you comment?

A. Keystone has consulted with the SD DENR regarding water resources. With specific regard to source water protection areas (SWPAs), Keystone initially contacted Brian Walsh with SD DENR in February 2006 to identify SWPAs along the original alignment. More recently, Keystone requested SWPAs within one mile of the DOS-filed centerline. The following table identifies these SWPAs. Keystone's current alignment is located upgradient of these sites or at a reasonable distance, with the possible exception of the SWPA in Kingsbury County, SD. Nevertheless, this area was previously identified as a sensitive location through the HCA evaluation process, due to the location of the Town of Iroquois and the South Fork Pearl Creek, and is therefore subject to protection under the Integrity Management Rule (49 CFR Part 195). Keystone will continue to coordinate with the SD DENR.

Table 1. Summary of SWPAs within One-Mile of Keystone Centerline

County	Distance from Centerline (feet)
Marshall	2235
Marshall	3218
Clark	3068
Kingsbury	4777
Yankton	1078 (inactive)
Yankton	3569

PHMSA uses recognized organizations and data sources for mapping HCA information. PHMSA-identified HCAs include surface and groundwater USAs (sensitive water resources are also classified as USAs) and ecologically sensitive USAs in SD. If previously unidentified HCAs are identified by Keystone through the consultation process with SD DENR or other agencies, Keystone will incorporate any new HCAs within one year of their identification as required by federal regulations (i.e., 49 CFR Part 195.452 (d) (3)).

8. Mr. Murdock also indicates at page 3 that Keystone has not fully mitigated for sensitive species. Is that the case?

A. Keystone has been in continuous consultation with SD DGFP since September 2006. Consultation for sensitive species under Section 7 is coordinated with the USFWS. A draft Biological Assessment (BA) that includes proposed mitigation for sensitive species was submitted to the USFWS. The USFWS has provided comments on the BA, the final BA will be submitted to the USFWS in early December 2007, and Section 7 consultation is expected to be completed by mid-December 2007.

9. Mr. Murdock also discusses the drain tile and jurisdictional ditches with respect to risk assessment. Is the answer the same as it was for Mr. Hannan?

A. Yes.

10. Mr. Murdock raises the issue of field verification of topography. Will Keystone perform field verification of HCAs?

A. Yes. Each HCA will be specifically reviewed, including field (on foot) verification, to ensure the adequacy of the IMP. To comply with the Integrity Management Rule (49 CFR Part 195), Keystone is responsible for considering the specific circumstances of their pipeline in the vicinity of HCAs and determining the analytical assumptions that are appropriate. Keystone will incorporate stream flow rates and terrain to assure the analysis is reasonably conservative. PHMSA may review the technical basis for these assumptions during integrity management inspections.

11. Mr. Murdock at page 4 also raises the issue of increasing the distance in downstream transport distance for the risk assessment. Is the answer the same as for Mr. Hannan in his testimony?

A. Yes.

12. Mr. David Wade, Manager of the BDM Rural Water System indicates that he's concerned about the Middle James Aquifer and recharge in the specific region where Keystone will cross it. Can you comment?

A. Yes. As Mr. Wade states, the area in northwestern Marshall County through which the anticipated ROW will pass does serve as a recharge area for the James Aquifer. ENSR reviewed the South Dakota Geological Survey report for Marshall County, Bulletin 23, 1975. The report provides maps and cross-sections that indicate the general direction of groundwater flow in the area, and the general lithology underlying the anticipated ROW.

One lens of the James Aquifer, located 5 or 6 miles further east of the anticipated ROW, appears to be hydraulically connected to permeable surficial fine sands that occur in the ROW area itself at the very northern border of the county. However, groundwater movement there generally heads northeastward away from the BDM water supply locale (which is to the southeast). Consequently, if a spill from the Keystone Pipeline occurred and it penetrated to groundwater prior to containment and cleanup, any contamination would move away from and not toward the BDM water supply area.

The James Aquifer is generally confined under 50 to 100 feet of clay or till along the ROW through Marshall County. Except for a couple of miles of the centerline that are located further south of the county line, the remainder of the ROW crosses clay or till, through Marshall county. Consequently, groundwater contamination of the James Aquifer is unlikely due to the depth of the aquifer and due to the presence of confining layers.

Based on the location of the ROW with respect to the James Aquifer and water supply withdrawals for the BDM Rural Water District, impacts on BDM water supplies from the Keystone Pipeline are unlikely.

13. Mr. Wade is also concerned about Keystone crossing BDM's utility system, and specifically the effects of a crude oil spill on the BDM system's PVC (polyvinylchloride) pipes. Can you comment on his concerns?

A. Yes. According to the American Water Works Association (AWWA) paper (Gaunt et al. 2006), attached to my rebuttal testimony, permeation incidents on PVC pipes are rare and no permeation incidents were reported with ductile iron, regardless of the type of gasket used. PVC pipe is highly resistant to gasoline, benzene, and toluene and their water solutions. The study states "Laboratory results indicate that PVC and ductile iron pipes can be safely used in areas of soil contamination regardless of the level of contamination."

PVC is highly resistant to permeation by benzene, toluene, and other compounds in all but the most extreme conditions of contamination. The American Water Works Association Research Foundation (AWWARF) has recently completed a report on the impacts of hydrocarbons on PVC pipes and pipe gaskets (AWWARF 2007: Website: www.awwarf.org/research/topicsandprojects/execSum/2946.aspx). The research found that "*PVC itself is impervious to gasoline, BTEX, and trichloroethylene (TCE) in groundwater at commonly encountered levels of contamination*". The concentration of BTEX in gasoline is not high enough to cause swelling of PVC pipe since the total concentration of BTEX has to exceed

40% to initiate a "moving front" in PVC (moving fronts are discussed in the paper). Since the concentration of BTEX in crude oil is less than one percent and is significantly less than BTEX in gasoline, PVC pipes would be impervious to crude oil contamination.

AWWARF also examined the impacts of hydrocarbons on water main gaskets. The report states " *PVC or ductile Iron (DI) mains with styrene-butadiene-rubber (SBR) gaskets and minimal average flow can be used in any level of gasoline contamination without exceeding BTEX MCLs* [maximum contaminant levels—drinking water standards]." Further the AWWARF report states that "*Laboratory results and utility experiences showed that the common practice of specifying DI mains with nitrile rubber (NBR) or fluoroelastomer rubber (FKM) gaskets in contaminated areas is generally unnecessary. SBR gaskets are satisfactory*". Again, since the BTEX concentrations in crude oil are significantly lower than in gasoline, there is no expectation that special gaskets are necessary to prevent contamination.

In summary, impacts from Keystone on outlying water supply pipelines are not anticipated, even if a spill near the water mains were to occur. Consequently, there is no reason to support the mitigation methods or associated costs that Mr. Wade recommends.

14. Ms. Brenda Winkler, at page 2, indicates that additional measures should be undertaken to assess the thickness of geologically sensitive areas and confirm the thickness of overburden and bedrock thickness along the ROW. Can you comment?

A. The information submitted for the DEIS clearly indicates that the entire anticipated ROW through South Dakota is within a glaciated province. Exposures of Niobrara Formation fissures, although they might occur in other parts of South Dakota or in other states, are highly unlikely along the ROW. For example, while the Niobrara Formation does occur in the counties mentioned, it is typically a confined aquifer in areas under or near the pipeline. As such, it is restricted from the surface by one or more relatively impermeable layers. To clarify, the reviewers should note that the literature cited for the occurrence of "karst features" is national in scope. Therefore, the interpretation of what constitutes a karst feature in that source is quite broad, and basically includes any carbonate rock at the surface or at depth. Along most of the ROW through South Dakota, the Niobrara Formation is buried under restrictive glacial till deposits, and/or restrictive shale beds of the Pierre Formation. It generally consists of marl, chalk, or calcareous shales. This is not the typical karstic terrain that geologists are often concerned with. Further, while the Niobrara Formation is multi-state in extent, its setting along the proposed route is generally deep and isolated from the proposed pipeline.

15. Mr. Jerauld Glanzer in his direct testimony discusses Wolf Creek with regard to the Keystone oil spill response plans. Can you comment?

A. The Wolf Creek drainage is considered a sensitive surface water resource. As such, segments of the Keystone Pipeline that have the potential to affect Wolf Creek if a release were to occur are subject to the Integrity Management Rule (49 CFR Part 195). Thus, risk to the Wolf Creek drainage is mitigated by increased regulatory requirements.

16. Does this conclude your rebuttal testimony?

A. Yes it does.

Dated this 14th day of November, 2007.

HEIDI TILLQUIST

Research - Topics And Projects

Impact of Hydrocarbons on PE/PVC Pipes and Pipe Gaskets [Project #2946]

Ordering Information:
ORDER NUMBER: 91204
DATE AVAILABLE: Fall 2007

Printed Report		PDF
Subscribers	Order Report	N/A
Non-Subscriber	N/A	N/A

PRINCIPAL INVESTIGATORS:
Say Kee Ong, James A. Gaunt, Feng Mao, Chu-Lin Cheng, Lidia Esteve-Agelet, and Charles R. Hurburgh

OBJECTIVES:
The objective of this project was to study the impact of hydrocarbons on polyethylene (PE) and polyvinyl chloride (PVC) pipes and elastomeric gaskets. Specific tasks were to (1) survey water utilities to learn about their experiences with plastic pipes and permeation of mains and services, (2) study permeation through PE and PVC pipes exposed to hydrocarbon contamination, (3) develop laboratory tests to predict permeation of pipes and gaskets, and (4) study permeation through pipe gaskets exposed to hydrocarbons.

BACKGROUND:
Some of the factors for the increased use of plastic pipes in water distribution systems are their ease of installation and handling, durability, and good resistance to the chemicals used in water treatment, such as chlorine. In many urban areas, plastic pipes may come into contact with contaminated soils as a result of leaks from underground storage tanks, chemical spills, and improper disposal of used chemicals. These pollutants from leaking storage tanks and contaminated soils can and have posed serious threats to the longevity and structural integrity of plastic pipes and elastomeric gaskets which, in turn, can affect the water quality in the distribution system. Although there are research studies and case studies documenting the permeation of organic compounds through plastic pipes and elastomeric gaskets, there is still a lack of understanding of the performance of PE and PVC pipe materials and elastomeric gaskets in hydrocarbon-contaminated soils commonly encountered under field conditions.

HIGHLIGHTS:
Either PVC or ductile iron (DI) water mains can be safely used in any level of gasoline contamination, even free product, as long as there is a minimal average water flow in the mains. Although benzene, toluene, ethylbenzene, and xylenes (BTEX) will permeate the gaskets, USEPA MCLs will not be exceeded. Similarly, PVC and DI pipes can be used with periods of stagnation (i.e., service connections) for any level of groundwater contamination by gasoline. PVC itself is impervious to gasoline, BTEX, and trichloroethylene (TCE) in

groundwater at commonly encountered levels of contamination.

APPROACH:
The research team surveyed utilities by mail and telephone to obtain information about their use of plastic pipes and experiences with permeation incidents and successful uses in known hydrocarbon-contaminated areas. Case histories with relevant laboratory data were developed. Permeation of PE and PVC pipes exposed to soil and water contamination was studied in pipe-bottle apparatuses. Novel pipe-drum apparatuses were used to study permeation of gasketed pipe-joints. New laboratory tests were developed to measure and predict permeation through PVC pipe. The moving front test was used in studies that revised and extended the understanding of the theory of permeation in PVC pipes, the thresholds of environmental contamination that might impact engineering decisions, and the impact of combinations of BTEX compounds on PVC pipe.

RESULTS/FINDINGS:

Surveys and Case Histories
One permeation incident per 14,000 miles of mains and 0.9 incidents per million service connections were reported by 151 utilities. The most common contaminant was gasoline. Laboratory data were not sufficient for conclusions regarding contamination thresholds upon which engineering decisions could be based.

PVC Pipe
PVC pipe material is impervious to gasoline because there is not enough BTEX in gasoline to swell PVC and cause permeation. Spills of benzene, toluene, or TCE permeate PVC pipe by direct contact with solvent or groundwater concentrations with greater than 60 percent of maximum solubility.

PE Pipe
Utilities should replace PE service connections immediately in case of hydrocarbon spills. MCLs are quickly exceeded before odor is detectable. Flow may dilute contamination in mains below MCLs.

Gasketed Pipe
PVC or DI mains with styrene-butadiene-rubber (SBR) gaskets and minimal average flow can be used in any level of gasoline contamination without exceeding BTEX MCLs. SBR gaskets can be used for 8 hour stagnation in gasoline-saturated groundwater. Utilities should use DI with NBR for stagnation in free product gasoline.

Predictive Tests (PVC)
The moving front test directly visualizes permeation progress using reflected light microscopy and can quantify differences in relative permeability. Sorption and near infrared tests are indirect measures of permeability.

IMPACT:
Laboratory results and utility experiences showed that the common practice of specifying DI mains with nitrile rubber (NBR) or fluoroelastomer rubber (FKM) gaskets in contaminated areas is generally unnecessary. SBR gaskets are satisfactory and engineering considerations other than permeation should usually govern pipe material selection. PVC pipe is suitable for all but the most unusual contamination conditions. There is no safe level of hydrocarbon contamination for PE service connections.

Longstanding recommendations and practices for use of plastic pipe and gaskets in hydrocarbon contamination have been shown to be unnecessarily conservative. New recommendations and theoretical understandings should reduce unnecessary costs to the industry.

PARTICIPANTS:

- City of Ames, Iowa
- EPCOR Water Services, Edmonton, Alta., Canada
- Griffin Pipe, Council Bluffs, Iowa
- Hultec S&B Technical Products, Fort Worth, Texas
- Uni-Bell PVC Pipe Association, Dallas, Texas

Performance of Plastic Pipes and Pipe Gaskets In Hydrocarbon Contamination: Field Experience and Laboratory Studies

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Abstract

Water utilities were surveyed and laboratory studies were undertaken to determine the limits of hydrocarbon contamination in which polyvinyl chloride (PVC) and polyethylene (PE) pipes and various types of pipe gaskets can be used successfully, without customer complaints or laboratory data exceeding U.S. EPA MCLs. Permeation incidents were reported at a frequency of one per 14,000 miles of mains and one per 1,000,000 PE/PVC service connections. Successful use of water mains in contaminated areas was reported at a frequency of one per 1,800 miles of mains and one per 2,500,000 plastic service connections. Gasoline was the most frequently reported contaminant. Laboratory studies showed that PVC pipe is highly resistant to gasoline and water saturated with gasoline. PVC pipe is also resistant to water solutions of benzene, toluene, and TCE but the most extreme levels of environmental contamination. The rate of progress of the moving front in PVC pipes exposed to pure benzene, toluene, and TCE is a function of the square root of time, whereas it is linear with time for aqueous solutions of those solvents. A method is described for predicting the resistance of PVC pipe to permeation based on visualization of the progress of the moving front during the first 24 hours of exposure to a contaminant.

Water Utility Experiences

Methods

A postal survey was used to obtain information from water utilities in the United States and Canada regarding their experiences with the performance of polyvinyl chloride (PVC) and polyethylene (PE) pipes and various types of pipe gaskets in soils contaminated with petroleum-based hydrocarbons. The four-page survey requested contact information, information about mains and service connections in the distribution system, and information about permeation incidents and successful uses in contaminated soils. Extensive follow up by telephone was required to obtain responses that were broadly distributed geographically and by utility size.

A permeation incident was defined as an occurrence that resulted in customer complaints of bad taste, odor, or illness or of laboratory data exceeding U.S. EPA MCLs, any of which could be attributed to permeation of water mains or services by hydrocarbons. A successful use was defined as an occurrence in which water mains or services were known to be in contact with hydrocarbon contamination without resulting in a permeation incident.

Results and Discussion

Survey Response

Survey responses were received from 151 water utilities in 50 U.S. states, three Canadian provinces, and the District of Columbia. The location and relative size of the responding U.S. utilities are presented in Figures 1 and 2. Five Canadian utilities responded, including utilities from the provinces of Alberta, Manitoba, and Saskatchewan. Because a water utility's risk of a permeation incident depends on both the miles of mains and the number of service connections (SCs), the relative size of utilities was classified in Figures 1 and 2 according the product (miles x SCs) of those numbers.

Mains

The 151 utilities responding to the survey reported 83,360 miles of mains, and 70% of these reported having at least some plastic mains. PVC and ductile iron (DI) pipes accounted for 18% and 16% of miles of mains reported, respectively (Figure 3). PE accounted for only 0.18% of miles of mains reported. Respondents considered only 0.54% of mains to be at risk of permeation.

Reports of permeation of water mains were rare, approximately 1 report per 14,000 mi. of mains. Of the 6 reported permeation incidents, 3 involved gasoline, 1 involved chlorinated solvents, and 2 involved unknowns. The pipe materials involved in permeation incidents were PVC (4), asbestos cement (AC) (1), and cast iron (CI) (1) (Figure 4).

Reports of successful uses were infrequent, about 1 report per 1,800 mi. of mains. Nearly all successful uses involved gasoline or chlorinated solvents. Isolated cases involving diesel fuel, polynuclear aromatics, and acetone were also reported. The pipe materials involved in successful uses were DI (32), PVC (9), CI (5), and steel (1) (Figure 4).

Protocols for use of mains in contaminated soils were reported by 19% of responding utilities (Figure 5). Use of DI with resistant gaskets (either NBR of FKM) was the most commonly reported protocol (10), followed by use of DI with no comment regarding gaskets (8), use of "no plastic" (4),and steel (2). Other protocols were reported by 4 utilities, including casing, "double wrapping", and "specifying alternate materials." Utilities specifying "no plastic" presumably use DI.

Service Connections (SCs)

The 151 utilities responding to the survey reported 5,444,218 SCs, and 49% of these reported allowing plastic SCs. PE and PVC pipe accounted for 6% and 5% of reported service connections, respectively (Figure 6). Respondents considered only 0.31% of SCs to be at risk of permeation.

Reports of permeation of PVC or PE SCs were rare, about 0.9 reports per million total SCs (Figure 7). Reports of permeation of all types of SCs were about 8 reports per million SCs. Of the 44 reported permeation incidents, 36 involved permeation of polybutylene (PB) by gasoline. The permeation incidents involving PE (3) and PVC (2) SCs involved gasoline. There were 2 reports of permeation of DI/SBR SCs by chlorinated solvents. There was one report of permeation of an EPDM gasket on a copper SC by asphalt solvents which had entered the curb box. No reports of permeation of SCs due to use of termiticides were received. In all cases, the corrective action for permeation of plastic service lines was replacement with copper.

Reports of successful uses of plastic SCs were very rare, about 0.4 reports per million total SCs (excluding the large number of reports involving copper SCs) (Figure 7). There were 2 reports of successful uses involving plastic pipe, one each involving PE and PB pipe. While DI accounted for only 0.11% of reported service connections, there were 13 reports of successful uses of DI SCs in contaminated soils. Similar to mains, utilities favor the use if DI pipe, often with FKM gaskets, for large services in hydrocarbon-contaminated areas.

Quantitative Data

Of 25 utilities reporting incidents or successful uses, 10 had laboratory data relating to 18 cases. Table 1 shows the availability of laboratory data for permeation incidents and successful uses involving mains and services, and for the three sample matrixes: soil, ground water, and potable water.

Table 2 anonymously presents all analytical data reported by utilities, indicating the sample matrix and the pipe and gasket materials involved. Utilities are identified only by relative size (Figure 2) and the US E.P.A. regions in which they are located. The reference numbers were assigned arbitrarily and serve to group data from individual occurrences.

Table 1. Laboratory Data Associated With Successful Uses Of Mains

Materials[1]	Highest Reported Concentrations In Ground Water
SBR Gaskets w/DI or CI Pipe[2]	15.4 mg/L PCE, 0.30 mg/L total BTEX, 25.8 μg/L benzene
DI/SBR Service Line	14 μg/L VOC[3], 25.8 μg/L benzene
PVC/FKM	1.5 mg/L total chlorinated (Sum of: 0.952 mg/L PCE, 0.133 mg/L TCE, 0.386 mg/L c-DCE, 0.034 mg/L VC)
DI/FKM Service Lines	0.30 mg/L total BTEX, 25.8 μg/L benzene, 0.715 mg/L total VOC[3]

1. Uses are for mains, except where noted. 2. Soil PCE, 3.6 mg/Kg.
3. Contaminants were unspecified chlorinated solvents.

Table 2. Laboratory Data Associated With Permeation Of Service Connections

Materials	Soil	Ground Water
SBR Gaskets w/DI or CI Pipe	0.036 - 3.6 mg/Kg PCE	0.90 - 15.4 mg/L PCE 0.17 - 0.30 mg/L total BTEX 25.8 μg/L benzene
PE Pipe	7.7 mg/Kg total BTEX 24 mg/Kg TPH	57.7 mg/L total BTEX 45 mg/L TPH

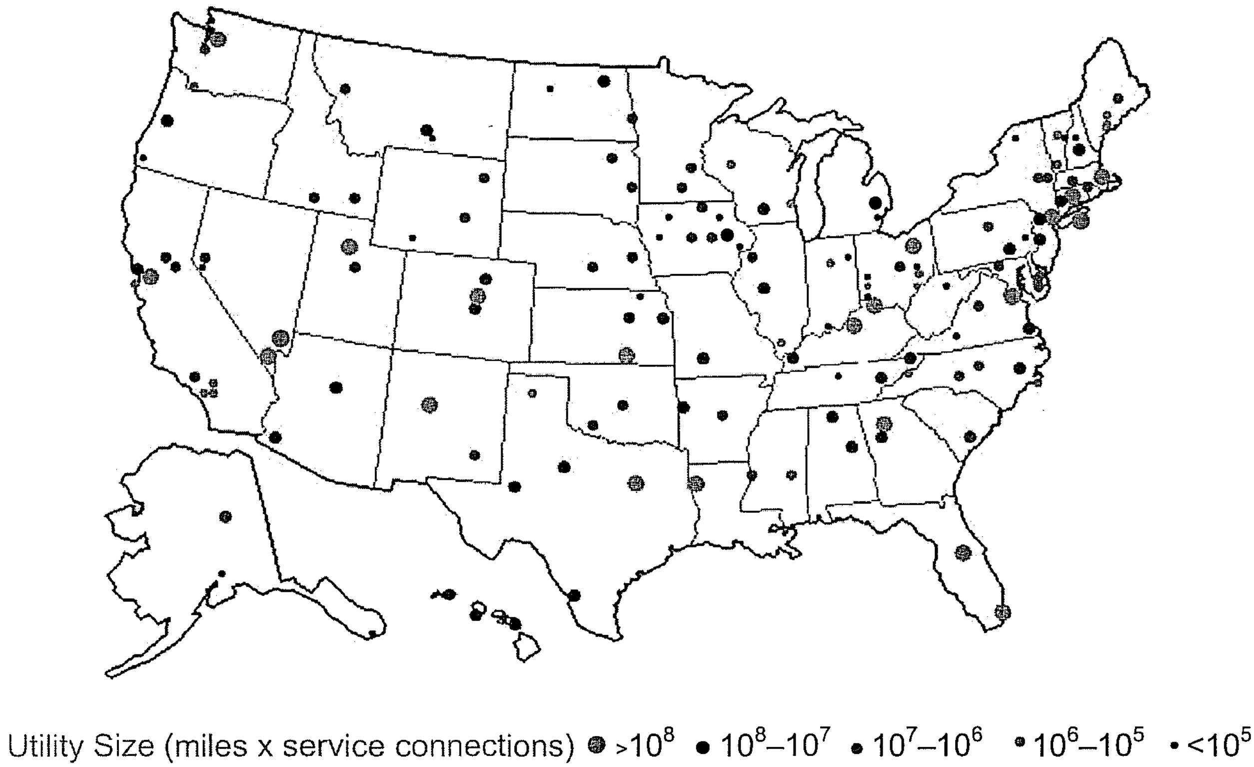

Figure 1. Geographical distribution of the responding utilities

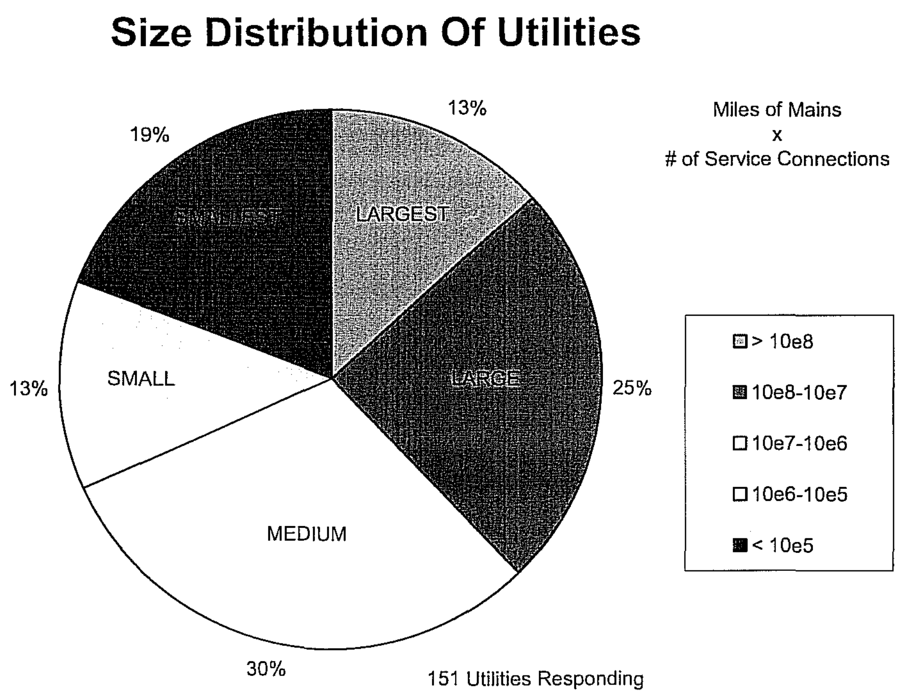

Figure 2. Relative size distribution of the responding utilities

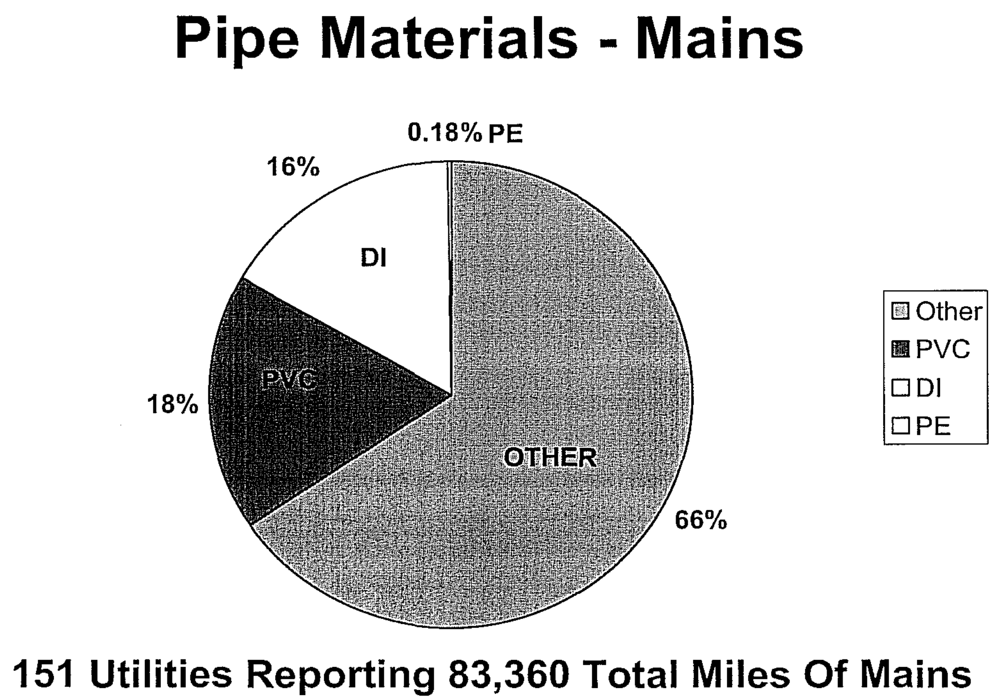

Figure 3 Pipe Materials Reported for Mains

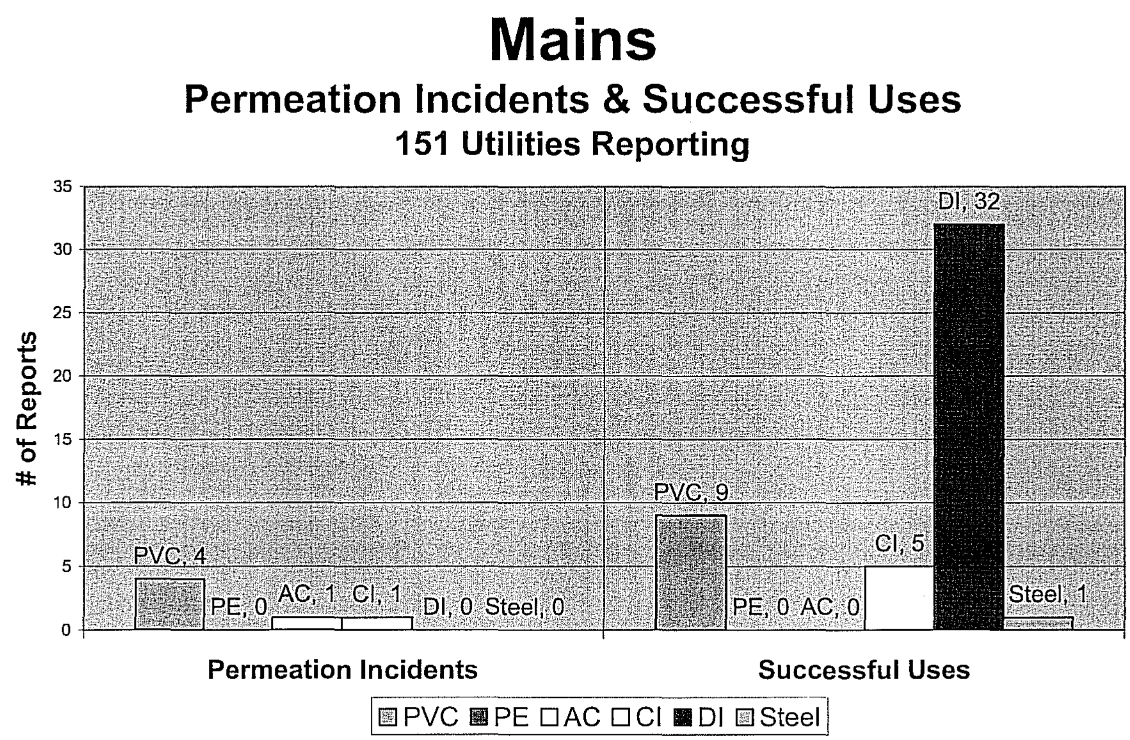

Figure 4 Permeation Incidents and Successful Uses Involving Mains

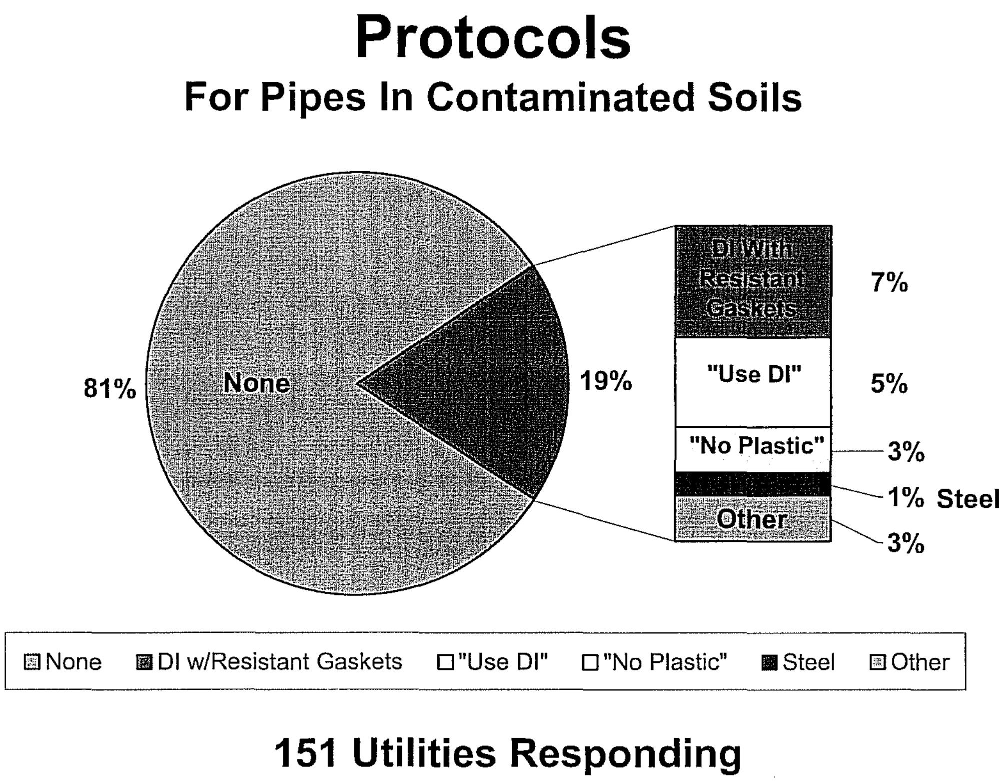

Figure 5. Protocols For Use Of Mains In Contaminated Soils

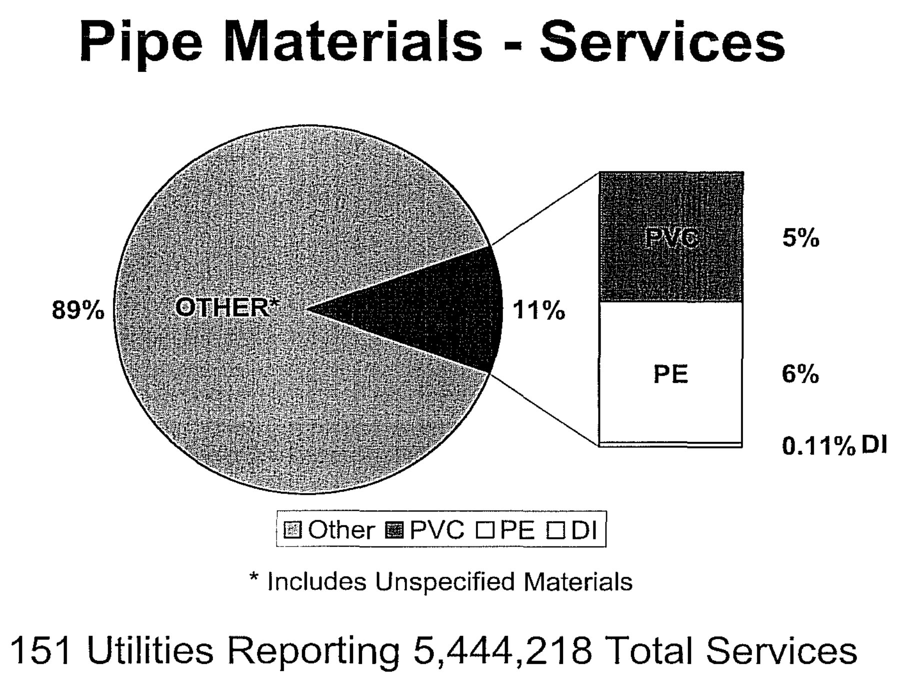

Figure 6. Pipe Materials Reported For Service Connections

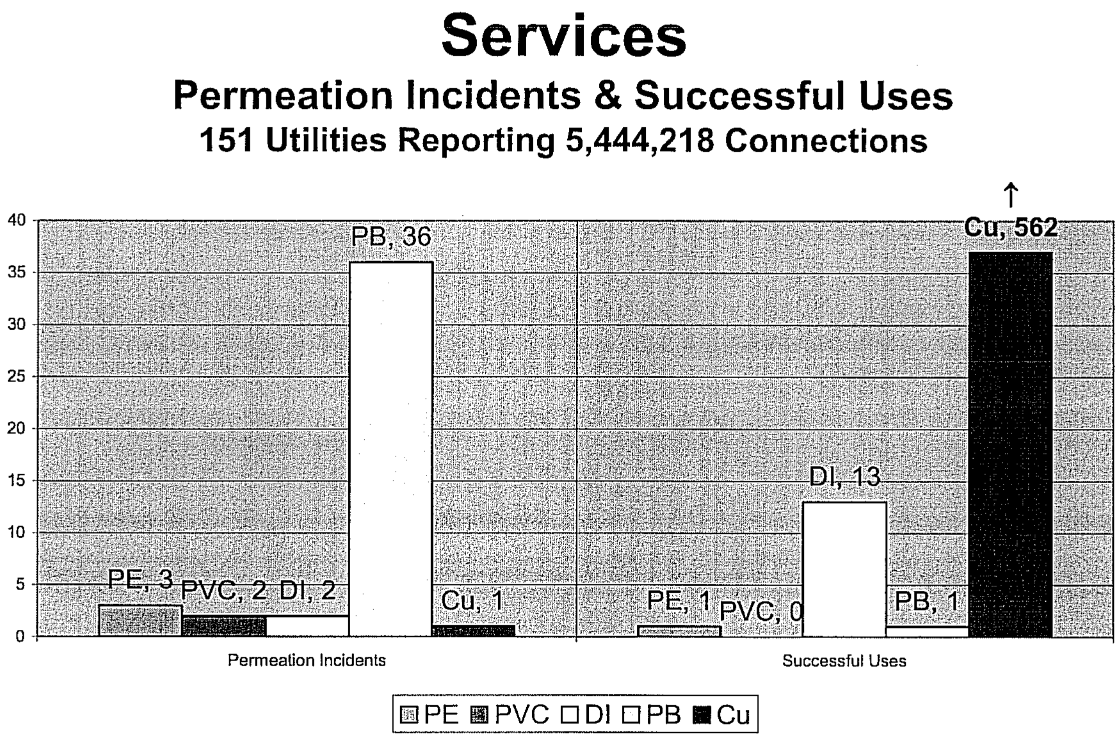

Figure 7 Permeation Incidents and Successful Uses Involving Service Connections

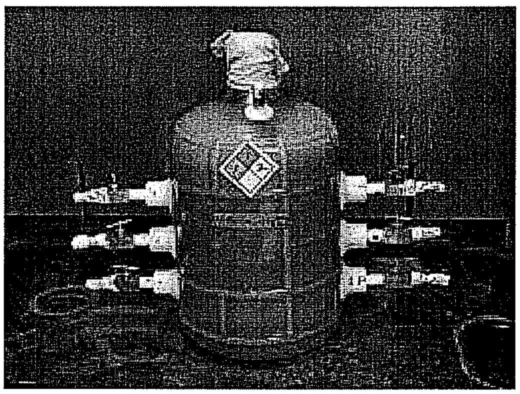

Figure 8 Pipe-Bottle Apparatus

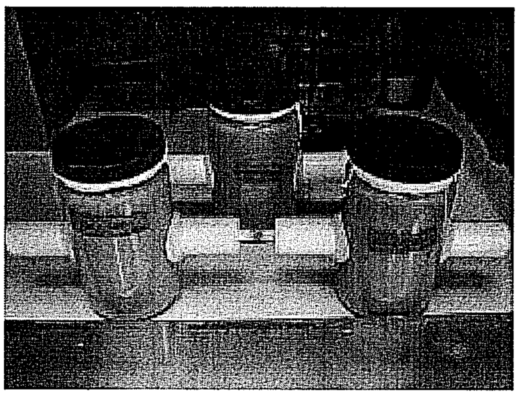

Figure 9 Mini Pipe-Bottle Apparatus

PVC Pipes - Laboratory Studies

Methods

Simulated Environmental Studies

PCV pipes were tested using pipe-bottle apparatuses (Figure 8) consisting of 10 L glass bottles and 1 in. PVC pipes mounted horizontally through holes drilled in the glass and sealed with epoxy putty. The pipe ends were sealed with PTFE plugs equipped with brass fittings and needle valves for filling and draining the pipes. Similar apparatuses were first used by Vonk (1985). Smaller versions of this apparatus using 1 L glass jars with PTFE-lined caps were also used (Figure 9). The pipes were filled with deionized water which was periodically drained for analysis and replaced, using air pressure for the 10 L apparatus and a syringe for the 1 L apparatus. The contamination medium was placed in the bottles so as to surround the pipes being tested.

Benzene, toluene, ethylbenzene, o-xylene, m-xylene, and p-xylene (BTEX) and trichloroethylene (TCE) were determined by purge-and-trap gas chromatography using a photoionization detector (PID).

Moving Front Test

Specimens of pipe were cut to a length of 1 cm with a miter saw and then immersed in 50 mL of the test solvent in a glass jar with a Teflon-lined lid. At various times, the specimens were removed from the solvents, wiped dry with paper towels, and examined using reflected light microscopy. The regions of the test specimens that had been swollen, or rubberized, by the organic solvents appeared darker than the un-swollen portions. The thicknesses of the swollen and un-swollen regions were measured by using the calibrated reticule of the eyepiece of the microscope.

Sorption test

Specimens of pipe were cut to a length of 1 cm with a miter saw. The specimens were washed with detergent, rinsed with tap water and distilled water, placed on a paper towel to air dry, and weighed using an analytical balance. The volume was determined gravimetrically by a water displacement method using an overflow can. Specimens were immersed in 50 mL of the test solvent in a glass jar with a Teflon-lined lid. At various times, the specimens were removed from the solvents, placed on paper towels, wiped, and allowed to air dry for thirty seconds before weighing. In all steps, the specimens were handled with stainless steel forceps. Pipe specimens were considered to have reached equilibrium absorption when three consecutive weighings differed by no more than 20 mg.

Results and Discussion

PVC Pipes Exposed To Gasoline

PVC pipes were exposed in pipe-bottle apparatuses to premium gasoline and deionized water saturated with gasoline. No permeation of BTEX compounds was detected during the first 10 months of exposure in these continuing experiments.

PVC Pipes Exposed To Pure Solvents

Significant permeation through PVC pipes in pipe-bottle apparatuses occurred within 6.5 days of exposure to pure TCE and within 16 days of exposure to pure toluene (Figure 10). Upon breakthrough, permeation occurred at a constant rate. No permeation was detected during the first 4.5 months of exposure to saturated aqueous solutions of benzene, toluene, and TCE in these continuing experiments. However, the moving front tests discussed below predict that permeation will occur in several months.

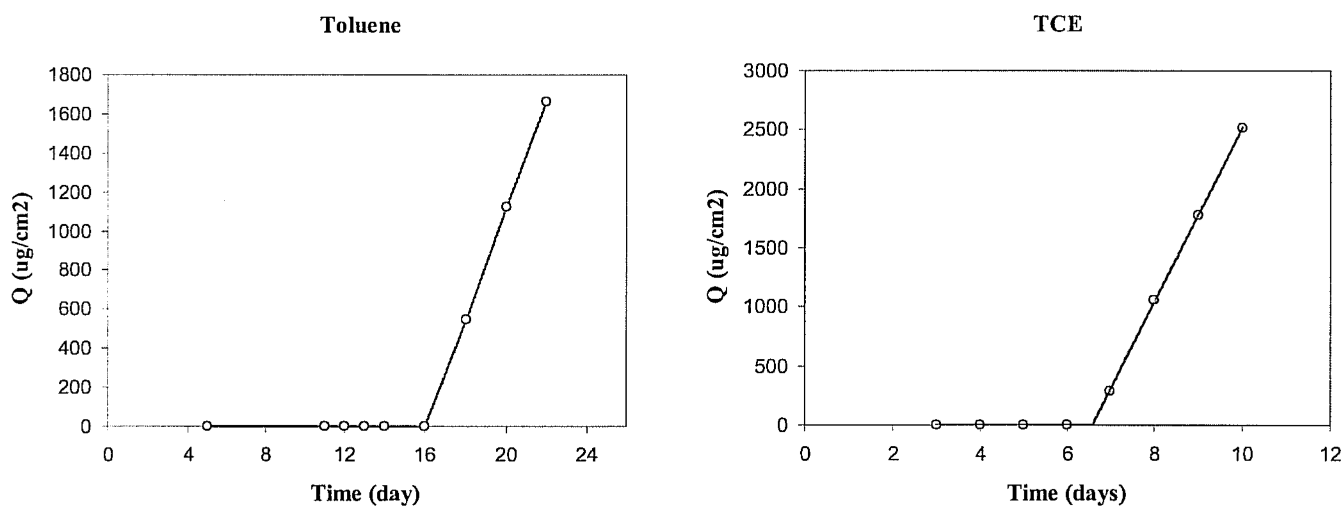

Figure 10 Cumulative Permeation Fluxes of Toluene and TCE in 1 In. PVC Pipe Exposed to Pure Toluene and TCE Solvent

Moving Front Test

(a) Pure toluene and TCE

The objective of the experiments using pure solvents was to investigate the relationship between the advancement of the moving front in the pipe material and the permeation breakthrough time obtained in the environmental simulations. For this purpose, 3.5 cm lengths of 1-inch PVC pipe were cut and the pipe ends were sealed with glass slides using a chemically resistant Epoxy, enclosing deionized water in the pipe. The pipe specimens were then immersed into pure solvent and periodically sacrificed to measure the progress of the moving front from the outside to the inside of the pipe.

Three parameters were measured in this experiment: the original pipe thickness (L_0), the thickness of the swollen layer at time t ($L_{s,t}$), and the thickness of the remaining glassy material (the distance from the sharp boundary to the inner wall, $L_{g,t}$) (Figure 11). The penetration distance at time t is then calculated by:

$$\text{penetration distance } (PD_t) = L_0 - L_{g,t}$$

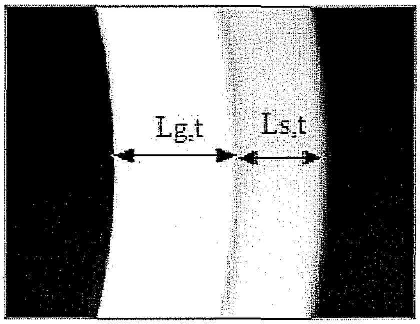

Figure 11 Definition of Lg,t and Ls,t

In pure solvents, a sharp boundary (moving front), separating the inner glassy core from the outer swollen layer, is distinctly observable as the solvents advance into the pipe. This offers an opportunity to carry out a dynamic observation of the progress of the moving front with time. Figure 12 shows the advancement of the moving front in 1 in. PVC pipe exposed to pure toluene. The moving front reached the inner wall on the 16^{th} day, the day when the breakthrough of toluene was detected in the environmental simulation test (Figure 10). The results indicated that no detectable permeation occurred until the moving front reached the inner wall of the PVC pipe. To the authors' knowledge, this is the first experimental study directly demonstrating the non-Fickian diffusion mechanism in PVC pipe.

The thickness of the outer swollen layer ($L_{s,t}$), and the thickness of the remaining glass core ($L_{g,t}$) were measured with time. The penetration distance (PD_t) with time was calculated based the difference between the original wall thickness and $L_{g,t.}$ Figure 13 shows the $L_{s,t}$ and PD_t obtained in pure toluene experiments.

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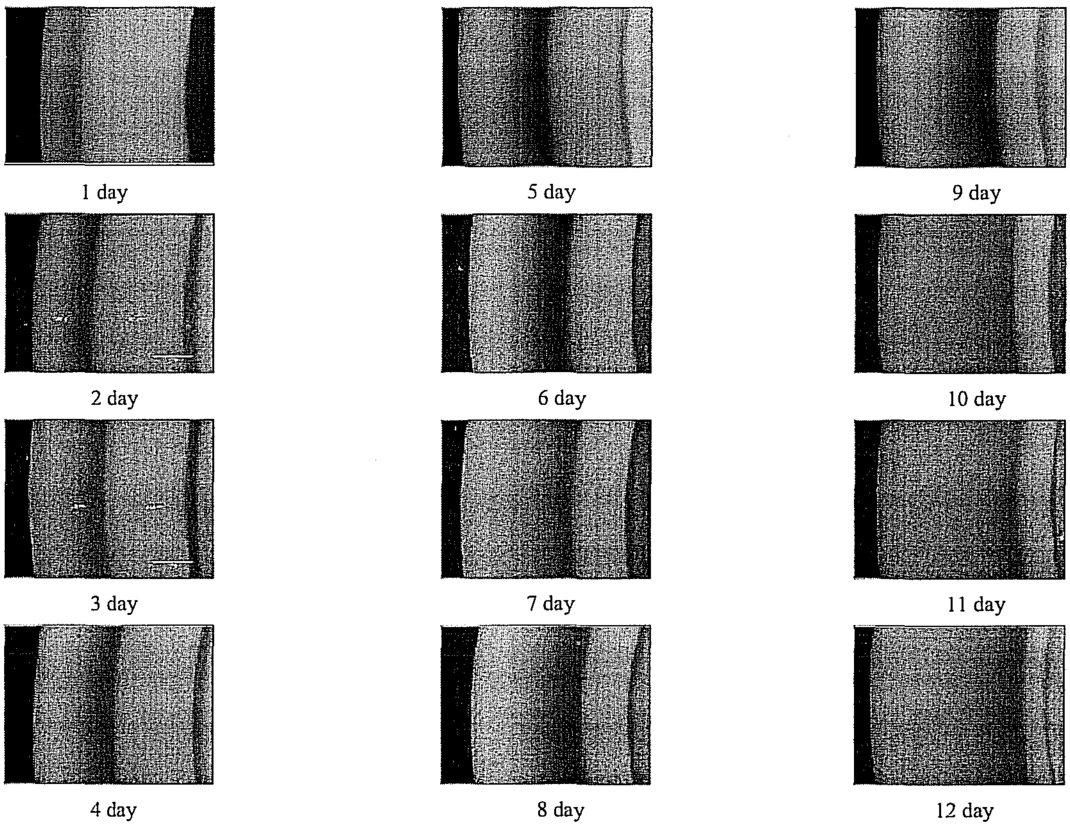

Figure 12 Advancement of Moving Front with Time in 1-inch PVC Pipe Exposed to Pure Toluene (right line: boundary of inner wall; mid line: moving front; left line: boundary of swollen outer wall.)

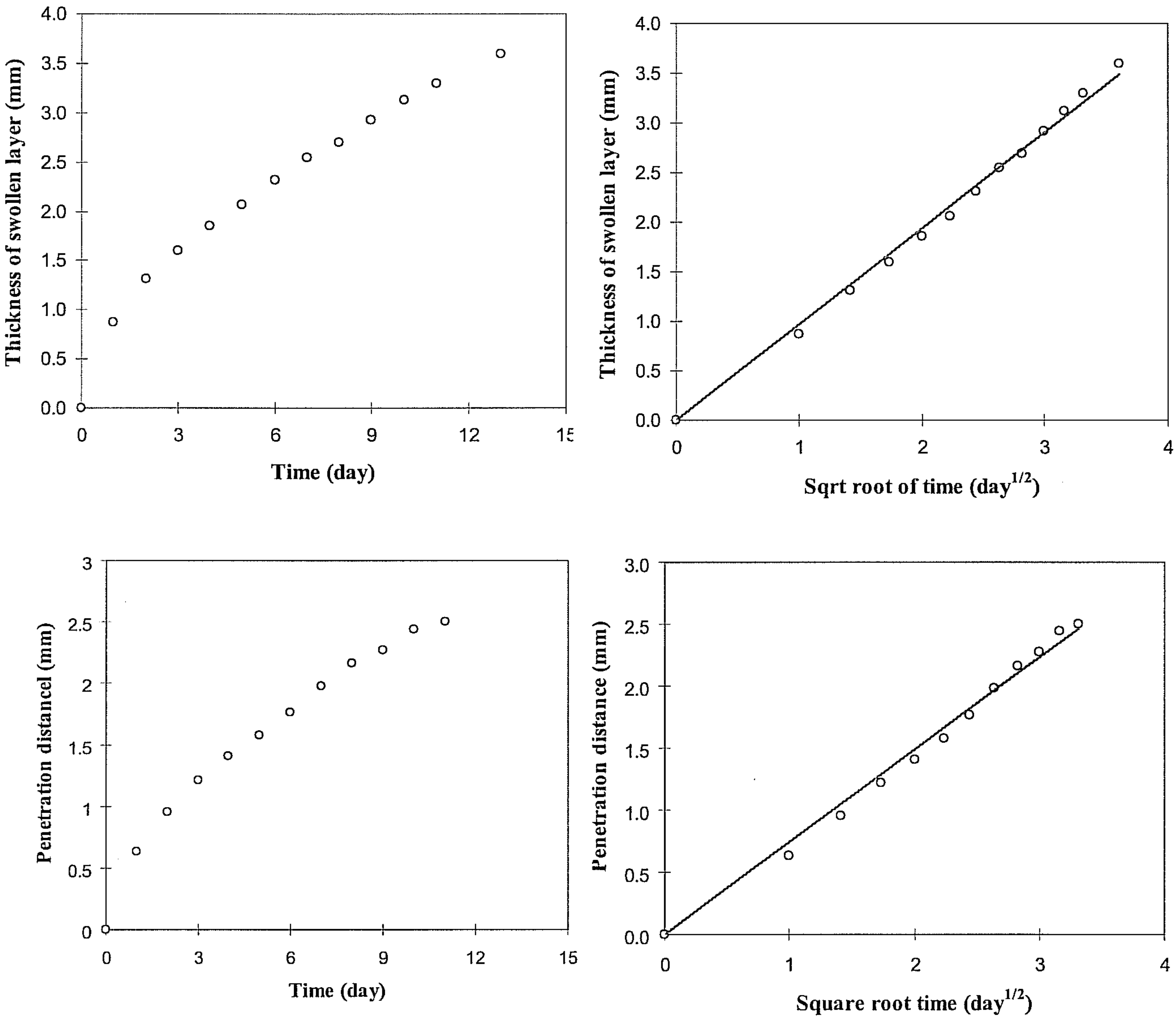

Figure 13 PVC Pipe Swollen Layer's Thickness and Penetration Distance with Time
(1 in. pipe exposed to pure toluene)

As shown in Figure 13, strong swelling and rapid advancement of the moving front occurred initially. Plots of the results of both sets of data were linearly dependent on the square root of time. The observations seemed to deviate from case (II) diffusion, which is characterized by a constant penetration rate and has been assumed to be the dominant mechanism for permeation through PVC pipe (Berens 1985, Vonk 1985). However, it should be noted that most of experimental observations of case II diffusion in PVC were made using thin film specimens pressed from pure powders, not manufactured PVC pipe.

The dependence of the penetration distance on the square root of time may help to predict the breakthrough time for the permeation of organic solvents in PVC pipe. To demonstrate this, a 24 hr moving front test was conducted using 1 in. PVC pipe exposed to pure TCE solvent. Figure 14 shows the advance of the moving front and the penetration distance vs. time.

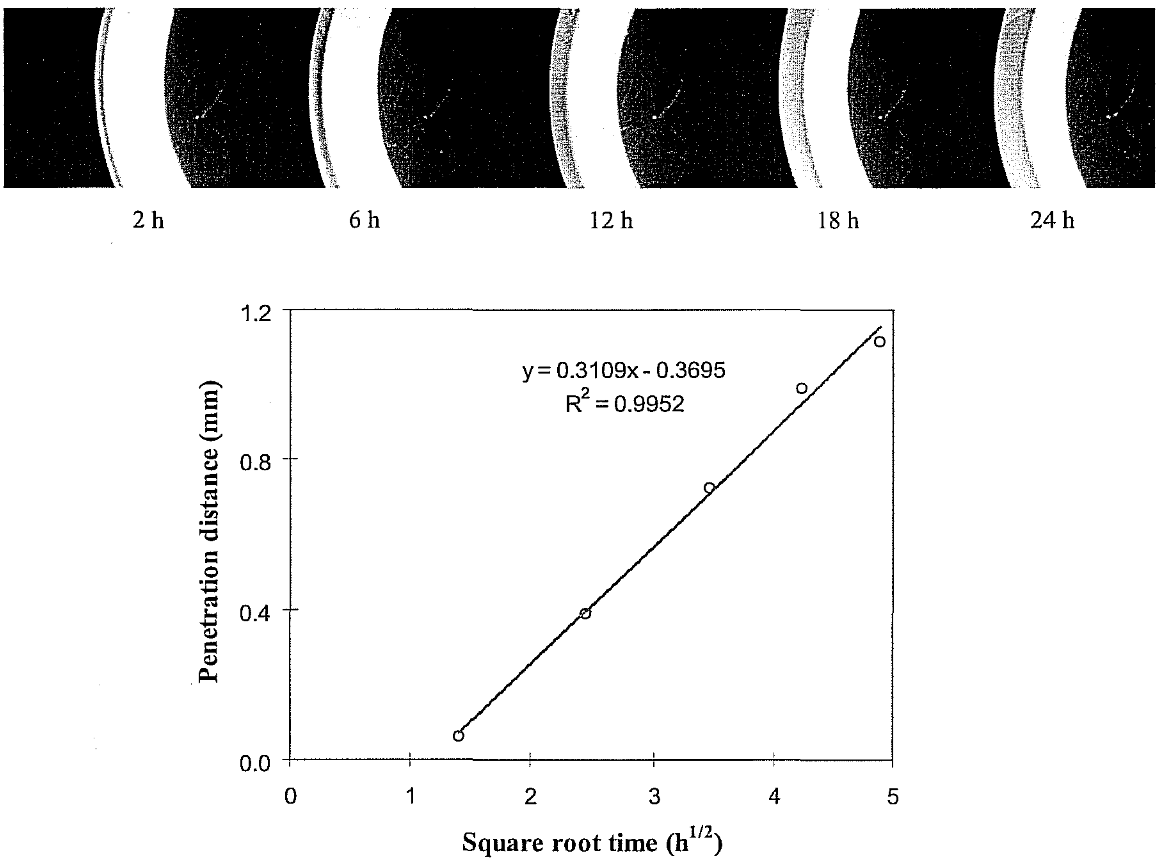

Figure 14 Advance of Moving Front in 1 in. PVC Pipe Exposed to Pure TCE

Using the regression equation obtained from Figure 14 and the pipe wall thickness of 3.5 mm, the breakthrough time was predicted to be:

$$t = \left(\frac{3.5 + 0.3695}{0.3109} \right)^2 = 155 hours = 6.5 days$$

Breakthrough occurred in the pipe-bottle experiment between the 6^{th} and 7^{th} day (Figure 10). This result suggests that a short-term test such as this could be used to predict the time required for a solvent to penetrate a PVC pipe, and that such a test could be used to compare the relative resistance of PVC pipes to permeation.

PCV Pipes Exposed To Aqueous Solutions Of Solvents

Weight gain versus time was measured using the sorption test for 1 in. PVC pipe samples immersed in aqueous solutions of toluene, benzene and TCE at five strengths (100%, 80%, 60%, 40% and 20% saturation) (Figure 15). The weight gain was linear with respect to time in aqueous solutions (not a function of $t^{1/2}$ as it is in pure solvents), and much slower than in pure solvents. As shown in Figure 15, none of these sorption experiments had reached equilibrium during 3 to 4 months of exposure in these continuing experiments. Significant sorption was found only for the 100% and 80% saturation levels, while the weight gains for 60%, 40%, and 20% saturation levels were below 2%. The sorption rate (%/day) decreased logarithmically as the percent of saturation (contaminant strength) was reduced (Figure 15). The results indicate that sorption is insignificant for contaminant levels below 25% saturation. Twenty five percent aqueous saturation is considered to be an extremely high level of environmental pollution. For example, the concentrations of toluene, benzene and TCE at 25% saturation are 125 mg/L, 425 mg/L and 275 mg/L respectively, which are seldom encountered in the field except very close to an area of non-aqueous phase liquid (NAPL) or dense non-aqueous phase liquid (DNAPL).

Moving front tests were also conducted for PVC samples under the same exposure conditions described above. The formation of a moving front was strongly dependent on the weight gain from aqueous solution. The critical weight gain which resulted in the formation of an observable moving front was 2 to 3 %. In the saturated solutions of benzene and TCE, the moving front appeared during the first week of exposure. In contrast, there was an induction period for the formation of the moving front in the saturated solution of toluene, mainly due to relatively low uptake of toluene (Figure 16). The moving front was also detected in the 80% saturated solutions once the weight gain exceeded 2%. No moving front was found in the other three solutions (60%, 40% and 20%) after 4 months of exposure.

The thickness of the swollen layer versus time for saturated aqueous solutions of toluene, benzene and TCE is shown in Figure 16. Generally, the thickness of the swollen layer increased linearly with time during the initial period, although a delay behavior was observed for toluene. This was due to the delay in the formation of the moving front as discussed above, probably due to the relatively lower solubility of toluene in water. In the experiments with pure solvents, the thickness for a completely swollen 1 in. PVC sample was found to be about 4.8 mm. Assuming the same thickness for a completely swollen sample in saturated aqueous solutions, the breakthrough time in saturated solution is estimated to be 8 months, based on the rate of swelling obtained from Figure 16. This method of prediction leads to an estimated 8 month breakthrough time for saturated solutions of benzene or TCE, and 12 months for a saturated solution of toluene. Experiments using sealed pipe samples to more accurately measure the breakthrough time in saturated benzene solutions are in progress.

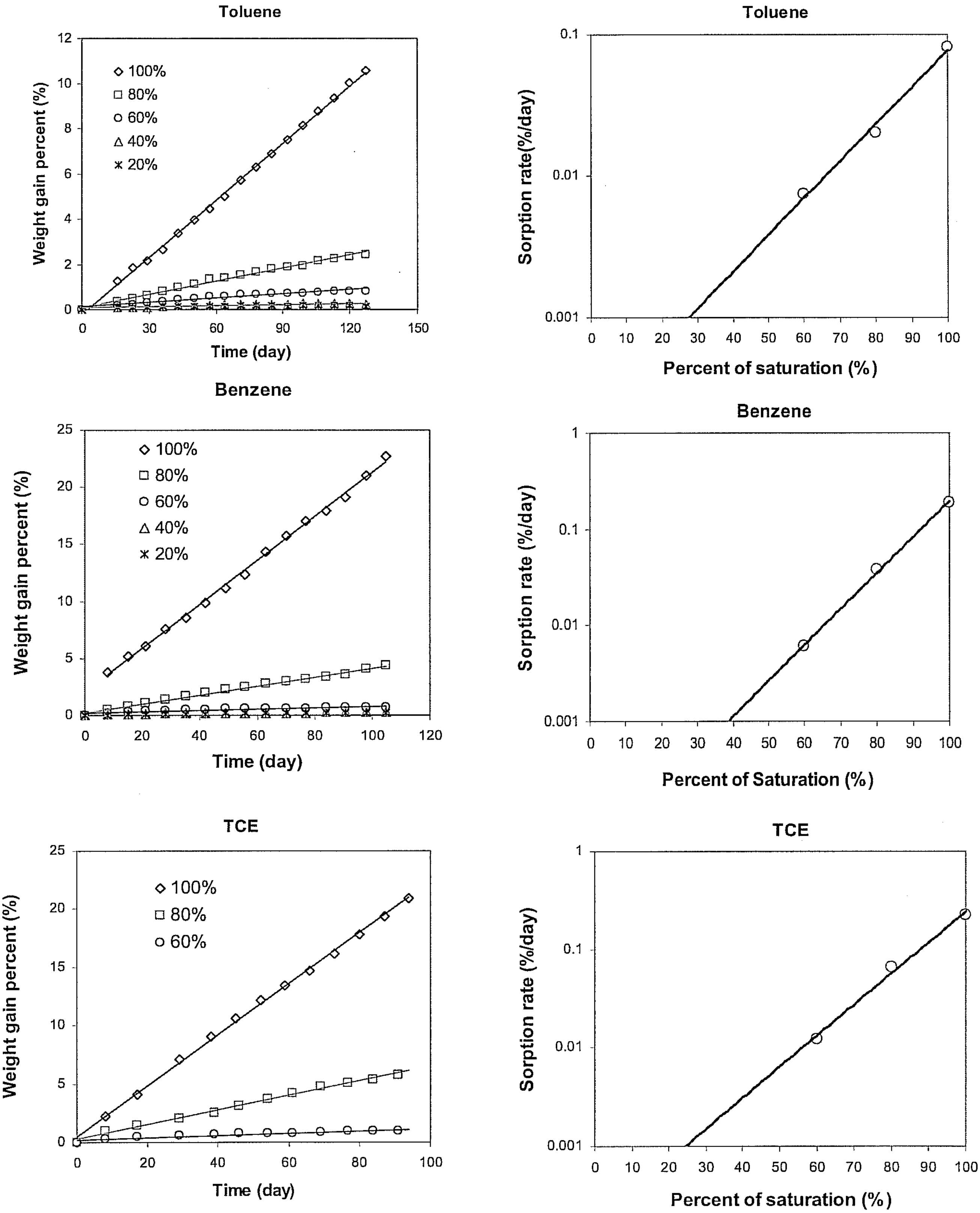

Figure 15 Sorption Data for 1-inch PVC Pipe Exposed to Toluene, Benzene and TCE Aqueous Solution (100%, 80, 60%, 40% and 20% saturation)

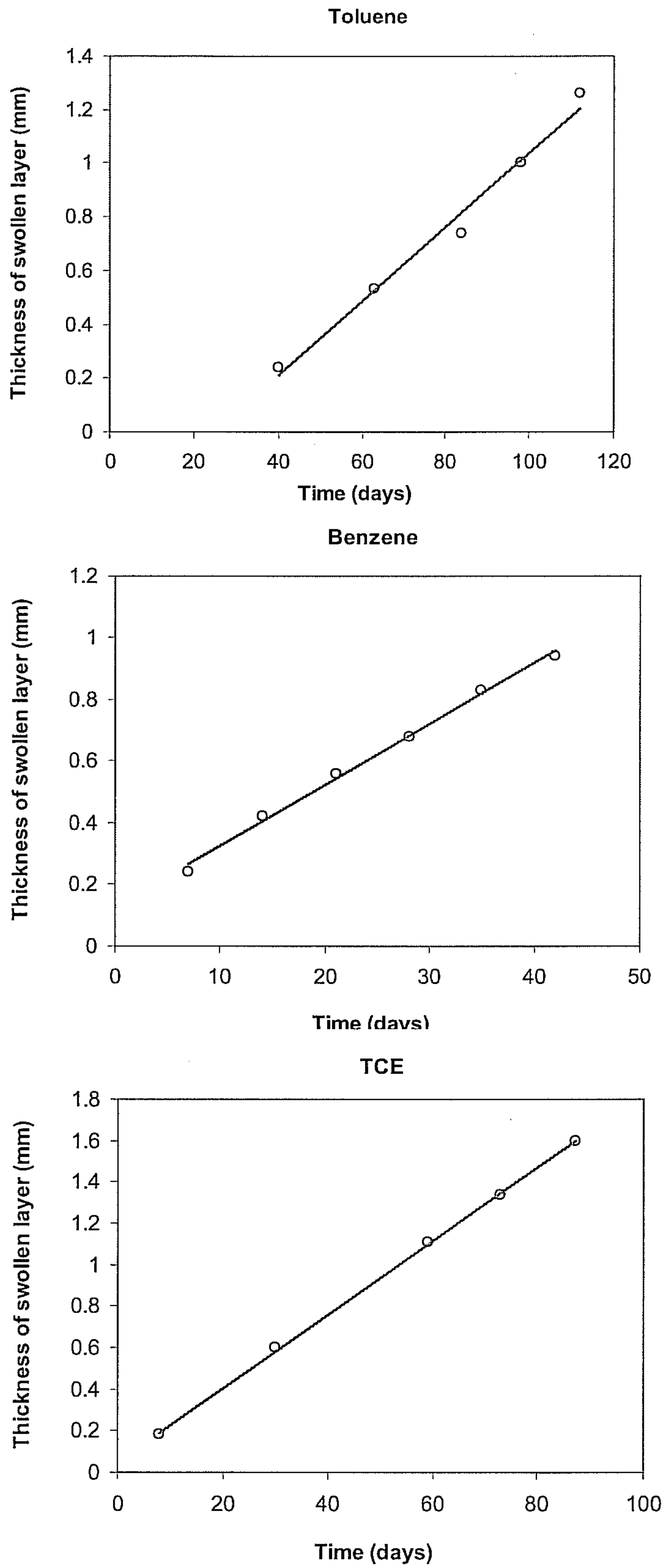

Figure 16 Thickness of Swollen Layer for 1-inch PVC Pipe Exposed to Toluene, Benzene and TCE Saturated Aqueous Solution

Polyethylene (PE) Pipes - Laboratory Studies

A paper describing the impact of gasoline on PE pipes can be found in the Universities Forum Distribution Section of these proceedings.

Gaskets - Laboratory Studies

Laboratory studies of the impact of hydrocarbons on gaskets used with DI and PVC pipe are in progress.

Conclusions

Permeation of water mains is rare and reports of successful uses in contaminated areas are infrequent. Gasoline is the most frequently reported contaminant. Chlorinated solvents and other fuels are less frequently reported. Only about 0.5% of mains are considered to be at risk of permeation. DI pipe is preferred by utilities for use in areas of known contamination, usually with resistant gaskets (especially Viton). No permeation incidents involving DI pipe were reported, regardless of the type of gaskets used. The use of PE pipe for mains is very rare.

Permeation of PE or PVC service connections is rare and reports of successful uses of plastic services in contaminated areas are extremely rare. Only about 0.3% of services are considered to be at risk of permeation. Utilities prefer copper services in areas of known contamination, and replacement with copper was the corrective action for all reported permeation incidents involving domestic services. Utilities prefer DI with Viton gaskets for large services in areas of known contamination. Soil or water analysis data associated with permeation incidents and successful uses is scarce and fragmentary.

Laboratory results indicate that PVC pipe can be safely used in soils contaminated with gasoline, regardless of the level of contamination. PVC is also highly resistant to permeation by benzene, toluene, and TCE in all but the most extreme conditions of groundwater contamination (aqueous saturated conditions). This resistance probably extends to other similar compounds that were not investigated in this study. Our work also shows that TCE and benzene are similarly aggressive toward PVC, and that the currently used recommendations for the compatibility of PVC with hydrocarbons (0.25 activity for BTEX compounds and 0.10 activity for TCE and other chlorinated compounds) may be unnecessarily conservative.

It should be possible to develop a rapid test to predict the resistance to permeation of a particular sample or formulation of PVC pipe. Visualization and measurement of the moving front using reflected light microscopy appears to be the most promising technique for this. It should be possible to develop a simple 24-hour moving front test to predict the breakthrough time of a standard solvent in any specimen of manufactured PVC pipe. Such a test should be a reliable indicator of the general resistance of that pipe to permeation and can be standardized and validated by collaborative inter-laboratory testing for inclusion in an AWWA and/or ASTM standard.

References

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