HANFORD VADOSE ZONE TRANSPORT FIELD STUDIES

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ABSTRACT

Potential groundwater contamination from wastes stored in the vadose zone at the Hanford Site near Richland, Washington is a significant concern to the U. S. Department of Energy. Field studies have been initiated to verify conceptual and numerical models that describe transport through the vadose zone at the Hanford Site. These studies are providing a systematic set of field data useful for assessing leaks from buried waste tanks. The first phase of this work is designed to evaluate water flux and plume development when conditions are dominated by high rates of water input and transport of low ionic strength (< 0.1M) solutions. The second phase will address the transport of high ionic strength (>1M) solutions. Tracer tests are presently being used to provide estimates of spatial and temporal distributions of contaminants in Hanford sediments. In all cases, the water volumes and salt tracer concentrations are being documented and flow and transport parameters evaluated.

Advanced characterization tools are being deployed for analyzing the simulated tank leaks. These include the use of three-dimensional subsurface imaging techniques. Criteria for technique selection are that it must be minimally intrusive and use existing infrastructure, which consists of a myriad of steel-cased wells. A suite of methods including cross-borehole radar, electrical resistance tomography, electromagnetic imaging, and high-resolution resistivity are being evaluated. The development of improved tools for probing the Hanford subsurface in new and more economic ways is expected to be a product of this research.

The following activities are currently ongoing: 1) Field experiments at a well-characterized test site using simulated tank leaks to investigate how layered sediments control the transport of water and contaminants in Hanford's vadose zone, 2) Integration of field-scale experiments and transport modeling to develop an improved capability for predicting plume migration rates under leaking Hanford waste tanks, and 3) Tests of advanced characterization tools that can detect salt plumes and are minimally affected by steel-cased wells.

INTRODUCTION

The scope of the Vadose Zone Transport Field Studies (VZTFS) is to conduct a series of tests at the Department of Energy's Hanford Site, designed to evaluate how contaminant plumes move in the vadose zone. This information will be used to improve predictions of vadose-zone contaminant transport at tank farms and other waste disposal sites. Activities include conducting a series of flow and transport experiments focused on dominant transport processes and parameters in the Hanford subsurface and in generating accurate and reliable databases for validation of three-dimensional numerical vadose zone models of flow and transport. The VZTFS scope will also include hydrogeologic investigations and characterization efforts at uncontaminated sites. The studies will address current data gaps related the mobile contaminants by making in-situ measurements of surrogate variables using qualified and reliable monitoring technologies. The VZTFS plan calls for conducting two flow and transport tests at an uncontaminated site to simulate a near-surface tank leak, followed by two flow and transport tests in deeper Hanford formation sediments. During FY 2000, the first of four field tests was completed using a low ionic strength solution (1000 ppm). A brief summary of the FY 2000 test is summarized in this report and details are provided in companion reports by national laboratory and contractors that have contributed to the FY 2000 effort.

The objectives of the VZTFS are to conduct controlled transport experiments at well-instrumented field sites at Hanford to (1) Identify mechanisms controlling transport processes in soils typical of the hydrogeologic conditions of Hanford's waste disposal sites, (2) Reduce uncertainty in conceptual models, (3) Develop a detailed and accurate database of hydraulic and transport parameters for validation of three-dimensional numerical models, and (4) Identify and evaluate advanced, cost-effective characterization methods with the potential to assess changing conditions in the vadose zone, particularly as surrogates of currently undetectable high-risk contaminants.

This report provides details from the FY 2000 field test. Note that this report is linked to companion contractor reports related to the FY 2000 VZTFS test and all can be found at: http://etd.pnl.gov:2080/vadose/. The VZTFS web site also contains the FY 2000 Test Plan (Ward and Gee 2000), a summary of the FY 2000 Advanced Characterization Workshop, and an annotated bibliography (Last and Horton 2000) on geophysical methods deployed at the Hanford Site.

VADOSE ZONE TESTING APPROACH

Testing has been approached in two phases. 1) Characterization of background site conditions and 2) Process characterization that will occur during and after the actual transport test and will include assessment of the physical and chemical properties affecting the vadose zone transport processes.

A test location was selected at Hanford in the 200 East Area (299-E24-111, referred to as the Sisson and Lu Site), where an extensive amount of characterization had already been completed (Sisson and Lu 1984 and Fayer et al. 1993, 1995). Ward and Gee (2000) provide details of the site selection process. Figure 1 shows the site location.

Figure 2 shows the site during testing May 31, 2000. The picture was taken from the east side of the test site looking across the bare soil of the 216-A-38 crib past the Sisson and Lu test site to the adjacent shrub-steppe vegetation in the background. The drill rig used to place advanced tensiometers and to provide core samples is show at the left of the picture. Pink flagging on the ground in the central part of the picture demarks locations where surface electrodes were placed for geophysical logging measurements.

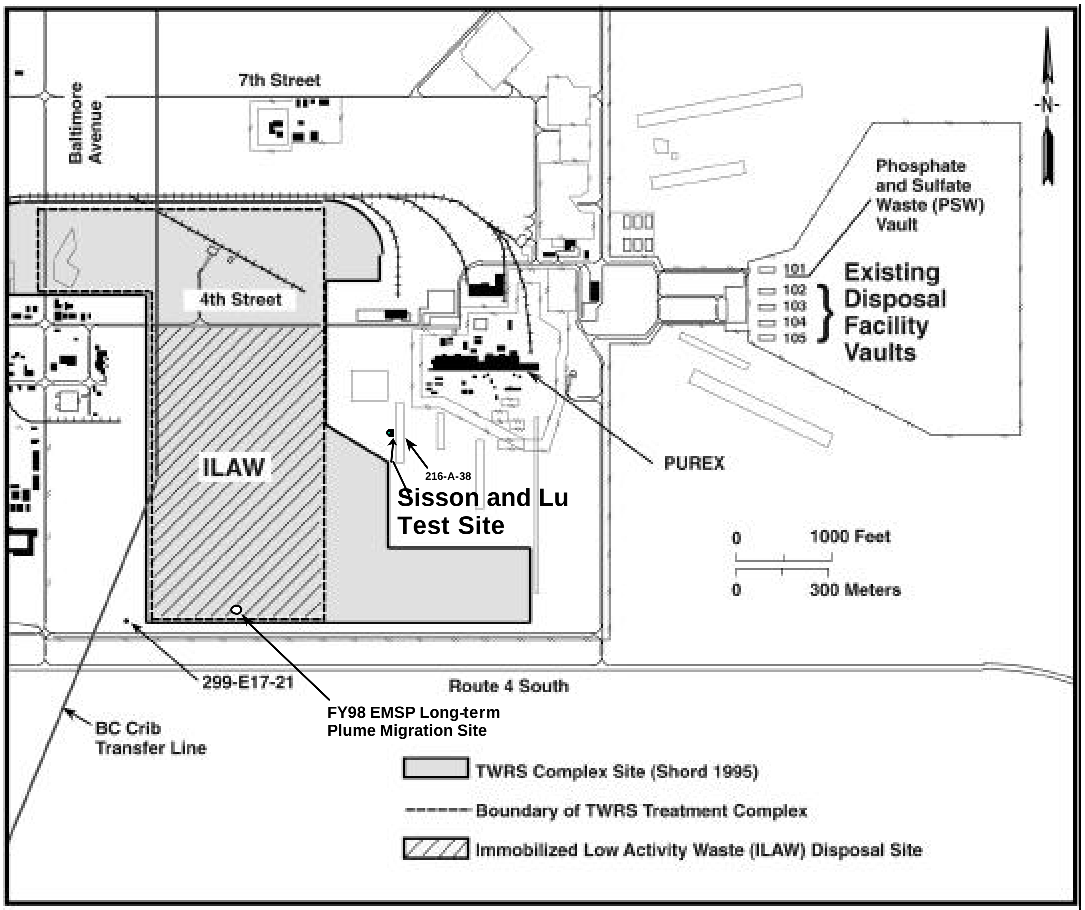

Fig. 1. Location of Sisson and Lu Test Site. The site is designated as 299-E24-111, Experimental Test Well Site in the Hanford Waste Information Data System (WIDS).

Fig. 2. FY 2000 Vadose Zone Transport Field Study Test Site, May 31, 2000.

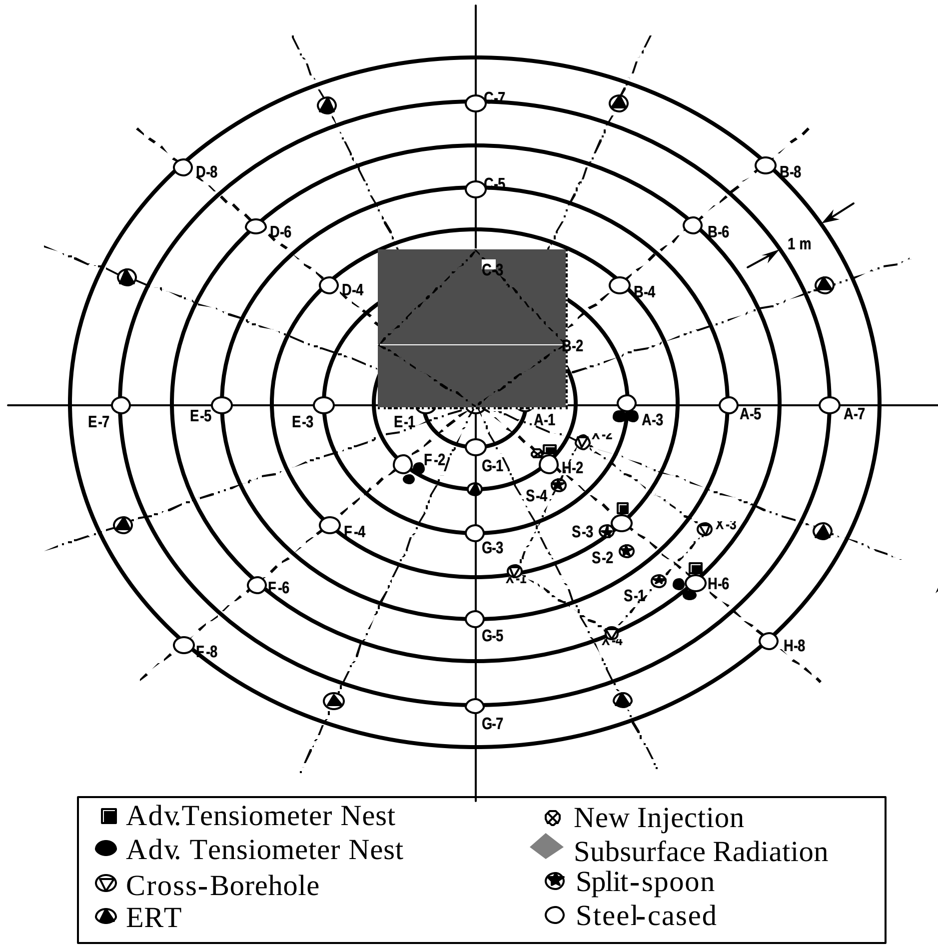

Fig. 3. Plan View of FY 2000 Test Site Showing Locations of Access Tubes, Vertical Electrode Arrays, Injection and Core Sampling Points.

METHODS

More than 20 technologies were screened to identify those that could be used to reduce the uncertainty in plume delineation when used alone or in conjunction with others. With this objective in mind, a short list of candidate technologies was identified based on the following criteria which included 1) the ability to identify key geologic features controlling water movement with a vertical resolution of 0.1 m or better and a horizontal resolution of 1 m or better, 2) the ability to locate wetting fronts and a change in water content of 0.01 m^3 m^{-3} or better with a repeatability of at least 0.01 m^3 m^{-3} , 3) the ability to determine shape and extent of non-gamma-emitting contaminant plumes or their surrogates, and 4) the ability to function and produce useful results in environments that are culturally noisy.

The nine technologies resulting from the screening process included neutron moisture logging, advanced tensiometry/suction lysimetry; electrical resistance tomography (ERT); crosshole radar tomography (CRT); crosshole seismic tomography; crosshole electromagnetic induction (CEMI); and high-resolution resistivity (HRR). Additional methods included tracers (including isotopes), and coring. The details of each of the nine methods selected and the collaborators who helped deploy the selected methods are listed in the VZTFS test plan (Ward and Gee 2000).

For the FY 2000 study, water content changes were the primary measurement variable. Water content as determined by neutron probe logging was selected as the primary standard upon which the other geophysical methods could be compared. Neutron probes were used in the past to monitor water content at the Sisson and Lu injection site (Sisson and Lu 1984; Fayer et al. 1993, 1995). These probes are also used routinely to monitor field water contents at the Hanford Site. Details of the calibration of neutron probes for monitoring water content at the Sisson and Lu site is provided by Fayer et al. (1995).

FIELD TESTS AND RESULTS

In late April 2000 the site was approved for use and installation of equipment (e.g., electrodes for electrical resisitance tomography, cross-borehole ports, and advanced tensiometers) began in early May. Electrode, port and tensiometer placements were completed by 20 May in time for scheduled baseline measurements by all of the geophysical methods prior to initiation of water injections. A total of 9 methods were tested. These included, neutron probe logging, electrical resistance tomography (ERT), cross-borehole radar (XBR), seismic (XBS), high-resolution resistivity (HRR), electromagnetic imaging (EMI), and advanced tensiometry (AT). In addition isotopic tracers were deployed during the test and subsequently sampled by soil coring. Soil coring was also used to obtain samples for hydraulic characterization. A schedule was set up so that baseline sampling and subsequent data collection from each method could be obtained in the most efficient manner and so that there was minimal interference between methods. For example, XBR and ERT measurement schedules were compatible and these measurements could be made simultaneously with the neutron probe. In contrast, the HRR and EMI measurements could not be taken at the same time so a rather strict schedule was set to ensure collection of the best possible data. Table 1 shows the detail of the schedule followed during the FY 2000 test.

After baseline data from all methods were obtained, a series of 5 injections occurred. Injections began on 1 June when 4000 L of water was metered into the 5-m-deep injection well over a 6-hour period. Subsequent injections occurred weekly for a period of 5 weeks. Neutron logging of 32 steel-cased wells (surrounding the injection well) occurred before the initial injection and followed each of the 5 injections within a day, with the exception of the injection that occurred on 26 June, 2000. On that day a wildfire burned within about 0.5 km of the test site. After the injection, the Hanford Site was closed to traffic due to the fire, so no neutron logging occurred at the test site 7 July. Subsequently two more readings of the 32 wells were completed during the month of July. One additional 4000 L injection was made on 18 September. This injection was made in order to obtain in-situ hydrologic properties using a combination of pressure measurements and neutron probe water content measurements at the same depth. Only limited water content measurements were made at a few selected locations and no other geophysical measurements were after the September injection. Details of the neutron-probe logging are provided in a companion report (Ward and Caldwell, 2000) found on the VZTFS web page. Table 1 shows the timing of the data collection activities for all 9 of the test methods. Reports for each of the methodologies are provided in the companion collaborator reports displayed on the VZTFS web page that can be found at: http://etd.pnl.gov:2080/vadose/.

Table I. List of FY 2000 Test Activities for the VZTFS project at the 299-E24-111 Experimental Test Well (Sisson and Lu) Site, 200 E Area, Hanford Site, Washington.

		Method 1	Method 2	Method 3	Method 4	Method 5	Method 6	Method 7	Method 8	Method 9
Date	**Action**	**Neutron**	**AT Tens.**	**ERT**	**XB Radar**	**Seismic**	**EMI**	**HRR**	**Isotopes**	**Coring**
05-May	Pre-Leak	Read 35								
06-May		Cross-Calibrate								
09-May				CPT Install (3 day)						
12-May			CPT Install (2 day)							
15-May					CPT Install (2 day)					
19-May										Install/Inject
20-May			Install Nest (2 day)				Set up/Read (3 day)			
23-May			Read-continuously	Setup/Read (3 day)						
25-May					Set/Read					
26-May					Read			Set/Read		
30-May								Read	Sample	Core (S-1)
31-May								Read	Samples	Core (S-1)
01-Jun	1st Leak			Read						
02-Jun		Read 32		Read						
05-Jun							Read (2 day)			
08-Jun	2nd Leak	Read 8								
09-Jun		Read 24								
12-Jun										
13-Jun					Read					
14-Jun				Read	Read					
15-Jun	3rd Leak	Read 8		Read						
16-Jun		Read 24		Read						
19 Jun								Read (6 day)		
21-Jun										
22-Jun	4th Leak	Read 8								
23-Jun		Read 24								
24-Jun										
28-Jun	5th Leak	Read 8/Fire			Read					
06-Jul									Samples	Core (S-2)
07-Jul	Post Leak	Read 32			Read(2 day)				Samples	Core (S-2)
10-Jul				Read (2 day)					Samples	Core (S-3)
13-Jul							Read (2 day)			
14-Jul							Read			
17-Jul		Read 32								
21-Jul									Samples	CPT (WL1)
31-Jul		Read 32								
1-Aug						Read (2 day)				
11-Sep									Samples	CPT (WL2)
12-Sep									Samples	CPT (WL2)
15-Sep			CPT (2 ATs)							
18-Sep	Pulse	Read (5 day)	Read (5 day)							

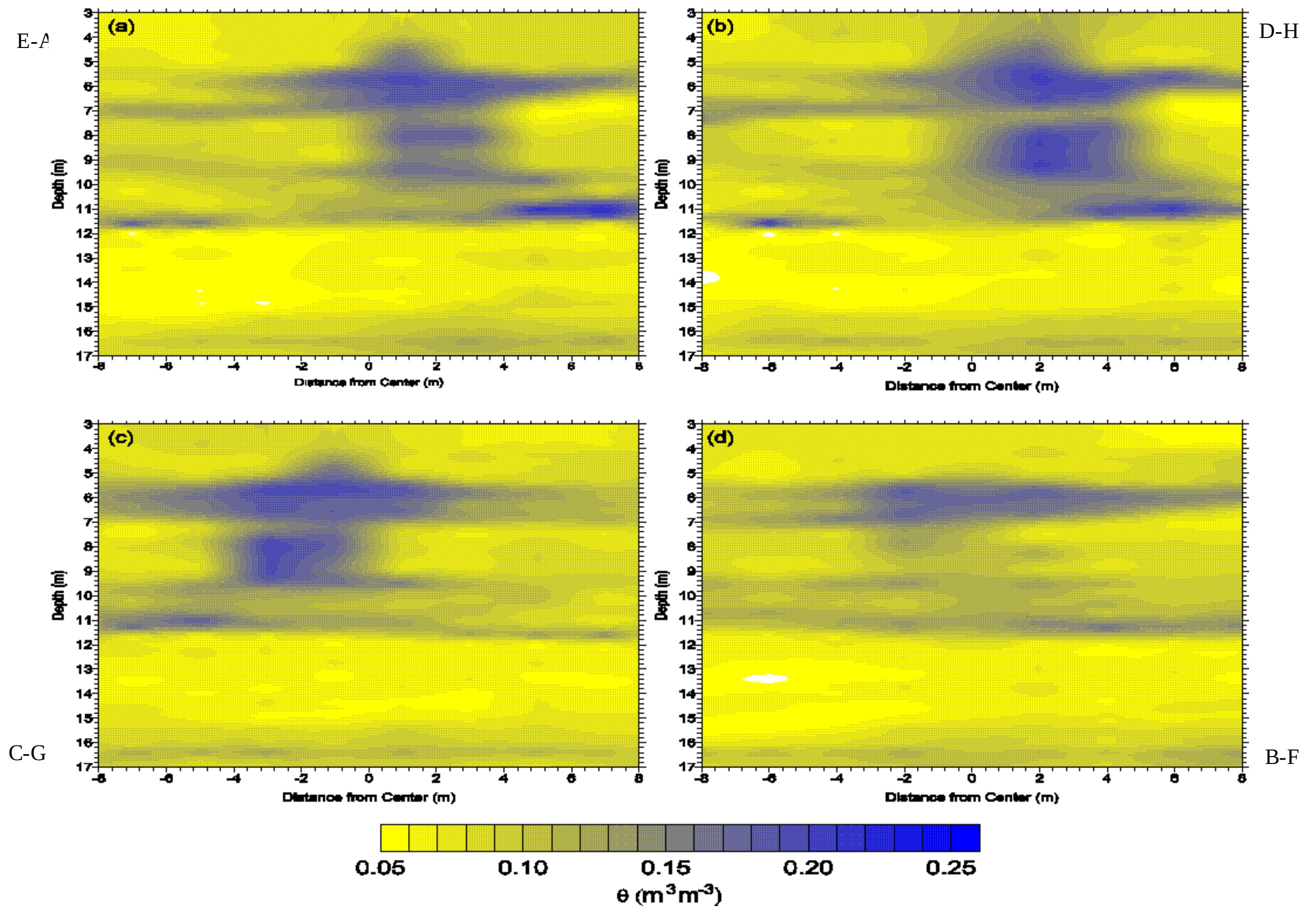

Fig. 4. Two-dimensional cross-sections of the water content profile measured by neutron probe after four injections on June 23, 2000. Figures a), b), c) and d) represent cross-sections taken along transects EA, DH, CG and BF, respectively (see Fig. 3).

Water content profiles measured by neutron probe (Figure 4) captured the nature of the plume during the course of the injection testing and indicated that water content changes below the 11-meter-depth were minimal, suggesting that the plume spread laterally along layers of finer sediments which were noted at 6 and 11 meters. The FY 2000 test was simulated using STOMP, a multiphase (unsaturated) flow and transport code developed at PNNL. Conditional simulation of the five injections was made using methods developed by Rockhold et al (1999). The simulations were conditioned on the initial water contents and the water retention characteristics of Hanford Site soils that are similar but not identical to those soils found at the Sisson and Lu site.

The results indicate that the model captures the general flow depths and directions of the plume but does not completely describe the extent of the lateral spreading of the plume. Hydraulic property data collected during the testing this past year may be helpful in improving the prediction of the lateral spreading. These estimates will be updated in FY 20001.

SUMMARY

The first of four field tests was conducted by PNNL and collaborators at the 299-E24-111 (Sisson and Lu) Injection site in the 200 E area of the Hanford Site. A total of 9 methods were tested to document a vadose zone plume produced from injecting a total of 20,000 Liters of Columbia River water into a 5-m-deep injection well, in five increments of 4,000 Liters each over a period of 5 weeks. Electrical resistance tomography (ERT), cross-borehole radar (XBR) and seismic (XBS), high-resolution resistivity (HRR), electromagnetic imaging (EMI), advanced tensiometry (AT) and isotopic tracers were deployed during the test. In addition, the site was monitored using a neutron probe and was cored multiple times. Water contents, obtained by neutron probe logging techniques, were used as baseline measurements upon which other geophysical measurements were compared. Prior to completing the test, the development of the water plume was simulated using conditional simulation techniques (Rockhold et al. 1999). The conditional simulation relied on estimates from hydrologic characterization of a limited number of samples previously taken from the site. While the computational results were in qualitative observation with measurements they did not predict the lateral extent of the plume.

All methods were successful to some degree in identifying changes in subsurface water contents (or pressures) as a result of the five injections. Electrical resistance tomography (ERT) showed promise in delineating the shape of the entire plume. However, the interpretation of signal responses was difficult, because of interference between the electrical signal and the dense "forest" of more than 35 steel-cased wells. Apparent changes in electrical signals were observed at depths of 18 meters but on closer inspection, real changes were confined largely to the 6 and 12 meters depths in conformance with water content changes observed by neutron probe logging. Cross-borehole radar was successful in identifying a section of the plume and matched well with neutron probe logging, but was limited to use relatively narrow spacing with plastic access tubes. Tests with electromagnetic induction (EMI), high-resolution resistivity (HRR), were marginally successful in showing changes in electrical properties but the surface measurements were unable to provide sufficient vertical resolution to identify the depth of penetration of the wetting front, an important parameter for plume migration investigations. Seismic monitoring was successful in delineating stratigraphy at the site. Peak concentrations of isotopic tracers (e.g., deuterium), sampled from vertical cores matched well with the bromide tracer data taken from adjacent cores and indicated the peak concentrations of the tracer plume.

Work in FY 2001 will focus on using the most successful geophysical techniques and will use isotopic tracers. A high salt concentration (>1M) will be added in the water injections and the salt plume will be tracked with geophysical logging and solution sampling techniques similar to those used in FY 2000.

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REFERENCES

1. M.J. FAYER, J. B. SISSON, W. A. JORDAN, A. H. LU, and P. R. HELLER. "Subsurface Injection Of Radioactive Tracers: Field Experiment For Model Validation Testing." Nureg/CR-5996. U. S. Nuclear Regulatory Commission, Washington, D. C. (1993).
2. M. J. FAYER, R. E. LEWIS, R. E. ENGLEMAN, A. L. PEARSON, C. J. MURRAY, J. L. SMOOT, R. R. RANDALL, W. H. WEGENER, and A. H. LU. "Re-Evaluation of A Subsurface Injection Experiment for Testing Of Flow and Transport Models." PNL-10860, Pacific Northwest National Laboratory, Richland, Washington (1995).
3. G. V. LAST and D. G. HORTON. "Review of Geophysical Characterization Methods Used at the Hanford Site." PNNL-13149. Pacific Northwest National Laboratory, Richland, Washington (2000).
4. M. L. ROCKHOLD, C. J. MURRAY, and M. J. FAYER. Conditional Simulation and Upscaling of Soil Properties." *In* M. Th. Van Genuchten, F. J. Leij, and L. Wu (eds.). "Proceedings of the International Workshop on Characterization and Measurement of the Hydraulic Properties of Unsaturated Porous Media", pp. 1391-1401. University of California, Riverside (1999).
5. J. B. SISSON and A. H. LU. "Field Calibration of Computer Models for Application to Buried Liquid Discharges: A Status Report." RHO-ST-46P. Rockwell Hanford Operations, Richland, Washington (1984).
6. WARD, A. L. and G. W. GEE. "Vadose Zone Transport Field Study: Detailed Test Plan for Simulated Leak Tests." PNNL-13263. Pacific Northwest National Laboratory, Richland, Washington (2000).